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Cognitive impacts of circadian misalignment and sleep disruption - shift working and new parenthood

Emily Breese

A thesis submitted to The Open University for the degree of Doctor
of Philosophy

School of Life, Health and Chemical Sciences
Faculty of Science, Technology, Engineering and Mathematics
The Open University

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Declaration

The work examined in this thesis is entirely my own. Contributions made by my colleagues are acknowledged in the relevant parts of text. This work has not been, and is not, currently being submitted for candidature for any other degree

Abstract

Laboratory studies of prolonged sleep deprivation have revealed several negative cognitive impacts. It is uncertain however, how applicable insights derived from these studies are to the various sleep disturbances found in real-world settings. Individuals regularly experiencing forms of sleep disturbance are shift workers (SWs) and new parents (NPs).

Shift work is increasingly common in contemporary society and these individuals often experience circadian misalignment. New parenthood is strongly associated with unpredictable sleep disturbance, though not the prolonged wakefulness applied in laboratory studies.

Improved understanding of cognitive deficits in these groups is of considerable importance, given that SWs, despite potential cognitive compromise, are expected to work as effectively and productively as non-SWs. Similarly, NPs are expected to care for a newborn whilst operating safely in the surrounding world. Therefore, direct cognitive assessment in these groups, as opposed to laboratory-based studies mimicking the patterns of sleep disruption experienced, is valuable.

Here, using online cognitive assessments, four domains that are vital in an occupational and parenting context (attention, response inhibition, working memory and visuomotor control) were evaluated in occupationally heterogeneous and homogenous SW cohorts, to determine the impact of job role, and in a NP cohort including both sexes, to evaluate any sex differences.

All cohorts were assessed in conditions of minimal fatigue to dissociate potential contributions of acute daily fatigue from more chronic lifestyle effects. A frontal EEG analysis of SWs was conducted, using EEG headbands, to screen for physiological correlates.

This study revealed little to no impairment in all four cognitive domains in SWs and NPs, suggesting that the cognitive impairments often reported in these groups are primarily driven by acute fatigue that can be alleviated with sleep. EEG analysis of SWs suggested the presence of some physiological changes, which could indicate compensatory mechanisms engaged to maintain the consistent cognitive performance observed.

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Abbreviations

4N: 4 consecutive night shifts
7N: 7 consecutive night shifts
ANOVA: Analysis of Variance
BSWSQ: Bergen Shift Work Sleep Questionnaire (BSWSQ)
CANTAB: Cambridge Neuropsychological Test Automated Battery
CSR: Chronic sleep restriction
dlPFC: dorsolateral prefrontal cortex
EC: Eyes closed
EEG: Electroencephalogram
EO: Eyes open
ERP: Event-related potential
fMRI: Functional magnetic resonance imaging
fNIRS: Functional near-infrared spectroscopy
GDPR: General data protection regulation
GNG: Go Nogo
IP: Incorrect press
MEQ: Morningness-eveningness questionnaire
NP: New parents
PFC: Prefrontal cortex
Po: Police
PSQI: Pittsburgh Sleep Quality Index
PVT: Psychomotor Vigilance Task
RI: Response inhibition
rMEQ: Revised Morningness-Eveningness Questionnaire
RT: Reaction time
RVIP: Rapid visual information processing task
SD: Sleep deprivation
SDR: Sleep deprivation resilient
SDV: Sleep deprivation vulnerable
SES: Socioeconomic status
SMR: Sensorimotor rhythm

SW: Shift work

SW1: Shift worker one

SW2: Shift worker two

SW3: Shift worker three

SWD: Shift work disorder

TMT: Trail Making Task

vIPFC: ventrolateral prefrontal cortex

WCST: Wisconsin Card Sorting Task

WM: Working memory

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Chapter 1: Introduction

This thesis aims to explore the cognitive impact of circadian misalignment, using ecologically valid participant samples. These are shift workers and new parents. Further, this thesis also aims to contribute to disentangling the impact of acute fatigue from that of chronic circadian misalignment by performing cognitive assessment of these two samples under conditions of minimal acute fatigue. Here, four widely assessed cognitive domains (attention, response inhibition, visuomotor coordination and working memory), which underpin key behaviours in both the occupational and parenting contexts, are examined.

This chapter will provide a detailed evaluation of existing studies which offer insight into the potential cognitive impacts of sleep deprivation and sleep disruption generally, and shift working and new parenthood specifically.

1.1 Sleep deprivation and circadian misalignment

Sleep deprivation (SD) can be defined as either chronic or acute. Chronic SD refers to repeated sleep restriction (less than the recommended 8 hours) across a period of time, while acute SD is a total lack of sleep across a short period of time (typically one or two nights) (Banks & Dinges, 2011; Philip et al., 2012). Laboratory studies using chronic or acute SD manipulations have been shown to have adverse effects on cognition (Anderson & Platten, 2011a; Doran, Van Dongen, & Dinges, 2001; Wimmer, Hoffmann, Bonato, & Moffitt, 1992), a negative impact on mood and motivation, and to cause changes in hormones (Bonnet & Arand, 2003; Taskar & Hirshkowitz, 2003).

Circadian misalignment refers to the inappropriately timed sleep and wake of an individual relative to their circadian rhythm (Glazer Baron & Reid, 2014). The circadian rhythm is the intrinsic timekeeper which regulates various biochemical, physiological and behavioural processes within an approximate 24 hour cycle, regulated by the suprachiasmatic nucleus in the hypothalamus (Hirayama & Sassone-Corsi, 2009).

The type of sleep deprivation and circadian misalignment experienced in most laboratory based chronic sleep deprivation studies has low ecological validity, in that extended periods of wakefulness are unlikely to happen in the real world. There are however real world populations who experience forms of sleep disruption. Shift workers regularly experience circadian misalignment (Miller, Wright, Hough, & Cappuccio, 2014). New parents on the other hand experience unpredictable SD of varying durations on a nightly basis (Gay, Lee, & Lee, 2004; Rudzik & Ball, 2016).

1.2 Shift workers

Shift work is defined as 'work that takes place on a schedule outside the traditional 9am-5pm day' (National Sleep Foundation, 2017). This pattern of work, and the associated lifestyle, is experienced by a substantial proportion of the population in industrialised countries with 28.7% of the US (Alterman, Luckhaupt, Dahlhamer, Ward, & Calvert, 2013), 18.3% of the EU (Eurostat, 2017) and 18.6% of the UK (Office for National Statistics, 2017) populations classified as shift workers.

Further analysis reveals that shift work patterns are utilised by a range of occupational sectors. For example, in the UK in 2017 sectors involving substantial shift working included 'Transport and storage' (37.7% of employment in sector), 'Health and social work' (33.5%) and 'Wholesale, retail repair of vehicles' (22.6%). Smaller proportions were recorded in other sectors including 'Manufacturing', 'Agriculture', 'Forestry' and 'Fishing' (Office for National Statistics, 2017). Beyond sector-level diversity, this occupational breadth also suggests that individuals with a wide range of demographic characteristics and socio-economic profiles experience shift working and that shift work patterns are applied to professions with a broad range of job-specific stressors including risks associated with decision-making. As will be discussed later in this chapter, it is therefore highly challenging to define the characteristics of a 'prototypical' shift worker, complicating the generalisation of any associated cognitive impact across this population.

Shift work can have benefits to both employees and businesses. Better child care arrangements, more pay and an easier commute have been highlighted as positive reasons people choose to work shifts (Beers, 2000; Hattery, 2001). For many employers the economic benefits such as time-of-use electricity costs, 24 hour productivity and the ability to keep up in a global market (Costa, 2001; Neipert, 1979) have promoted this pattern of working.

However, this type of occupational behaviour can also have adverse effects on the employees concerned, with reports of increased risks of health issues such as cardiovascular problems (Elliott & Lal, 2016), some cancers (Davis, Mirick, & Stevens, 1995; Haus & Smolensky, 2013) and diabetes (Buxton & Okechukwu, 2015) in this population. The disruption to social activities and interpersonal relationships caused by this work pattern should also be considered (Harrington, 2001), particularly given that shift workers are often reported to experience depression and other mental health issues (Caruso, 2014; Harrington, 2001; Lyall et al., 2018).

Beyond clinical indications of mental health issues, understanding if and how engaging in shift work impacts routine cognition is also crucial, both from the perspective of the employee for whom shift-dependent cognitive impairment could increase the risk of occupational injuries (Folkard & Tucker, 2003; Ryu et al., 2017) and also for the employer, particularly if shift working

employees are required to make decisions that if incorrect could have substantial implications for the organisation with respect to regulatory compliance, facility safety, the environment and both employees and the public. To underline the importance of this issue, it is notable that many major disasters such as Chernobyl, Exxon Valdez, Challenger and Three Mile Island occurred during the early hours of the morning and have been associated with human error (Harrington, 2001).

Intuitively, any cognitive impairment observed in shift workers could be related to the combined effects of normal fatigue accumulated during a given work period (as would be experienced by non-shift workers following completion of a typical 7-8 period at work) and the degree of SD generally assumed to be associated with shift working cohorts. Indeed, evidence shows that shift workers do experience a degree of SD, with indications of poorer quality and shorter length sleep reported (Harrington, 2001; Monk et al., 2013). Taken together, this would suggest that shift working, via induction of SD, can impact routine cognition. However, shift working may have more nuanced effects on cognition in addition to SD induction, in that these employees have the same opportunities (in terms of amount of time per day) to sleep relative to their non-shift working counterparts. They also have regular rest periods ('days off') during which they can attempt to return to normal sleep patterns and reverse any SD. Although restoration of cognitive performance in shift workers experiencing sleep debt has been suggested to take more than one night of recovery sleep (Chang, Wu, Chen, & Hsu, 2018; Sallinen et al., 2008) there has yet to be established a clear guideline on the best way to overcome sleep debt, with suggestions that it is down to the individual to establish which strategies work best for them (Knauth & Hornberger, 2003).

The impact of shift working on the cognitive capacity of individual employees may also be associated with the routine circadian misalignment experienced by these individuals. This element (circadian misalignment) distinguishes shift workers from non-shift workers and understanding how it impacts cognition is a critical objective of this area of research.

1.3 New parents

New parents also experience a form of SD, though different to the sleep experiences of shift workers which are more largely characterised by circadian misalignment.

At the time of writing there had been an estimated 67,392,922 births in the world in 2020 (01/07/20), with an estimated 250 babies born every minute, a figure predicted to rise (Lamble, 2018; The World Counts, 2020). This rapidly increasing population of newborn babies has a knock on effect on the sleep state of a growing number of adults. Following the birth of a child, parents experience altered sleep patterns and increased fatigue (Rudzik & Ball, 2016). Gay et al. (2004) found that from late pregnancy to one month postpartum, mothers lost an average of 41.2

minutes of night time sleep and fathers lost an average of 15.8 minutes. Further, both parents self-report more sleep disturbance and fatigue during the first month postpartum, than during pregnancy. This is consistent with the findings of Swain et al (1997) who found that postpartum women's sleep patterns were most disturbed during the first week postpartum, compared to controls. They experienced longer time awake during the night, the greatest number of awakenings, and took the greatest number of naps, compared to the remainder of the study. Whilst these sleep patterns had moderated by the third week postpartum they were still significantly more disturbed than those of controls (Swain, O'Hara, Starr, & Gorman, 1997).

New parenthood is also often accompanied by psychological and interpersonal stress (Huston & Holmes, 2004; Perry-Jenkins, Smith, Goldberg, & Logan, 2011). It is estimated that between 10-20% of new mothers experience postpartum depression, and between 25-50% of these mothers have episodes lasting 6 months or longer (Beck, 2002; Bina, 2008; Miller, 2002). There is a marked lack of literature examining this prevalence in men, though Paulson and Bazemore (2010) suggest this to be around 10%, with higher rates reported 3-6 months postpartum (Paulson, Bazemore, Prevalence, & Fac, 2010). Sleep deprivation and difficulties in getting to sleep have been found to be clearly related to mental health issues, including depression (Holsboer-Trachsler & Seffritz, 2000).

Measures of neural activity, such as resting state fMRI, have been suggested as a means to detect potential effects of postpartum cognitive impairment on brain function. Zheng et al (2018) examined spontaneous neural activity in 22 postpartum women, who did not have depression. They found decreased activity in the posterior cingulate cortex and prefrontal cortex in postpartum women, compared to controls, which correlated with impaired cognitive functioning. However they found no differences in grey or white matter volume, suggesting that the altered activity in postpartum women may occur prior to any major structural abnormalities (Zheng et al., 2018).

Sleep disruption, stress and mental health issues have all been shown to impact cognitive performance (Lieberman, Tharion, Shukitt-Hale, Speckman, & Tulley, 2002; Anderson & Platten, 2011a; Doran, Van Dongen, & Dinges, 2001; Wimmer, Hoffmann, Bonato, & Moffitt, 1992). Understanding precisely how the sleep disruption in new parents impacts routine cognition is vital, for both the safety of the parent and those around them, given that new parents are responsible not only for a newborn but also for themselves. The importance of this is compounded further given that at least one parent typically returns to the work environment relatively soon after the birth when they may be experiencing SD-dependent cognitive impairments.

1.4 Issues in the current research landscape

There is considerable variability in the shift working literature, limiting the generalisability of the conclusions drawn by individual studies. The existing new parent literature is also limited in that it predominantly focuses on the mothers during pregnancy, typically avoiding analysis during the post-partum period and often excluding non-birth partners from assessment. Beyond these issues, there are several points related to experimental design and implementation which make inter-study comparisons challenging and potentially also confound data interpretation in both populations.

Firstly, with regards to the literature examining shift work, while it is possible to draw an important distinction between SD and circadian misalignment in the shift worker context, a proportion of the evidence indicative of shift working-dependent cognitive impairment is derived from laboratory-based SD studies which have little ecological validity (Chellappa, Morris, and Scheer, 2019).

Secondly, while some studies improve ecological validity via assessment of shift working populations, these individuals are often cognitively evaluated immediately before and then immediately after a shift. While such within-subject design has considerable merit, in this circumstance any 'before' and 'after' comparison indicative of a cognitive impairment cannot disentangle the effects of acute work-related fatigue from any effects of chronic circadian misalignment. Indeed, fatigue has been reported in many shift working groups following shift completion (Geiger-Brown et al., 2012; Härmä, Sallinen, Ranta, Mutanen, & Müller, 2002; Waggoner, Grant, Van Dongen, Belenky, & Vila, 2012). In order to decouple this relationship, within-subject studies of shift workers should include non-shift working control groups which while simple in principle, can provide a substantial recruitment challenge, given that such groups must be matched across a large number of demographic and occupational parameters.

Alternatively, to better differentiate the cognitive effects of circadian misalignment from those of acute work-related fatigue, evaluating shift workers on their first 'day off' after a work period (and after they have slept) should also be considered.

Thirdly, the way in which companies employ shift workers varies markedly. Work patterns such as nights, rotating (clockwise and anticlockwise), split and evening shifts are often used, but variation in regards to length of shift, work to rest day ratio and shift cycle repetition exists within these. As an example, the UK Office for National Statistics distinguishes between 10 distinct types of shift: Three-shift working, Continental shifts, Two-shift system, Early/late-double day, Sometimes nights sometimes days, Split shifts, Morning shifts, Evening or twilight shifts, Night shifts, Weekend shifts and Other type of shift work (Office for National Statistics, 2017). Consequently, the pattern of shift work across different professions is extremely varied, making

comparison between studies focused on sample populations working according to different shift patterns potentially difficult.

A further contributor to the limited comparability of studies focused on different sample populations concerns the precise type of work being performed. As noted earlier, shift working is used across a range of diverse occupational sectors which can place distinct cognitive- and stress-related demands on employees. For example, many factory-based roles require repetition of the same task for extended periods with little need for decision making, while roles in health/medicine, such as emergency physician, are associated with higher task unpredictability and considerably higher stakes decision making. Such differences in stress, occupational predictability and responsibility can influence cognition (Sandi, 2013) and this adds a further level of sample heterogeneity to shift working groups. This in turn further limits the generalisability of conclusions drawn from individual studies in this area.

Fourthly, regarding testing in both shift working and new parent populations, there is variation between the assessment tools used to examine potential cognitive impairments. Whilst all the tests used have been shown previously to measure the stated constructs there is no consensus as to which is the most sensitive and reliable. Even when the same task is used across studies, there is variation with regards to test length, stimuli and outcome variables measured, which may impact the detection of any impairment, as will be discussed later in this chapter. A further issue concerns the interpretation of the data collected from a given task, as many of the cognitive assessments used tax multiple aspects of cognition. As an example, the Stroop task can be used to assess both attention and response inhibition. However, comparing any attentional impairment inferred due to a change in Stroop performance detected by one study against an attentional impairment detected in another study using a task with a different response inhibition profile could complicate interpretation as to the precise cognitive impairment profile.

The ecological validity of the cognitive assessments used is also a point of concern with respect to shift working participants. Whilst the assessments are well-validated with respect to construct validity, it could be argued that the tasks do not bear significant occupational relevance to shift workers. Chaytor and Schmitter-Edgecombe (2003) suggest that whilst most neuropsychological tests have a moderate level of ecological validity when predicting cognitive functioning, there are many factors which can influence this, including the effects of the sample population and the person completing the assessment (self-assessed, significant other, clinician). As the shift working population is so varied and the cognitive demands placed upon individuals experiencing such work patterns so occupationally specific, many of the cognitive assessments used may have limited suitability in this population. The combination of a low ecologically valid context of test (laboratory based) and use of low ecologically valid cognitive tasks limits the applicability.

Taken together, a settled consensus concerning the cognitive impact of the shift working lifestyle and the circadian disruption associated with new parenthood remains somewhat elusive, due to the considerable variability between the findings of existing studies. While this variability could imply that the impairments are small in magnitude or only expressed transiently in the presence of other enabling factors, there are a number of characteristics inherent in both populations which could contribute and the approaches used to evaluate these groups often also make studies incomparable.

1.4.1 Shift worker individual variation

A further important issue for research in this area concerns the variation between individual shift workers. Such inter-individual variation may yield sub groups of individuals who are better suited to shift work due to their ability to maintain normal cognitive functioning despite circadian misalignment. Indeed, it has been suggested that some individuals may tolerate shift work better due to their age, sex, morningness/eveningness, certain personality traits, sleep strategies and circadian structure (Costa, 2003; Saksvik, Bjorvatn, Hetland, Sandal, & Pallesen, 2011). It is not known however whether such an ability would be inherent i.e. that these individuals possess a degree of resilience at birth, or acquired i.e. that over the course of a shift working life these individuals have built up a tolerance to this pattern of work.

Establishing whether an 'ideal' shift worker (i.e. an individual with a high cognitive resilience to this lifestyle) is born or develops through experience could have huge implications for this population. For example, if shift working resilience was found to be inherent, recruitment processes for shift working occupations could be adapted to identify those applicants best suited for shift work. Alternatively, if shift working resilience was found to be acquired, businesses could adapt training or occupational practices to maximise the rate at which tolerance develops within their workforce. At this point, the two possibilities appear equally plausible. Specifically, an inherent resilience in relation to shift work could have a genetic basis analogous to the genetic contribution suggested for resilience to anxiety and depression (Hettema, Prescott, Myers, Neale, & Kendler, 2005; Russo, Murrough, Han, Charney, & Nestler, 2012; Southwick & Charney, 2012). Alternatively, the capacity to develop this resilience could have parallels with the development of tolerance in drug addiction (Ramsay & Woods, 1997; Siegel, 2005) and other addictive behaviours (Babić, Martinac, & Pavlovic, 2018) as a consequence of repeated exposure to particular cues and contexts.

Whilst shift working clearly cannot be conceptualised as either a psychopharmacological or behavioural addiction, the convergence of cues/context/occupation-specific behaviours and circadian misalignment regularly experienced by individuals exposed to this pattern of work may be sufficient to trigger mechanisms similar to those associated with the development of tolerance

in the addiction context. This leads to a number of predictions that could be evaluated in shift working populations. For example, as in the addiction context, a shift worker that has developed an equivalent to tolerance would likely need to work longer hours (e.g. over time) or experience a greater degree of circadian misalignment before an impact on cognition (akin to reward system activation in tolerant addicts following exposure to a higher drug dose or a gambling scenario with higher inherent risk) would be detected. Equally, it may be that within a single shift, workers with the highest levels of tolerance would exhibit the smallest fatigue related cognitive decline from baseline. While this has yet to be explicitly assessed in the existing literature, further exploration of the inter-individual variability in shift workers observed to date is warranted as a reference for future study.

1.4.2 Female dominant new parent literature

An issue associated with much of the existing literature assessing the cognitive impact of circadian misalignment associated with new parenthood is the largely exclusive focus on the mother. It is vital to assess both parents following the birth of a child, given their differing experiences. These differences principally include the hormonal and physical changes experienced by the mother. For example, the oestrogen levels in a woman fluctuate across a lifetime and specifically rise during pregnancy. This hormone has been suggested to improve performance in working memory tasks (Gasbarri, Pompili, & Onofrio, 2008; Hampson, 1990). Further, new parents have been shown to experience different magnitudes of sleep loss, with mothers losing more night time sleep than fathers (Gay et al., 2004). These differences may contribute to differentially severe cognitive impairment in mothers and fathers following the birth of their child.

Further, as mentioned previously, much of the existing literature assesses women during pregnancy and examines the cognitive impact of pregnancy and associated sleep disruption. This is likely to be distinct from the unpredictable pattern of awakenings experienced following birth and yet the post-partum period is often excluded from studies of this population. Therefore, systematic studies assessing cognition in both parents in the post-partum period would provide valuable new insights.

1.5 Cognitive Domains

Four cognitive domains will be examined in this thesis; attention, response inhibition, working memory and visuomotor coordination. These are domains that have been highlighted as being potentially vulnerable to sleep deprivation, have been examined previously in shift workers and/or new parents and have clear ecological relevance to both populations. Each will be discussed in detail, with current studies involving shift workers and new parents critically assessed.

1.5.1 Attention

A single conceptualisation of attention remains elusive. Cognitive approaches to attention include Broadbent (1958) who suggested the filter model of attention. This proposed that incoming sensory stimuli are processed initially based on basic physical properties, for example pitch, location and colour. The filter prevents overloading and selects which information gains conscious awareness. This theory was subsequently revised by Triesman (1964) with the attenuation theory model of selective attention. Here the filter acts as an attenuator of information, increasing or decreasing attentional capacities towards incoming stimuli. More recent authors such as Raz and Buhle (2006) state that this element of cognition 'refers to...the preparedness for and selection of aspects of our physical environment...or some ideas in our mind'.

Beyond this sort of high level description, extensive debate is on-going, with some viewing attention as a single selection mechanism specialised for the processing of task relevant information (Thiele and Bellgrove, 2018), while others suggest it is composed of multiple independent control networks (Petersen and Posner, 2012; Posner and Petersen, 1989).

Irrespective of these terminological challenges and competing conceptualisations, there is consensus that this cognitive domain can be further differentiated into elements with distinct functional specializations, each supported by a variety of brain regions with varying degrees of overlap. These functional specialisations include sustained, divided and focused/selective attention (Romberg, Bussey, & Saksida, 2013).

Sustained attention is defined as the ability to maintain a focus of cognitive activities on a given task or source (Hoonakker, Daignon-Camus, & Bonnefond, 2017) over extended periods of time (Perry & Hodges, 1999). It is also considered a state of continuous readiness to respond to any random event (Romberg, Bussey, & Saksida, 2013). This element of attention is routinely evaluated using signal detection tasks such as the Psychomotor Vigilance Task (PVT) (Dinges & Powell, 1985) and choice signal detection tasks such as the 5-Choice Serial Reaction Time Task (Leonard, 1959). In these cognitive tests, measures such as accuracy and reaction time are used to evaluate sustained attention performance. Sustained attention has been suggested to be supported by the right sided frontoparietal network (Coull, Frith, Frackowiak, & Grasby, 1996; Perry & Hodges, 1999; Posner, 2008). Further, in an EEG study, increases in delta and beta bands, associated with sleep and active thinking respectively, have been seen during a PVT, performed in 18 healthy participants (Tian, Wang, Dong, Pei, & Chen, 2018). Given that this task measures sustained attention, and is therefore fatiguing this function of attention, it is expected that an increase in bands associated with sleep would be seen. Indeed, an increase in PVT reaction times has been associated with an increase in delta (Ko, Komarov, Hairston, & Jung, 2017). Further, the

initiation of a cognitive task would lead to active concentration, as evidenced by an increase in beta.

Divided attention is conceptualised as the distribution of attentional resources by concentration on multiple relevant stimuli or processes simultaneously (Perry & Hodges, 1999; Spelke, Hirst, & Neisser, 1976). This element is supported by the dorsolateral prefrontal cortex and anterior cingulate gyrus, with both areas exhibiting activation under conditions designed to promote division of attentional resources (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991; Perry & Hodges, 1999). Dual attention assays, in which two attentionally demanding tasks are performed simultaneously, such as learning words whilst performing an auditory discrimination task, are often employed to assess this aspect of the construct (Romberg et al., 2013).

Selective attention is defined as the process of focusing on a single relevant stimulus, process or modality at one time, while actively ignoring all other irrelevant or distracting stimuli (Perry & Hodges, 1999; Romberg et al., 2013). This element of attention is dependent on activation of the superior parietal cortex (Corbetta, Shulman, Miezin, & Petersen, 1995) and various posterior parietal systems (Perry & Hodges, 1999) and is often assessed using paradigms such as the Stroop task (Stroop, 1935).

There is good evidence to indicate that attention (as a unified construct) can be adversely impacted by gross disruptions in sleep patterns. This is derived from laboratory studies in which attention is assessed following periods of forced total SD. In these studies attentional impairments were detected following both long term (more than 48 hr) (Doran et al., 2001) and also less severe, shorter term (less than 48hr) SD (Lim & Dinges, 2010). Building on these findings, studies in which the effect of SD on the various sub-elements of attention were examined have also demonstrated vulnerabilities in the sustained (Drummond et al., 2005), divided (Williamson & Feyer, 2000) and selective (Joo, Yoon, Koo, Kim, & Hong, 2012) components of this construct when considered in isolation.

These findings highlight the possibility that any disturbance in sleep pattern may have an impact on some element of attentional performance. However, as these studies are laboratory based and reliant on considerable periods of forced total SD, the findings cannot be directly extrapolated to shift working populations in which individuals still have regular opportunities for sleeping although experiencing circadian misalignment, nor to new parent populations in which periods of sleep may be unpredictably disrupted.

1.5.1.1 Attention and shift work

Recently, Chellappa, Morris, and Scheer (2019) evaluated attentional performance in a cohort of 'chronic' shift workers defined as individuals working five or more night shifts per month and

having experience of at least 12 months of shift work. They showed impaired PVT performance in conditions of simulated night shift working relative to simulated day shift working, which appeared to be exacerbated by more than 10 hours of wakefulness. This provides an important perspective, in that it mirrors the effects observed in SD studies involving individuals not exposed to shift working conditions. However, whilst a representative shift working population was used in this study, the cognitive assessment was still conducted in a laboratory setting under strict timing conditions, therefore limiting ecological validity.

Characterisation of attentional performance in shift workers in more occupationally-relevant contexts is vital. From an organisational perspective, understanding the differential levels of productivity observed between shift types (Tucker & Folkard, 2012) is a key focus. In addition, it is of considerable importance to gain insights into the characteristics of individuals working in occupations in which generalised attentional impairments or an increased frequency of attentional lapses could put them or others at risk.

Veasey et al. (2002) conducted a meta-analysis of 10 studies assessing the performance of surgical residents both before and following occupational sleep disruption caused by being on-call. This analysis suggested that surgical complication rates may increase when the residents performing surgery have been on-call. While likely a product of impairments in multiple cognitive domains, compromised attentional performance could make a substantial contribution to this adverse outcome.

Worker safety is also found to be compromised by shift work. Wagstaff (2011) conducted a meta analysis of 14 studies assessing worker safety across shifts. Rotating shift work (including nights) was associated with an increased risk of accidents when compared to exclusive night shifts, suggesting a potential benefit of a consistent working routine and fixed degree of circadian misalignment. Clearly workplace safety incidents and accidents are often multi-factorial in origin but it is again reasonable to suggest that attentional lapses or other impairments in this domain could contribute to these events.

Similarly, it has been reported that traffic accidents increase in drivers following night shift work (Lee et al., 2016). Lee et al. (2016) assessed drowsiness and driving performance in 16 night shift workers at baseline (after 7.6 ± 2.4 h sleep) and after a night shift. Both driving sessions were performed during daylight therefore any impairments observed could not be attributed to visibility. Significantly more near-crashes and early drive terminations (where the test was stopped due to safety concerns) were recorded in the post night shift condition. Given the importance of attentional performance in driving (Lees, Cosman, Lee, Fricke, & Rizzo, 2010), these findings are consistent with a period of work impacting subsequent attentional performance, although again, disruptions in a number of other cognitive domains may well contribute.

However, the particular sensitivity of night shift workers here is notable, when it is considered that their day shift colleagues will have completed a similar number of hours of work-related activity and likely have been awake for a similar period of time prior to driving. Indeed, Brandenberger et al. (2010) found that both day shift workers and permanent night shift workers showed significant decrements in cognitive proficiency measures following a 12 hour shift (gesture proficiency, hand movement smoothness, instrument movement smoothness, time elapsed and performance errors). However, despite there being no difference in baseline pre-shift testing, night shift workers exhibited greater impairments when evaluated after their shift. This may suggest that the circadian misalignment experienced by night shift workers can accentuate the deleterious effects of occupation-related fatigue on cognitive performance.

The impact of shift work on cognitive measures of attention has been explored in a number of studies, with a considerable degree of divergence in the findings. Narciso et al. (2016) reported a 13% increase in reaction time and a 425% increase in attentional lapses, as measured by the PVT, in polysomnography technicians working a single 12-hour night shift. This loss of sustained attention performance across the shift was likely to have been related to the reported 59% increase in sleepiness by the participants, although the lack of a day shift comparison cohort in this study prevents dissociation of the relative contributions from acute work-related fatigue and the differential extent of circadian misalignment experienced by night shift workers.

In common with the polysomnography technicians surveyed by Narciso et al. (2016), acute fatigue following a shift has been reported as increased perceived sleepiness in a variety of populations including nurses (Geiger-Brown et al., 2012), train drivers (Härmä et al., 2002) and police officers (Waggoner et al., 2012). However, the attentional impact observed by Narciso et al. using the PVT is not replicated consistently across other shift working populations, suggesting that this impairment may not be solely driven by the cognitive consequences of acute work-related fatigue.

For example, an investigation of miners at each stage of a 28-30 consecutive day rotating shift cycle found that participants reported increased fatigue with increased time awake irrespective of the type of shift worked or if they were on a day off (Legault, Clement, Kenny, Hardcastle, & Keller, 2017). While assessment compliance in this population was reported to be limited, PVT performance in these individuals, assessed at 4 points during each shift and day off, showed no differences in PVT reaction time (or attentional lapses) during a day shift or on a day off. However, there was some evidence of differences in performance across night shifts, with a significant decrease in reaction time (suggesting enhanced performance) between 8pm and midnight. This single time period within the night shift represented the highest level of performance across all of the assessment windows surveyed irrespective of shift type or day off

status, with no other performance differences detected. Consecutive shifts (or days off) were also reported not to have any impact on performance. The significance of this temporal epoch to the transient enhancement of PVT performance reported is not clear, and while the relative lack of impact observed could be a result of limitations in study design it could still be interpreted as suggesting far less profound attentional changes in this population than those reported by Narciso et al.

Similarly, Geiger-Brown et al. (2012) found that whilst nurses on a 12 hour night shift experienced higher levels of sleepiness towards the end of their shift when compared to day shift nurses, there was no difference in mean PVT reaction times between these shift types, suggesting unaffected attentional performance. It should be noted however that Geiger-Brown et al. did report other shift-dependent cognitive impairments, specifically an increased number of early PVT responses. This suggests that the fatigue resulting from the 12 hour shift impacted these individuals' executive function (specifically response inhibition) rather more than their sustained attentional capacity.

These divergent findings may be due to technical differences between the PVT assessments used in these studies, with shortened PVT's (Geiger-Brown et al., 2012; Legault et al., 2017) suggested to be less sensitive to the effects of circadian misalignment (Loh, Lamond, Dorrian, Roach, & Dawson, 2004). Indeed, comparing attentional assessments across different shift worker studies is particularly challenging, given the wide range of other assessments that have been applied to these populations.

The discrepant findings concerning the effect of shift working on attentional performance could also be a consequence of some difference(s) between the populations surveyed. A considerable range of factors contribute to differences between specific occupational groups. For example, different working environments expose people to varying levels of physical exercise and stress, and to decision making, with consequences ranging from trivial to potentially life-and-death in some cases. Understanding how each of these could potentially impact cognitive performance yields an almost unlimited parameter space, such that identifying critical factors is a considerable challenge.

More broadly, this highlights the difficulties associated with comparing studies of shift working individuals using specific occupational groups while in their respective environments. Assessing individuals outside of the work environment (i.e. on a day off), therefore to some extent standardising such factors, may provide a more consistent platform upon which potential shift working-dependent attentional impairments can be characterised. Such a testing paradigm would also serve to decouple the effects of work-related fatigue and the broader shift working lifestyle on cognition, a distinction which is currently not possible in many study designs. An

occupationally-matched group of non-shift workers assessed using the same parameters in each study would also provide further useful insights, in that this group would offer details into which characteristics were a result of occupation related factors as opposed to a mismatched circadian rhythm.

Another issue of concern is the widely varying parameters of the shifts themselves, any of which could reasonably be anticipated to differentially impact attentional performance. Significantly, the length of shift appears to have little impact, with Rhéaume and Mullen (2017) finding no difference in attention between 8 hour day workers and 12 hour shift workers (working 12 hour shifts for four days then several days off). This could suggest a peak of impairment after 8 hours that cannot be exceeded with an additional 4 hours of work or that the extended shift length establishes a degree of resistance counteracting any further time dependent worsening of the impairment. Evaluation of the sleep characteristics of these groups further complicates this interpretation. Specifically, the 12 hour shift workers had less sleep and their sleep was less efficient than their 8 hour counterparts which might suggest they should be increasingly vulnerable to cognitive compromise. However, Rhéaume and Mullen (2017) also report that this group napped more frequently. Napping is considered beneficial for shift workers as it can supplement the sleep they receive, improve sleep related performance and decrease sleepiness (Ruggiero & Redeker, 2014). However it is often not occupationally practical to employ in the workplace. As napping was not controlled in this case, it may be that the 12 hour shift workers were additionally impaired but able to effectively compensate with their increased naps. Napping is therefore another important factor to consider when assessing studies involving shift working populations.

The precise balance between sleep and wakefulness may also be a critical factor. McHill et al. (2018) used a 32-d protocol of 20 hour days, involving 17 healthy individuals, assigning them to either a control (receiving 6.67 h sleep opportunity and 13.33h wakefulness) or chronic sleep restriction (CSR) group (receiving 4.67 h sleep opportunity and 15.33 h wakefulness). The PVT, Visual Analogue Scales and Karolinska Sleepiness Scale were used to assess sustained attention, self-reported alertness, and self-reported sleepiness respectively. There was no difference between control and CSR groups in self-reported alertness or sleepiness. A lack of awareness may indicate that the attentional impairments observed here were too subtle for these individuals to be aware of or that attentional processing is inaccessible to metacognition. These impairments indicated that chronic short sleep deprivation doubled reaction time performance and increased lapses five-fold relative to the extended period of wakefulness condition. This potential lack of awareness/insight could have detrimental effects when applied in the occupational setting, given that a decrease in attention without awareness may lead to over-confidence and ultimately result in accidents.

A further issue when considering populations experiencing either SD or the circadian misalignment characteristic of shift working is the potential for the population to be stratified on the basis of resistance to these sorts of disruption. Killgore et al. (2009) examined attentional performance in 54 individuals subjected to 41 hours of sleep deprivation with bi-hourly testing on a PVT variant. The top and bottom 25% of the cohort were categorised on the basis of performance as 'SD resistant' and 'SD vulnerable'. The baseline neurocognitive abilities of these two groups were then compared. Whilst no differences on non-executive functioning tasks were detected, significant differences were observed in executive functioning tasks (assessed using Letter Fluency, the Stroop Colour-Word Task and Colour Trails Form 2). This suggests that PVT performance could plausibly be used to screen individuals for the level of susceptibility of their broader prefrontal executive to the effects of SD, although the utility of this approach in a shift working population remains to be assessed. This is a critical investigation, given that prolonged exposure to a shift working routine may well cause 'SD-like resistance' to develop in these individuals.

It is reported that those who have a more frequent circadian misalignment (night shift workers) will have poorer sleep quality and timing (Monk et al., 2013). Poorer sleep quality and SD have been shown to have a negative impact on attention (Doran et al., 2001; Lim & Dingus, 2010) as well as yield an increase in sleepiness following a shift, across a range of disciplines (Geiger-Brown et al., 2012; Härmä, Tenkanen, Sjöblom, Alikoski, & Heinsalmi, 1998; Waggoner et al., 2012). However, given the variability in the impact of shift working on attention noted here, it may be that individuals who choose to participate in shift work either inherently possess or come to develop increased levels of SD resistance, enabling them to compensate for their disrupted sleep characteristics.

In a similar vein, the morningness/eveningness status of an individual may well also be an important factor, given that brain activity differences in a region of the locus coeruleus and in the suprachiasmatic area have been found between 'morning type' individuals (who wake up early and perform better earlier) and 'evening type' individuals (who perform better in the evening). Specifically, maintaining attention in the evening was associated with higher activity in these regions, in evening types compared to morning types (Schmidt et al., 2009), although again a shift working population has not been evaluated using this approach. This is a key concern, given that shift work may, due to its nature, attract more evening-type individuals and retain them for longer within the population.

Notwithstanding the challenges associated with comparing the various tasks used to assess attentional performance, and addressing the multitude of characteristics inherent in the various shift working populations, evidence does suggest that shift work adversely impacts this cognitive

construct. Given this, it will be important to identify and characterise the relevant underlying neural correlates. While evidence from shift workers in this domain is yet to be collected, the neural correlates of PVT performance in the context of fatigue have been explored. Drummond et al. (2005) found that optimal PVT performance (as indexed by fast reaction times) involved the typical frontoparietal sustained attention system and a variety of cortical and sub-cortical motor-related structures when participants were well-rested. However, following SD sufficient to result in impaired PVT performance, correlations with activity in a different range of structures, including many associated with the default mode network, consisting of brain regions that show more activity when at rest but awake (Glass, Ware, & Mattson, 2014), were detected.

This could suggest that poor PVT performance in fatigued individuals results primarily from task specific disengagement (possibly due to the activation of the default mode network) causing increased attentional lapses or impairments in the execution of the necessary motor outputs (due to the lack of activation of motor-related structures), resulting in increased reaction times and potentially manifesting as increased failures to respond (which would present as attentional lapses). The conclusions drawn regarding the involvement of the motor system impacting reaction times, as opposed to signal detection and discrimination systems or decision making, are supported by Lawrence et al. (2003). Using fMRI, they showed that a greater activation within the presupplementary motor area was correlated with faster response times on a rapid visual information processing task (RVIP).

The potential for shift working to impair motoric ability has been reported elsewhere. Specifically, San Chang et al. (2011) observed a motoric impairment in a cohort of shift working nurses (San Chang et al., 2011). Significantly, the extent of this impairment was greater following two consecutive night shifts when compared to four consecutive night shifts. These findings could suggest the engagement of a compensatory mechanism by which performance is protected and partially rescued under conditions of continued circadian misalignment. However, a cohort of nurses on a day off was not included in this study to determine if the absolute levels of performance observed here are consistent with a generalised shift work-dependent impairment. Notwithstanding, this study reinforces the potentially counterintuitive finding noted earlier that increased exposure to a consistent shift working routine may be more beneficial cognitively than a more variable shift pattern. It also underlines the fact that shift-working-related motoric changes could inadvertently confound performance of cognitive tasks requiring individuals to make physical responses and this could in turn interact with the relative motoric demands of the tasks concerned. Indeed, there was no evidence of an attentional deficit in this population as measured by the Taiwan University Attention Test. Being based on a self-paced search for specific target characters among 780 items printed on a sheet of paper, this test arguably has a reduced

motoric profile relative to tasks such as the PVT which requires highly accurate, high speed responses.

1.5.1.2 Attention and new parenthood

In contrast to the relatively extensive literature evaluating the impact of shift work on attention, the existing body of work focused on attention in new parents is far smaller. This makes the drawing of robust consensus conclusions far more challenging and highlights the importance and value of further studies in this population.

Insana et al. (2013) examined postpartum women over the course of 12 weeks following child birth. Despite improvements in post-partum sleep (measured using wrist actigraphy), they observed a worsening performance on a PVT, however this was not exhibited until the second week postpartum (Insana, Williams, & Montgomery-downs, 2013). Performance decline was linked with sleep fragmentation rather than sleep time. They suggested that a cumulative effect of sleep deprivation influenced this seemingly paradoxical interaction (Insana et al., 2013).

Indeed, similar attention impairments were observed in mother–father dyads, with new mothers and fathers showing worse PVT performance than sex matched controls (Insana & Montgomery-Downs, 2013). Mothers and fathers showed no significant differences regarding subjectively measured sleep quality, sleepiness or fatigue. Mothers did however perform worse on the PVT than fathers. The lack of difference in sleep and fatigue is in contrast to that of Gay et al. (2004) who reported mothers lost more night time sleep than fathers in the post-partum period (Gay et al., 2004).

There is also evidence to suggest that the impact of new parenthood associated sleep deprivation on attention is reversible. Wilson et al. (2019) examined PVT performance in 78 postpartum women during a residential early parenting program. After the five day programme involving increased sleep opportunities, supervised practise of infant settling strategies and psychological support, the new mothers showed an improvement in PVT reciprocal mean reaction times. This would suggest that 5 days of recovery sleep can lead to an improvement in attention.

Overall, this literature seems to suggest that sustained attention is negatively impacted by sleep deprivation associated with new parenthood, however a short period of recovery sleep (5 days) can lead to improvements.

Taken together, these findings suggest that attention, whether considered as a unified construct or sub-divided into elements such as sustained, divided and selective attention, is affected adversely by disruptions to sleep. There is also some evidence that shift work may similarly impact this domain. However this is highly dependent on the assessment used and the precise characteristics of the population screened. In addition, differentiating the impact on attention of

acute work-related fatigue and more persistent shift work lifestyle-related effects remains challenging, as does understanding the neural basis for these effects. Similarly, the sleep disruption experienced by new parents appears to lead to attentional impairment, though it seems to be partially recoverable with sleep. Yet there is a clear lack of exploration of this cognitive domain within new fathers. Finally it is unclear whether any chronic attentional impairment is caused by new parenthood/shift work or whether recovery sleep is enough to fully restore functioning.

1.5.2 Response inhibition

Response inhibition is defined as the suppression of actions that are no longer necessary or that are inappropriate for a given context. This functionality supports the selection and emission of flexible goal-directed actions in the context of a changing environment (Verbruggen & Logan, 2008).

Response inhibition can be assessed with a variety of paradigms including the Stop Signal Task (Congdon et al., 2012), the Go Nogo (GNG) Task (Aron & Poldrack, 2005) and the Stroop Task (Troyer, Leach, & Strauss, 2016). Many response inhibition related processes overlap with those involved in attention, as they are dependent upon intact attentional function and control. While the subdivision of response inhibition into different sub-domains is arguably less extensive than the approach taken with attention described previously, it is apparent that these response inhibition tasks each assess different elements of this construct.

Specifically, the Stop Signal Task measures controlled inhibition whereas the GNG Task assesses automatic inhibition. To exemplify this dichotomy, Littman and Takács (2017) found that the same population (54 students) generated differential performance across these two tasks. This was due to the use of stimuli with a negative emotional valence (selected from the Geneva Affective Picture Database and the International Affective Picture System) which have been shown to affect executive control and lengthen response times in several cognitive tasks (Estes & Adelman, 2008; Estes & Verges, 2008). Exposure to these negative stimuli impacted performance in go trials and improved inhibitory function in the Stop Signal Task, while having minimal effects on performance in the GNG Task which, being more automatic, is less sensitive to the emotional valence of the stimuli.

Regarding neural correlates, the performance of these tasks in conjunction with neuroimaging has indicated the related activation of a number of brain regions. Specifically, activation in both frontal and inferior parietal regions has been associated with GNG performance (Simmonds, Pekar, & Mostofsky, 2008). Independently, activation of both the prefrontal cortex (Ridderinkhof, Van Den Wildenberg, Segalowitz, & Carter, 2004; Rubia, Smith, Brammer, & Taylor, 2003) and the subthalamic nucleus (Aron & Poldrack, 2006; Ray et al., 2009) have been associated with the GNG

and Stop Signal tasks. Further, fast wave/slow wave ratio (beta/delta and theta waves) has been shown to be negatively correlated with inhibited performance on an emotional go/no-go task (Putman, Peer, Maimari, & Werff, 2010). Specifically, beta was greater for fearful faces than happy ones, indicating a more inhibited response bias towards fearful stimuli.

The neural correlates of response inhibition may also have a circadian dependence. For example, inhibition-related responses in the medial frontal gyrus, middle cingulate cortex, thalamus and other areas known to be involved in response inhibition significantly decrease from morning to evening (Song et al., 2018). The impact of these changes on performance of response inhibition tasks such as GNG is complex, in that Go trial accuracy increased in the evening, perhaps consistent with a generalised liberalisation of responding due to reduced inhibitory activity, but no change was observed in Nogo trials arguably where the demand for inhibitory capacity is higher. This could suggest that these diurnal changes, while in structurally relevant areas, have only a minor impact on behavioural output, or that the level of inhibition required in the GNG can tolerate these changes in activity.

Of particular significance to this thesis, a neuroimaging study (Chuah, Venkatraman, Dinges, & Chee, 2006) has investigated response inhibition in the context of SD. These findings provide some support for the claim that some individuals differ in their capacity to protect their cognitive functioning during SD through differential marshalling of cognitive resources. Specifically, individuals were screened using the GNG before and after 24 hours of SD and stratified into either high, moderate or low vulnerability groups based on the extent of the change in GNG performance. No age or impulsivity differences were found between the groups. Imaging revealed that those individuals better able to maintain response inhibition after sleep deprivation exhibited altered levels of stop-related phasic activation in the right ventral PFC and also generalised increases in activation of the right ventral PFC and right insula. Also, the inhibitory efficiency of the high vulnerability group after sleep deprivation differed significantly from the moderate and low vulnerability groups with no significant difference detected between the latter two groups. Further analysis indicated that whilst inhibitory control did not differ between the groups when rested there was a trend towards increased variability in the high vulnerability group, suggesting that these individuals may have inherent difficulties in inhibiting responses even when rested, perhaps due to an inherent difference in these individuals. It was suggested that higher right ventrolateral PFC activity may be needed in these individuals for satisfactory performance (Chuah et al., 2006). This differential pattern of activation correlated with GNG performance following SD is suggestive of a mechanism by which response inhibition can be better preserved in some individuals. Whether this mechanism is inherent in individuals who are more tolerant of SD or develops as a consequence of repeated exposure to SD is a key question that remains to be addressed.

The intimate association of effective response inhibition with the capacity to tolerate a changing environment and be cognitively flexible makes the stability of this construct in the face of work-related fatigue and shift working itself particularly crucial in the occupational context. A specific challenge when considering response inhibition is the speed with which it fatigues. Using the GNG, Kato et al. (2009) found that response inhibition is impaired within 60 minutes of being engaged, with key performance measures of reaction time, errors and mental fatigue all increasing in relation to time spent on task. While response inhibition is unlikely to be actively and consistently engaged on a single high intensity task for such a duration in more ecological settings than the extended GNG, this study serves to highlight the particular demands of utilising this construct and note the fatigue it generates. Correspondingly, a key factor not addressed in this study is the rate at which response inhibition capacity recovers after a period of active engagement.

Beyond the evidence noted earlier (Chuah et al., 2006), other studies have examined the impact of SD on response inhibition. For example, Anderson and Platten (2011) found significant increases in failures to respond and increased incorrect response emissions in the GNG following one night of SD (equating to 36 hours of wakefulness) in 32 otherwise healthy unmedicated individuals. Emotional valence of the stimuli (selected from the 'General Service List' word database) did appear to have a role in that these performance impairments were only observed when the stimuli were negative (e.g. frown) (Anderson & Platten, 2011).

This is consistent with the findings of Drummond et al. (2006) who assessed individuals with the GNG each day between two consecutive nights of SD. This produced a progressively evolving profile of performance, beginning with evidence of inability to withhold responding on the first day, followed by decreases in response accuracy and slower response initiation after the second night. However, these impairments were normalised after one night of recovery sleep, suggesting that whilst SD has a pervasive impact on response inhibition, it can be recovered relatively quickly.

These findings have been further replicated by Mander et al., with GNG impairments detected after 38 hours of continuous wakefulness (Mander et al., 2010). These impairments were also recovered after only a single night of recovery sleep. However, there was evidence of high inter-individual variability between normal sleep and recovery sleep, suggesting that the impact of SD and the restorative effect of the subsequent recovery sleep on response inhibition may vary markedly between individuals.

These studies would suggest therefore that response inhibition is sensitive to SD, with impairments detected after a single night without sleep. Inconsistent with this claim, Binks et al. (1999) found no significant difference in response inhibition between a rested group and a group

exposed to 34-36 hours SD, based on completion time or number of errors in the Stroop Task. However it is important to note the difference in assessment paradigm here. As mentioned previously, the Stroop Task, GNG and Stop Signal Tasks all rely on different underlying processes and may assess different aspects of response inhibition (Khng & Lee, 2014; Littman & Takács, 2017). Therefore, it may be that SD of up to 36 hours impacts the response inhibition elements evaluated in the GNG and Stop Signal Tasks while the dominant component evaluated in the Stroop Task is resistant. Stroop performance may also be proportionately less sensitive to the effects of SD on response inhibition than either the GNG or Stop Signal paradigms. Another concern is the differing balance of other cognitive demands associated with each task; for example, the GNG requires high levels of sustained attention, whereas this demand is typically lower in the Stroop Task due to its comparatively slower event rate.

Response inhibition has also been examined in the context of sleep restriction, which in contrast to SD permits limited opportunities for participants to sleep during assessment. Stenuit and Kerkhofs (2008) found that after three days of sleep restriction allowing 4 hours of sleep per night, both older (50-60 years) and younger females (20-30 years) exhibited impaired response inhibition, as evidenced by an increase in errors and longer reaction times in the Stroop Test. This suggests that the 4 hours of sleep per night is insufficient to prevent the deterioration in response inhibition observed here.

It should be noted that Stroop performance in this study was based on a comparison between performance on the third night and performance on the morning after a recovery sleep at the end of the study (Stenuit and Kerkhofs, 2008). While eliminating the possibility of practice effects confounding a comparison between first and third night performance, this design effectively builds in a potential practice induced enhancement of performance in addition to the final recovery sleep session. It is also not possible to chart the progression of any impairment across the three nights of sleep restriction in this study. This would be useful as it may be, for example, that the impairment resulting from 20 hours of wakefulness on the first day (similar to the SD studies discussed previously) is sufficiently small in magnitude to be offset by the permitted 4 hours of sleep, but that a further 20 hours of wakefulness results in a further accumulation of impairment which becomes too large for a further 4 hours of sleep to offset.

This cohort was also evaluated for GNG performance but no significant effect of age or testing condition (days of sleep restriction) was detected on reaction time or number of errors, although there was some evidence of a change in reaction time between baseline performance (assessed on the first full day of the study) and sleep restriction day 2 (Stenuit and Kerkhofs, 2008). Given that the GNG is thought to be susceptible to practise effects (Schapkin, Falkenstein, Marks, & Griefahn, 2007) and the participants here performed GNG on multiple occasions (Stenuit and

Kerkhofs, 2008), it may be that any effect of sleep restriction on task performance was offset, leading to the divergence of findings.

Taken together, these data indicate strong evidence for adverse effects of SD on response inhibition. It is also apparent that the effects can be reversed with recovery sleep, although the period of sleep required in relation to the period of wakefulness sustained is uncertain.

1.5.2.1 Response inhibition and shift work

As noted previously, given the importance of response inhibition in maintaining cognitive flexibility, understanding how the circadian misalignment experienced by shift workers impacts this cognitive process is important from an occupational perspective. Many shift working jobs involve responding quickly to an ever-changing environment, for example when repetitively operating heavy machinery or attending to a patient, with impaired response inhibition potentially leading to injury or death. However, response inhibition in shift workers is an understudied area and more research explicitly focusing on this is needed.

Of the few studies focussing on this population, response inhibition has been suggested to be negatively impacted in shift workers. Kaliyaperumal et al. (2017) found 71% of shift working nurses scored less on the Stroop task during a night shift, compared to a day shift (Kaliyaperumal, Elango, Alagesan, & Santhanakrishanan, 2017). Similar findings were observed in male office workers (business process outsourcing employees), again using a Stroop task. Comparison of shift and non-shift working individuals in this study revealed an impairment in response inhibition in those undertaking shifts (Shwetha & Sudhakar, 2012).

1.5.2.2 Response inhibition and new parenthood

Similar to the shift working population, relatively few studies have evaluated response inhibition in new parents. Assessment of response inhibition in new parents is key, given the new parents need for cognitive flexibility whilst simultaneously looking after a newborn, caring for themselves and operating safely in the outside world. Bannbers et al. (2013) examined postpartum women 48 hours after delivery, 4-6 weeks after delivery and non-postpartum controls. No differences in GNG task performance were observed between groups or across time points suggesting no response inhibition impairment as a result of new parenthood (Bannbers et al., 2013). This contrasts with much of the sleep deprivation literature outlined above. Given the evidence described above that response inhibition impairment may be recoverable with sleep (Drummond, Paulus, & Tapert, 2006; Jin et al., 2015; Mander et al., 2010), it is plausible that the effect of new parenthood, where individuals are still able to sleep but at unpredictable times/lengths, would show less impairment than that seen in laboratory based SD studies.

An important focus for future studies of response inhibition in both populations is stress. As noted previously, there is evidence to indicate that shift workers experience more stress than their non-shift working counterparts (Coffey, Skipper, & Jung, 1988; Ulh a, Marqueze, Kantermann, Skene, & Moreno, 2011). This has been observed in multiple and diverse occupational samples, including nurses, factory workers (Kim et al., 2002) and police officers (Gerber, Brand, P hse, Hartmann, & Holsboer-Trachsler, 2010). Similarly, new parenthood has been shown to be linked with increased psychological and interpersonal stress (Huston & Holmes, 2004; Perry-Jenkins et al., 2011). Data derived from animal models of stress exposure has indicated that response inhibition is specifically impacted by this manipulation (Mika et al., 2012). It seems highly likely therefore that shift working individuals and new parents will also exhibit impairments in this critical cognitive domain, although whether this is due to acute fatigue, circadian misalignment, or exposure to stress hormones will be a key issue to evaluate.

1.5.3 Working memory

Working memory (WM) is typically viewed as the capacity to transiently hold key information ‘in mind’ to help inform vital decision-making processes. Models of WM commonly involve three components; the central executive, the visuospatial sketch pad and the phonological loop. The central executive receives inputs then channels the information to the appropriate centre to be stored. It is also responsible for removing irrelevant information. The visuospatial sketchpad is responsible for temporarily storing any visual or spatial information ‘in mind’, whereas the phonological loop stores phonological information (Baddeley and Hitch, 1974). Baddeley (2000) subsequently proposed a fourth component, the episodic buffer, which communicates with long-term memory as well as storing information not covered by the other slave systems. There have since been further developments of this model, with Baddeley and Hitch (2018) now characterising the system as a hierarchy of buffer stores.

Effective WM is a key aspect of normal cognitive functioning (Carruthers, 2013). The occupational relevance of WM is substantial, as, no matter what the work environment, the ability to receive, hold in mind and interpret information is necessary for effective workplace performance. In the context of highly stimulating work environments such as hospitals and when working with dangerous machinery, the consequence of a WM impairment, particularly around the filtering of irrelevant information, could also be very serious. Similarly, within the population of new parents a failure in working memory could result in serious injury to a newborn or the parent themselves.

WM can be assessed with a number of cognitive tasks (Wilhelm, Hildebrandt, & Oberauer, 2013). These tasks typically consider WM capacity (i.e. the amount of information an individual is able to hold in mind) and/or WM retention duration (i.e. the length of time an individual is able to store that information for). For example, the N-Back task measures WM capacity (Kirchner, 1958).

There are two main N-Back variants, spatial and verbal, with the former based on comparison of distinct spatial locations and the latter comparing digits/characters, although picture-based versions also exist (Meule, 2017). In the N-Back task participants are required to hold information from a trial in mind and use that information to guide responding in the trial that occurs n trials subsequent, responding when the stimuli match.

In contrast, the Delayed Match to Sample Task depends on the visuospatial component of WM (Parr & White, 1992). Participants are shown a stimulus and then, after a short delay, shown the same stimulus with several other 'foil' stimuli and are required to indicate which matches the original sample. This measures WM retention duration.

The Sternberg Working Memory Task involves providing participants with a list of items which they must hold in mind for the duration of a retention interval. These individuals are then asked if specific words/items appeared on the list (Sternberg, 1969). This task assesses WM capacity, duration and retrieval speed.

Clearly, these tasks can be manipulated in a number of ways to impact difficulty, including adjusting the number of items to hold in mind, increasing the number of 'foils' to distinguish between and increasing the duration for which the information must be retained. This can drastically affect the results obtained and must be taken into consideration when comparing studies in which this construct is evaluated.

Given the diversity of WM tasks and parameters, considerable divergence in findings is perhaps unsurprising. Indeed, direct comparison of laboratory WM assessments such as the N-back and clinical assessments such as the relevant Wechsler Adult Intelligence Scale IV (WAIS-IV) and Wechsler Memory Scale III (WMS-III) sub-tests may be untenable (Wechsler, 1981). A factor analysis suggests that the most effective approach to assessing WM combines three laboratory tasks and one clinical sub-test (Letter-Number Sequencing) which were highly positively correlated (Shelton, Elliott, Hill, Calamia, & Drew Gouvier, 2009). Consequently, interpretations based on a single assessment of WM may be limited and should be avoided in the design of future studies targeting this construct.

Regarding neural correlates, WM performance is broadly dependent on normal functioning in prefrontal and parietal cortical areas. However, given the range of WM tasks, it seems reasonable to anticipate some variation in the precise pattern of activation. Wager and Smith (2003) performed a meta-analysis of 60 WM studies involving imaging and found that the type of WM task performed influenced the precise pattern of activation observed. This speaks directly to the varying demands of different WM tasks.

For example, tasks involving executive functioning (such as N-Back and the Item Recognition Task) were associated with activation of Brodmann Area 7 in the posterior parietal cortex. Whereas verbally driven WM tasks (such as verbal N-back) were associated with activation of left frontal regions, but only under low executive demand conditions (Wager and Smith, 2003). A left hemispheric dependence of verbally driven tasks is perhaps unsurprising, considering language associated functions are often similarly lateralised (Binder et al., 1997; Frost et al., 1999). In contrast, executive demand increased right lateralization in the frontal cortex for spatially driven WM tasks (such as spatial N-back) (Wager and Smith, 2003).

The importance of prefrontal activity to WM is further supported in a study by Curtis and Esposito (2003), which suggested a crucial role for the dorsolateral prefrontal cortex (dlPFC) in maintaining information by directing attention to internal representations of sensory stimuli and motor plans. Kane and Engle (2002) similarly concluded that the dlPFC is critical for executive attentional functioning. Further insight into the role of the PFC was obtained by Prabhakaran et al. (2000) who reported fMRI activation of this region associated with maintaining integrated information (both verbal and spatial).

Load of task is also suggested to cause differences in brain activity. McEvoy et al. (2000) examined 20 healthy adults using a spatial N-Back (a 1-back and a 2-back) (McEvoy, Smith, & Gevins, 2000). They found frontal midline theta was significantly larger in the more difficult 2-Back than in the easier 1-Back task. Both slow and fast alpha on the other hand, were significantly smaller in the difficult task than in the easy task. Theta waves are associated with drowsiness, and an increase during a more cognitively complex task may be indicative of task fatigue. Alpha waves are most prominent when in a relaxed state. It is expected that alpha would be smaller in a task that has a higher cognitive load.

Despite the importance of WM to cognition and the substantial occupational relevance of this construct, relatively few studies have evaluated WM in the context of shift working, new parenthood, circadian misalignment, or extended SD. Given evidence of the impairing effects of these situations on the other aspects of cognition discussed here, the comparatively small number of WM focused studies is surprising. This may be a consequence of WM being highly demanding with respect to cognitive resource such that it is highly likely these manipulations would adversely impact it.

Supporting the view that WM is highly sensitive to disruption, even perceived fatigue has been shown to have negative effects. Using an automated version of the Operation Span Task (Unsworth, Heitz, Schrock, & Engle, 2005) in undergraduate students, Clarkson et al. (2011) found that perceived fatigue (obtained through false feedback from a previous low resource depletion task) led to reduced WM capacity.

There is some evidence that SD adversely affects WM. Chee et al. (2006) examined the impact of 24 and 35 hours of total SD on WM in 26 healthy students. WM was assessed using the LTR task, the PLUS task and the PLUS-L task at baseline (rested wakefulness one week prior to sleep deprivation), after 22-24 hours and after 34-35 hours SD. In the LTR task participants are presented four letters (memory stimulus set), followed by a single letter (probe). Individuals are asked if the probe stimulus was a match to any in the memory stimulus set. The PLUS task is similar in that participants have to indicate if a probe letter is a match or non-match. However they are shown only two letters e.g. B + J and required to remember for the match/non-match the consecutive letter e.g. C + K. The PLUS-L task is identical to the PLUS task except that in the non-match trials the probe is the same as one of the memory stimulus set e.g. B. Whilst performance accuracy declined in all three tasks following SD, consistent with impaired WM, and an increase in variability in the 34-35 hour group was observed, there was no significant difference between the SD conditions, perhaps suggesting a performance minimum beyond which WM accuracy cannot be further compromised. A similar pattern was observed when reaction time was analysed, with SD-dependent impairments detected. For this measure, the biggest change occurred between baseline and the 22-24 hour condition, with no significant difference between the 22-24 and 34-35 hour conditions, again suggestive of a performance minimum having been reached.

This study also explored the potential for individual differences in resilience to the effects of SD's impact on WM performance. Chee et al. 2006 stratified the cohort as either sleep deprivation vulnerable (SDV) or sleep deprivation resilient (SDR) based upon the greatest and smallest accuracy difference in WM performance following SD. The eight most SDR and the eight most SDV individuals were further examined. This analysis revealed that the SDV subgroup had a larger reaction time decline following SD when compared to the SDR subgroup, suggesting a greater magnitude of impairment.

Evidence of similar individual differences has been obtained in independent studies. Using the Sternberg Task, 33 healthy young men were evaluated by Mu et al. (2005) before and after 30 hours SD. As previously, based on overall performance changes, 10 sleep-deprivation vulnerable (SDV) and 10 sleep-deprivation resilient (SDR) individuals from this cohort were further examined. Both sub-groups exhibited increases in reaction time and decreased correct response rates following SD, consistent with a WM impairment. Neuroimaging also indicated a significant reduction in global brain activity after SD in both sub-groups. Further analysis also revealed a difference in the nature of the activity decrease between the sub-groups. In the SDV sub-group the overall decrease was due primarily to reductions in parietal and bilateral prefrontal circuits. In contrast, in the SDR sub-group this was mainly attributed to the diminished activation of bilateral parietal circuits without the involvement of the PFC. The SDR sub-group also showed significantly

more task-related activation when both rested and sleep deprived compared to the SDV subgroup.

In common with a number of the other cognitive domains highlighted in the chapter, this work suggests significant inter-individual differences in response to SD-related manipulations of cognition, possibly due to mechanisms that preserve cognitive function as far as possible, although whether these are inherent or result from repeated exposure to SD is uncertain.

The importance of WM task difficulty in the context of SD has also been examined. Following 31 hours SD, Lythe et al. (2012) observed impaired N-Back performance accuracy but not response latency with the magnitude of impairment correlated with memory load (comparing 1, 2 and 3-Back paradigms). They also observed decreased activation in right vIPFC and right inferior parietal lobe when compared to the rested state. The pattern of activity observed was found to be dependent on task difficulty. Specifically, as task demand increased, activations were observed in right premotor cortex (extending into right dlPFC and right vIPFC), anterior cingulate cortex, left lateral prefrontal cortex, left lateral premotor cortex, bilateral insula, left dlPFC, right anterior PFC, and bilateral posterior parietal lobes with a peak in right inferior parietal lobe. These activations were seen irrespective of SD status, perhaps suggesting that increased task difficulty requires an elevation in cognitive resource allocation (Lythe, Williams, Anderson, Libri, & Mehta, 2012).

Task demand may also interact with WM to impact performance in the context of SD. For example, Chee and Choo (2004) performed two WM tasks, LTR (assessing WM maintenance) and PLUS (assessing manipulation of verbal WM) in 14 individuals before and after 24 hours SD. Response times for both tasks were significantly slower following SD, again consistent with impaired WM performance. However, performance was better preserved in the more complex PLUS task. This finding is congruent with an independent study using a range of N-Back variants. Following 36 hours SD in a healthy participant group, N-Back performance was relatively more preserved in more cognitively complex versions of the task (Terán-pérez et al., 2012).

While the mechanism underlying this somewhat counter-intuitive finding is uncertain, enhanced task performance as a function of task difficulty has been reported in other domains, including attention (Washburn & Thompson Putney, 2001). In the case of WM, it could perhaps be partially a consequence of increased interference (as would occur by progressing from a 2-back to a 4-back for example) necessitating increased cognitive resource allocation to filter out unnecessary stimuli resulting in a generalised improvement in task performance. When participants experience increased uncertainty during a trial because of this interference effect their response times may slow as they take more time to establish what the correct answer is (Harbison, Atkins, & Dougherty, 2011). This is supported by the finding that N-Back response times increased after 30

hours SD (even though accuracy was not further decreased after 36 hours SD) in the Terán-pérez et al. (2012) cohort.

So far this section has considered laboratory-based SD studies, the extent of deprivation arguably being sufficiently large to substantially reduce ecological validity. Such a pattern of SD is dissimilar to the experience of most shift workers. Similarly the unpredictable sleep disruption associated with new parenthood is unlike that seen in typical laboratory SD studies. Therefore, whilst it is reasonable to conclude that WM is adversely impacted by SD, effects in the shift working and new parenthood contexts cannot be directly extrapolated from these data.

One group that may provide some further insight is insomniacs. While not an ideal model of circadian mismatch, the SD experienced by these individuals is somewhat more naturalistic than the forced deprivation experienced in laboratory conditions. Fortier-Brochu et al. (2012) performed meta-analyses on 24 studies comparing cognition in those with insomnia and normal sleepers. Insomniacs were shown to have mild to moderate impairments in both WM retention and manipulation. WM retention was assessed using the Sternberg Task, Memory Span Task and Digit Span Task (forward). WM manipulation was assessed using the Rapid Visual Information Processing Task, Digit Span Task (backwards), Letter Number Sequencing Task and N-Back Task. That impairments were detected across such a broad range of paradigms suggests a robust adverse effect of insomnia on WM.

However, this does not necessarily reflect a generalised insomnia-dependent cognitive impairment. Indeed, while impairments were also detected in some attentional processes (choice reaction time, information processing and selective attention), a number of other attention-related elements were not affected (alertness, divided attention, sustained attention and vigilance). Similarly, there was no apparent effect of insomnia on general cognitive function according to measures assessing intelligence and via screening measures for dementia (Fortier-Brochu et al., 2012). This suggests differential sensitivity across cognitive domains, with WM being particularly sensitive. While again not providing direct evidence that shift working or new parenthood can affect performance, these data further support the view that WM may be particularly impacted in this population and that it is reasonable to anticipate a heterogeneous profile of impairment across distinct cognitive domains.

1.5.3.1 Working memory and shift work

Kazemi et al. (2018) assessed WM function across two shift patterns (4 consecutive night shifts (4N) and 7 consecutive night shifts (7N)) using the N-back (1-back design). They found that whilst there was no impact on reaction time in the task between shift types there was a difference between the number of correct responses, with 7N shift workers getting significantly more correct. The 7N shift workers also had significantly better sleep quality than the 4N workers

(assessed using the Pittsburgh Sleep Quality Index (PSQI)). This would suggest that those working a longer (and therefore more stable) shift pattern were able to adapt to their circadian misalignment and improve their sleep quality and therefore minimise any cognitive impairment. Sleepiness (assessed using the Karolinska Sleepiness Scale) showed no differences. It is important to note that no data from a non-shift working comparator group was collected in this study. Therefore, how the performance of these shift workers compares to baseline remains unclear.

Recently, Thomas et al. (2020) completed a pilot study assessing 20 shift working maritime pilots and education matched controls. Using a spatial working memory test (a component of Cambridge Neuropsychological Test Automated Battery (CANTAB)) to examine working memory, they found no evidence of cognitive impairment relating to shift work. Shift workers did experience worse sleep quality and total sleep time, compared to controls, assessed using the PSQI and a sleep-wake diary. The authors highlight the need for these conclusion to be interpreted in the context of the study's limitations, namely the small sample size (Thomas, Overeem, Claassen, Dresler, & Kessels, 2020).

Aside from the aforementioned, there is a lack of studies specifically assessing WM in non-extreme shift working populations which therefore precludes drawing any further definitive conclusions at this time.

1.5.3.2 Working memory and new parenthood

As with shift working, very few WM studies have been conducted in the new parent population. Janes et al. (1999) assessed sleep and WM in primigravid (first time being pregnant), primiparous (first time having been pregnant) and nulligravida (never been pregnant) women. They found the primigravid and primiparous groups subjectively reported poorer memory performance since pregnancy. Performance on the backward digit span test from WAIS -III found the primigravid and primiparous groups scoring significantly lower than nulligravida women, supporting the self-reported findings. However, no differences were seen in another working memory task (a reading span task) (Janes, Casey, Huntsdale, & Angus, 1999). This suggests that the working memory components assessed in one task are distinct from those measured in the other. Task selection and the profile of sub-processes that each task depends upon clearly plays a role in determining whether impairment is seen. Given the inconsistent results from two working memory tasks it is likely that the impairment seen in new parents is subtle. This may be due to the relatively small degree of sleep deprivation experienced by new parents, in comparison to that experienced in chronic SD studies (often greater than 24 hours). The precise impact of new parenthood upon working memory therefore remains unclear.

Overall, WM is clearly sensitive to both artificial and natural forms of sleep deprivation/disturbance. Further, the relationship between WM and sleep appears to be

complicated by issues around cognitive demand and task difficulty. Similarly, identifying the neural correlates of WM may also depend on the assessment used and the relative difficulty of the task variant selected. In common with some of the other domains evaluated here, there is also evidence of inter-individual differences in resilience to sleep deprivation/disturbance potentially mitigating some of the otherwise adverse effects on WM. Finally, despite the importance of this cognitive domain to normal functioning and its occupational relevance, to our knowledge, it has yet to be widely assessed in shift working individuals routinely experiencing circadian mismatching or in new parent cohorts experiencing an unpredictable degree of chronic SD.

1.5.4 Visuomotor coordination

Visuomotor coordination is the ability to synchronise visual information with physical movement. Visuomotor coordination can be measured using a variety of assessments, including the Trail Making Task (TMT) (Corrigan & Hinkeldey, 1987), Letter Cancellation Task (Richards, Kuh, Hardy, & Wadsworth, 1999), Digit Symbol Test (Wechsler, 1981) and a modification of Bourdon-Wiersma Task (Van Zomeren & Brouwer, 1994). As with most cognitive assessments, these tasks are not construct pure, in that performance is not exclusively dependant on visuomotor coordination. However these are tasks in which visuomotor coordination makes a substantial contribution to overall performance.

The TMT consists of two elements; TMTA and TMTB. These require individuals to connect either numbers (TMTA) or numbers and letters (TMTB) in ascending order i.e. 1, A, 2, B, 3, C. The Letter Cancellation Task requires participants to scan a field of letters and identify specific target letters as quickly and accurately as possible. The Digit Symbol Test, a subtest of the WAIS-R (Wechsler, 1981), requires individuals to code a series of numbers based on a key given. The Bourdon-Wiersma test is a visual cancellation task where participants are required to find targets on paper. Typical output measures from these tasks include the number of errors committed and the time to completion.

Concerning neural correlates, the parietal cortex has been shown to be intimately associated with maintaining normal visuomotor capabilities. This is apparent when comparing the visuomotor coordination performance of healthy individuals to data collected from individuals with parietal damage and who exhibit impairments including gaze apraxia, optic ataxia and apraxia (Culham, Cavina-Pratesi, & Singhal, 2006). The importance of the parietal cortex is further highlighted through fMRI imaging of participants completing the TMT (MacPherson et al., 2017). Such imaging studies have also highlighted activation in various left frontal regions and the left middle and superior temporal gyrus (Zakzanis, Mraz, & Graham, 2005) during performance of the TMTB when compared to TMTA. TMT performance may not be exclusively lateralised to the left hemisphere

though, as lesion studies have associated the number of TMTB errors (but not time to completion) with right hemispheric frontal damage (Kopp et al., 2015). Savoie et al. (2018) examined parietal EEG activity during a visuomotor coordination task. They found low theta shortly after movement onset followed by an increase in alpha during much of the post movement period (Savoie, Thénault, Whittingstall, & Bernier, 2018). This suggests that whilst a movement is being performed the individual is alert (evidenced by low theta), however once the action has occurred a more relaxed state is induced (increased alpha).

The neural correlates of TMT performance may also be affected by the age of the individual. Functional near-infrared spectroscopy (fNIRS) indicates different activation patterns in elderly participants (mean age 70.95 ±3.55 yrs.) and young individuals (mean age 25.7±3.02 yrs.) whilst completing a TMT (Müller et al., 2014). The young group showed predominant activation in the right hemisphere covering the ventrolateral prefrontal cortex (vIPFC), left hemisphere covering the lateral portion of the vIPFC and dorsolateral prefrontal cortex (dIPFC) as well as premotor regions. In contrast, the elderly group exhibited right hemisphere signals covering large parts of the vIPFC and lateral parts of the dIPFC as well as premotor areas and the left hemisphere exhibited activations in superior parts of the vIPFC and large parts of the dIPFC. The elderly group also displayed more significantly activated channels than the young group (18/52 vs. 15/52), suggestive of broader neural activation (and potentially greater allocation of cognitive capacity) to complete the same task. Importantly, despite performing the task more slowly, consistent with reduced global processing speed, the elderly group did not commit more errors, consistent with more deliberative but equally accurate performance.

Similar to the occupational importance of attentional performance discussed previously, the maintenance of suitably high levels of visuomotor coordination under conditions of fatigue, in the context of shift work-related circadian mismatching or new parenthood-related sleep disruption is also crucial for the continued health and well-being of individuals and those around them.

Initial studies involving substantial SD indicate that this cognitive domain is vulnerable to impairment. For example, disruptions in visuomotor performance attributed to increased rigidity of thinking and a rise in visual search time were detected in the TMT after 36 hours total SD (Wimmer et al., 1992). A similar profile of impairment was found after 40 hours of total SD in individuals assessed using the Letter Cancellation Task (Gennaro, Ferrara, Curcio, & Bertini, 2001). That consistent SD-dependent performance impairments were detected in independent populations using distinct assessment approaches suggests this to be a robust finding. However, the extent of the SD applied in these studies is considerable and a loss of visuomotor coordination in these individuals is likely to be one manifestation of the generalised cognitive impairment they would be expected to experience. As such the ecological validity of these findings may be limited.

Indeed, visuomotor coordination assessments following shorter SD manipulations indicate a different pattern of results. For example, Alhola et al. (2005) found that after 25 hours SD, mature females (58-72 years) showed no decrease in visuomotor performance as measured using the Digit Symbol Test and a modification of the Bourdon-Wiersma Test, with the consistency of performance between the two tests providing an indication of robustness.

Given the differences in the duration of SD used in these studies, a reasonable initial conclusion would be that visuomotor coordination performance is protected for at least 25 hours prior to a SD-dependent performance impairment occurring. This relatively extensive protection could indicate the importance of this cognitive domain to survival or alternatively its relative simplicity compared to other more cognitively demanding functions which are more vulnerable to disruption.

However, this conclusion should be tempered given that the same assessments were not used in the three studies highlighted. Furthermore, participant differences may be a critical factor to consider in that sex and age (Davies, 1976; Tonetti, Fabbri, & Natale, 2008) have both been shown to affect sleep quality and duration. This in turn may affect how different participant groups are affected by simulated total SD. Differences in occupation may also have contributed with male undergraduate students, non-shift working males and predominantly retired post-menopausal women examined in the three studies.

The mechanisms underlying visuomotor coordination deficits, when factors such as visual acuity and manual dexterity are excluded, are unclear. It has been suggested that visuomotor coordination may be particularly reliant on the length of iconic memory (Raidy, Scharff, & Austin, 2005). Iconic memory is a component of the visual memory system, providing sensory memories which last for a brief period of time before fading. Iconic memory is known to engage posterior parietal cortical regions (Todd & Marois, 2004), and given the dependence of visuomotor coordination tasks such as the TMT on parietal function, this could suggest a point of overlap for further study. In particular, characterisation of the vulnerability of iconic memory to SD, acute fatigue and circadian mismatching are important issues to consider.

While visuomotor coordination is clearly impacted to some extent by SD, these findings cannot be directly extrapolated and applied to shift working or new parent populations as they do not address the impact of circadian mismatching on this cognitive domain and, given that neither group is likely to be required to face 25 continuous hours of SD, are not ecologically relevant.

1.5.4.1 Visuomotor coordination and shift work

Studies which have specifically assessed this construct in shift working groups have revealed a variety of findings. Machi et al. (2012) found no difference in the performance of emergency

physicians completing both TMTA and TMTB before and after both day and night shifts, suggesting no impact on visuomotor coordination. This lack of impairment is consistent with the SD findings of Alhola et al. (2005), suggesting that visuomotor coordination is immune to both short term circadian misalignment and up to 25 hours of SD.

However, Machi et al. (2012) included a range of shift lengths (between 6 and 10 hours) in the analysed population, such that any duration-dependent impairments may have been masked. Similarly, the design used may have confounded TMT performance with practice effects such that any post-shift TMT impairment may have been lost. As noted in the attention section previously, occupational differences may also be an important consideration here, particularly as no occupationally matched, non-shift working group was included and, as emergency physicians, this population is highly educated and skilled and likely to be very experienced in working shifts. As such, it may be that they have developed some level of inherent resilience or acquired tolerance to the cognitive impact of circadian mismatching over time.

Indeed, contrary to Machi et al. (2012), Titova et al. (2016) found that both current shift workers (in a variety of occupations) and those who had recently stopped shift working (within the past 5 years) exhibited impaired TMT performance when compared to individuals who had never worked shifts. Also, no significant performance difference was found between non-shift workers and those who had stopped working shifts more than five years ago (Titova et al., 2016).

This suggests that occupation may well be an important factor in determining the level of immunity visuomotor coordination has from the effects of circadian mismatching. It also suggests that the adverse impact of shift working on visuomotor performance develops quickly with exposure to shift working and requires at least five years without circadian mismatching to recover, although the mechanism of impairment and recovery is uncertain.

Importantly, this impairment mechanism may be linked to SD, given that individuals in this study with a shift work history (including those former shift workers) regularly received less than 7 hours sleep and had a higher cumulative sleep disturbance score compared to non-shift workers and that retired individuals and students were excluded from these analyses (Titova et al., 2016). Titova et al. also suggest a link to stress, although this is unlikely to be related to occupational sources, given that all groups compared consisted only of people in active employment (Titova et al., 2016). However, a relationship between shift work status and elevated levels of hormones such as cortisol has been reported (Li et al., 2018) and as the observed impairment takes at least 5 years to normalise, it could reflect a multi-faceted effect on physiology, as would be yielded by chronic exposure to stress hormones. However, recent data suggests that the adrenocortical axis responsible for the stress response is not always activated under shift working conditions. Significantly, the population in which the association between shift work and adrenocortical

stimulation was not detected was a group of hospital physicians (Osterode, Schranz, & Jordakieva, 2018), again perhaps suggesting a particular adaptation (either inherent or developed through continued shift work exposure) in this group of individuals. It is important to note that hospital physicians likely have a higher stress occupation than shift workers in other employment sectors and as such it may not be appropriate for the conclusions of this stress hormone study to be generalised.

Titova et al. looked specifically at individuals classed as middle aged and elderly (45-75 years). Since age is known to impact cognitive capabilities (Murman, 2015), it could be that the relative resilience of visuomotor coordination in the shift working groups examined was reduced, thereby increasing the possibility of an impairment. This population was not screened for age-dependent neurological diseases known to impact cognition such as dementia, which could have also contributed to the impairment detected. In addition, it is unclear if participants had been at work immediately prior to assessment (and therefore may have been experiencing acute work-related fatigue) or were well rested. The range of years outside of shift work in the group that had not worked shifts for at least 5 years is also unclear, such that whether the apparent recovery of the deficit was driven by individuals with a much longer history of non-shift work is unknown. Finally, as this study utilised a computerised task in an older population, age-dependent changes in manual dexterity, vision and computer proficiency may have had some bearing on the impairment observed, as while not large, some difference in mean age across the groups was detected. Specifically the current shift working group was reported to be the youngest while the never worked shifts control group was the oldest (Titova et al., 2016).

While the evidence presented thus far regarding the impact of shift working on visuomotor coordination is somewhat equivocal, as with the SD studies noted earlier, any protection afforded to this cognitive domain may well be dependent on shift length. For example, Leonard et al. (1995) showed that over long shifts (32 hours with 4.5 hours of sleep) a significant TMT performance reduction occurred in pre-registration medical house officers when pre-shift and post-shift performance was compared. While this highlights a potential visuomotor coordination vulnerability in a shift working population, in the absence of data collected following a typical sleep cycle, the impairment observed here may reflect the accumulated acute fatigue due to extended hours worked, more akin to the effects of prolonged SD than an effect of shift working per se.

Indeed, a study comparing the impact of 12 and 24 hour shifts on visuomotor coordination in air medical providers offers additional insight. Guyette et al. (2012) found no difference in TMT performance between a 12 hour shift group and a 24 hour shift group assessed at the beginning and end of a shift. This would suggest a degree of inherent resilience or acquired tolerance for

visuomotor coordination for relatively extended periods in this population. As noted previously when comparing such studies to others, the characteristics of the population must be considered. For example, aside from demographic differences, the use of fatigue management strategies such as opportunities for rest during these shifts, and the intensity of the work being conducted, may all be important factors that mark out this population as distinct from the physicians assessed by Leonard et al. Interestingly, in this study TMTA performance was found to improve in both groups after a shift and an improvement in post shift TMTB performance was detected exclusively in the 12 hour group. This could be a manifestation of a practice effect on performance of the TMT assessment, although why the 12 hour shift group experienced an effect on TMTB and the 24 hour group did not is unclear.

The temporal dependence of the potential impact of shift working on visuomotor coordination has been further evaluated by Proctor et al. (1996). This study assessed visuomotor coordination, via the TMT, in shift working automotive workers with the added variable of post-shift overtime. Here, participants would work a fixed 8 hour shift starting at 06.30, 14.30 or 22.30 with regular TMT assessment. It was found that when compared to workers not performing overtime, TMTB completion time was significantly increased in those individuals working beyond their standard shift assignment (when adjusted for shift worked, job type, hours worked and consecutive days worked before test day). This could suggest that with continued exposure to a regular shift working routine, some level of acquired tolerance/inherent resilience for visuomotor coordination is developed but that when routine is varied (i.e. due to a change such as continuing to work beyond the standard duration), the protection mechanism cannot adapt and visuomotor coordination is compromised.

Taken together, these findings suggest that visuomotor coordination is sensitive to sleep deprivation, work related fatigue and circadian mismatching as occurs in shift working, but there appear to be relatively specific thresholds after which impairments are manifested.

The relationship between the impact of accumulated fatigue and shift working status also appears complex. Therefore interpreting studies involving shift workers who have both a shift working lifestyle and are fatigued is potentially difficult without the appropriate control conditions. Based on the findings of Titova et al. (2016), it is likely that shift working history may also have a role, although the temporal specificity and underlying mechanisms are unclear.

As with attention, a mechanism may serve to protect this cognitive domain in shift workers, with this being occupation dependent to some extent. Whilst these individuals do experience SD it is possible they develop a tolerance to the adverse effects of shift working over time. It is suggested that some individuals may have differential vulnerability to the effects of sleep loss on some areas

of cognition including high level executive functioning (Dongen, Baynard, Maislin, & Dinges, 2004; Killgore, 2010) and visuomotor coordination may be similarly affected.

1.5.4.2 Visuomotor coordination and new parenthood

As with many cognitive domains, there is a lack of research regarding the impact of new parenthood on visuomotor coordination. Indeed, to the best of our knowledge few studies have been conducted in this population. Given the apparent resilience of visuomotor coordination to long periods of SD it is likely that new parents would show little to no impairment in this area, given the fact they are able to sleep at times and therefore are not experiencing this extreme SD. However, as mentioned previously, it is not possible to directly apply the findings from the SD literature to this population, given their multiple differences.

Indeed Treadway et al (1969) compared a sample of 21 pregnant and 9 non-pregnant women on a variety of measures including the TMT. Pregnant women were tested before and after (less than 5 days) the birth of their child. They found a significant increase in the time required to complete the TMT in postpartum women, suggesting impaired visuomotor performance following the birth of a child (Treadway, Kane, Jarrahi-Zadeh, & Lipton, 1969). Further, Henry and Sherwin (2012) found significant differences in visuomotor control, assessed in nulliparous controls and pregnant women, using the Digit Symbol Task. Pregnant women were tested once whilst pregnant and again postpartum. However, contrary to the authors' predictions, there was not a decline in performance postpartum, though on both testing sessions the pregnant women performed worse than their non-pregnant controls (Henry & Sherwin, 2012). In contrast, Zheng et al (2018) found no significant differences in TMT performance between postpartum and nulliparous women. Overall the current literature examining visuomotor coordination in new parents is varied. Whilst it appears that in some cases, compared to a non-pregnant control, pregnant women perform worse, there are mixed outcomes when it comes to postpartum women.

1.6 Cognitive testing

The existing new parent and shift worker literature is predominantly conducted using face-to-face, laboratory based assessments. When discussing the generalisability of these studies, considerations regarding the influence of work related fatigue (due to testing before and after a shift), as well as the use of restricted sample groups (predominantly female new parents and occupationally homogenous shift workers), must be acknowledged. Indeed, the ecological validity of the existing literature, concerning both shift workers and new parents, has been questioned extensively here. Further, as described above, the cognitive tasks used in these studies do not represent every day activities and as such do not hold high ecological validity. When conducted in a controlled testing environment such as a laboratory, this validity is further lowered.

Online cognitive testing offers an opportunity to elevate the ecological validity of studies. Whilst the cognitive tasks used remain occupationally/parentally irrelevant, testing within a home environment, at a time relevant to the study, increases the overall ecological validity of findings. By continuing to use these non-relevant but standardised and robust tasks, comparisons can easily be made between laboratory based and online based experiments.

The use of computerised cognitive testing is now common place, with multiple standardised cognitive batteries now easily available to researchers (CANTAB, EMOTICOM, and Cambridge Brain Sciences (CBS)). Further, the current COVID-19 pandemic has also led to an increase in online cognitive testing, as face-to-face assessments are no longer as viable. This method enables testing of populations who are not able to attend a more traditional laboratory based assessment, such as patients in an intensive care unit (Honarmand, Malik, Wild, & Gonzalez-lara, 2019), as well as test at times not easily accessible, for example immediately after waking up. Additionally, this form of testing enables large scale cognitive assessment to be conducted, with sample sizes collected that would not be possible with in-person testing (Thirkettle, Lewis, Langdridge, & Pike, 2018; Wild, Nichols, Battista, Stojanoski, & Owen, 2018).

1.7 Conclusions

This chapter has considered the existing literature exploring the effects of sleep deprivation/disruption generally, and shift working and new parenthood specifically on four well-characterised domains of cognition.

While there is some evidence across all four cognitive domains of sleep disruption-related impairments, the literature exhibits a considerable degree of variability. In particular, the presence/absence and magnitude of any impairment appears strongly dependent on the cognitive assessment used and, even in cases where ostensibly the same paradigm is applied, the exact assessment parameters can clearly also have an impact. In the context of shift working, the extent of this variability appears to be accentuated further on the basis of both occupation and the precise shift working pattern experienced, with some evidence of longer, more stable shift cycles reducing cognitive impact. Whilst findings regarding new parents are somewhat more consistent, this may be driven by the relatively small existing evidence base. Furthermore, the lack of assessment in new fathers demonstrates the need for further study.

These findings emphasise the importance of universal implementation of standardised cognitive assessment instruments across future studies of this population to enhance comparability. It also highlights the considerable challenge associated with characterising a 'prototypical' shift worker – indeed, should this prove to be impossible, it may be that the generalisability of all future studies of the shift working population will have to be explicitly limited to the precise sub-group

represented in each study. In the context of new parents, the clear hormonal, physical and sleep related differences seen between new mothers and fathers (or, for non-normative couples, the pregnant parent and birth partner) highlights the need for extensive testing in both parental units.

Specifically regarding shift working, this chapter also highlights the need for experimental designs better suited to disentangling the potentially combined effects of the acute work-related fatigue and chronic circadian misalignment uniquely experienced by shift workers when cognitively assessing this population. The existence of inter-individual variability in the resilience to/tolerance of shift working and associated neural correlates is also apparent across a number of independent studies evaluated in this chapter. Further exploration of the extent and neurobiological underpinnings of this variability will be a key concern for future studies of this population, as will enhancing our understanding of whether such differential resilience/tolerance is inherent or can be developed with continued experience of shift working and exposure to circadian misalignment. Given the continued implementation of shift working across a wide range of occupational sectors and the potential deleterious health effects of this practice, addressing these concerns is of vital importance.

Finally, the ecological validity of much of the existing literature, in both shift working and new parenthood studies, has been criticised consistently throughout this chapter. As discussed, when assessing the cognitive impact of an occupation related daily routine (shift work) and the major change in lifestyle associated with becoming a parent, it is vital the study is designed to maximise ecological validity. The capability to evaluate participants with minimal disruption to their daily routine, something that is particularly necessary for assessment in new parents, is an important consideration. Therefore, understanding the viability of online, remote cognitive assessment of participants in their home/environment of their choice, will provide important new insights.

1.8 Aims of the thesis

The critical analysis of the existing literature has revealed a relatively limited evidence base exploring the cognitive impact of real-world forms of sleep disruption and circadian misalignment.

Given the societal importance of both shift working and new parenthood, understanding how these lifestyles impact cognition without depending on extrapolation from laboratory-based studies of extended SD is crucial. This forms the basis of this thesis, as summarised in the following specific aims.

1. Examine the impact of shift work on attention, response inhibition, working memory and visuomotor coordination without the confounding effect of work-related fatigue

2. Examine the impact of new parenthood on attention, response inhibition, working memory and visuospatial coordination, assessing both mothers and fathers
3. Evaluate the utility of and issues associated with online cognitive assessment to access these populations while minimising disruption to daily routines
4. Assess if shift work has a persistent physiological effect on the brain in the absence of post-work fatigue

2.1 Ethics and informed consent

The data presented in this thesis comes from a selection of human cohorts. All research presented in this thesis has received ethical approval following review by The Open University's Human Research Ethics Committee (HREC/2016/2444/Breese/2, HREC/2017/2549/Breese/1 and HREC/2669/Breese). These studies also adhere to all BPS ethics standards (The British Psychological Society, 2018) and the BPS ethics guidelines for Internet-mediated Research (The British Psychological Society, 2017).

All participants, regardless of whether assessed online or in person, received a full information sheet and debrief form. Each participant was required to provide informed consent before being enrolled. Participants were informed of their right to withdraw at any point and contact details of the research team were provided at the beginning and end of testing, should participants wish to ask any questions. Recruitment adverts (both online and in person), information sheets, consent forms and debrief forms can be found in the appendix.

2.2 Data storage and management

The data collected in this thesis is stored within OU systems, under password protection. Data is treated in strict confidence in accordance with the General Data Protection Regulation (GDPR, European Parliament, 2016). All data was anonymised at point of collection through the use of unique personal identifiers. Anonymised data will be retained within OU systems for 10 years after the completion of the project, in line with the Open University's research data retention schedule.

2.3 Overview of online platforms

All cognitive tasks were created and hosted on the Gorilla Experiment Builder (www.gorilla.sc Anwyl-Irvine, Massonnié, Flitton, Kirkham, & Evershed, 2018). This software has been created to enable online experiments to be built and delivered with data collected securely. In compliance with BPS and NIHR guidelines all identifying data, demographic information and performance data are stored separately and Gorilla is fully compliant with GDPR.

Online participant recruitment occurred through Prolific (www.prolific.co). Prolific is an online participant platform with over 10,000 active participants world-wide, that specifically caters to scientific research. The participant sample is profiled, high quality and provides for very fast data

collection. This enabled data to be collected quickly and provided an easy platform through which to financially compensate participants.

2.4 Overview of cohorts' task design and demographics

Six different cohorts were used in the collection of the data presented in this thesis. Below the study design, recruitment method, criteria for inclusion and exclusion and participant groupings are outlined for each cohort.

Given the recruitment method used for cohorts SW1, SW2, SW3 and NP sample size potential was open-ended. For the first cohort (SW1), a target of 100 participants was set due to this study being the first one of this design. Following improvements in task design, the SW2 cohort was collected, with a larger target size to increase statistical power. Due to a lack of existing literature no a priori power calculations could be conducted. Similarly, the New Parent (NP) cohort size had no appropriate previous research on which to base power calculations. For the SW3 cohort no individuals who had taken part in either of the prior studies were permitted to take part, therefore limiting the number of suitable participants available in the Prolific sample pool. The Police (Po) sample, as discussed below, was collected using advertising through the Open University Centre for Policing Research and Learning leading to direct communication with four UK constabularies. This meant sample size was dictated by the responses received within the time period allocated for data collection.

2.4.1 Shift worker 1 (SW1)

The SW1 cohort was the first group of shift workers assessed for this thesis. This cohort consisted of night and rotating shift workers as well as a day/evening control. Originally it was planned to recruit a control group that worked exclusively during the day. However, following data collection, many participants indicated they worked 'days' but either started or finished in a time range that would technically make them shift workers (according to the definition of shift work given by the National Sleep Foundation (2017)) 'shift work is work that takes place on a schedule outside of the traditional 9am-5pm day'). These individuals were still able to sleep relatively normal times i.e. finished their shift before midnight. Therefore, following initial screening, the parameters of the control group were extended to include these individuals who were not likely to be experiencing significant circadian misalignment, ensuring the group was large enough to provide meaningful analysis.

Responses to the demographic questionnaire were used to sort participants into one of the three groups. These questions were:

1. What rotations have you worked previously? (How many day shifts vs. night shifts) e.g. 4 night shifts, 4 days off, 4 day shifts – free text response
2. Have these always alternated between night and day shifts? – yes, no I have worked permanent nights previously
3. What shifts have you worked in the last month? – free text response
4. What shift rotation do you currently work? e.g. 4 nights, 4 days, 4 days off

The following shift group categorisation criteria were applied:

- Night shifts were categorised as any shifts worked past midnight in a stable/permanent shift pattern
- Rotating shifts were categorised as shifts that regularly rotated through day and night
- Day shifts were categorised as shifts that were conducted at any time through the day finishing at 12 midnight or before

Figure 1 outlines the SW1 cohort study design these participants received.

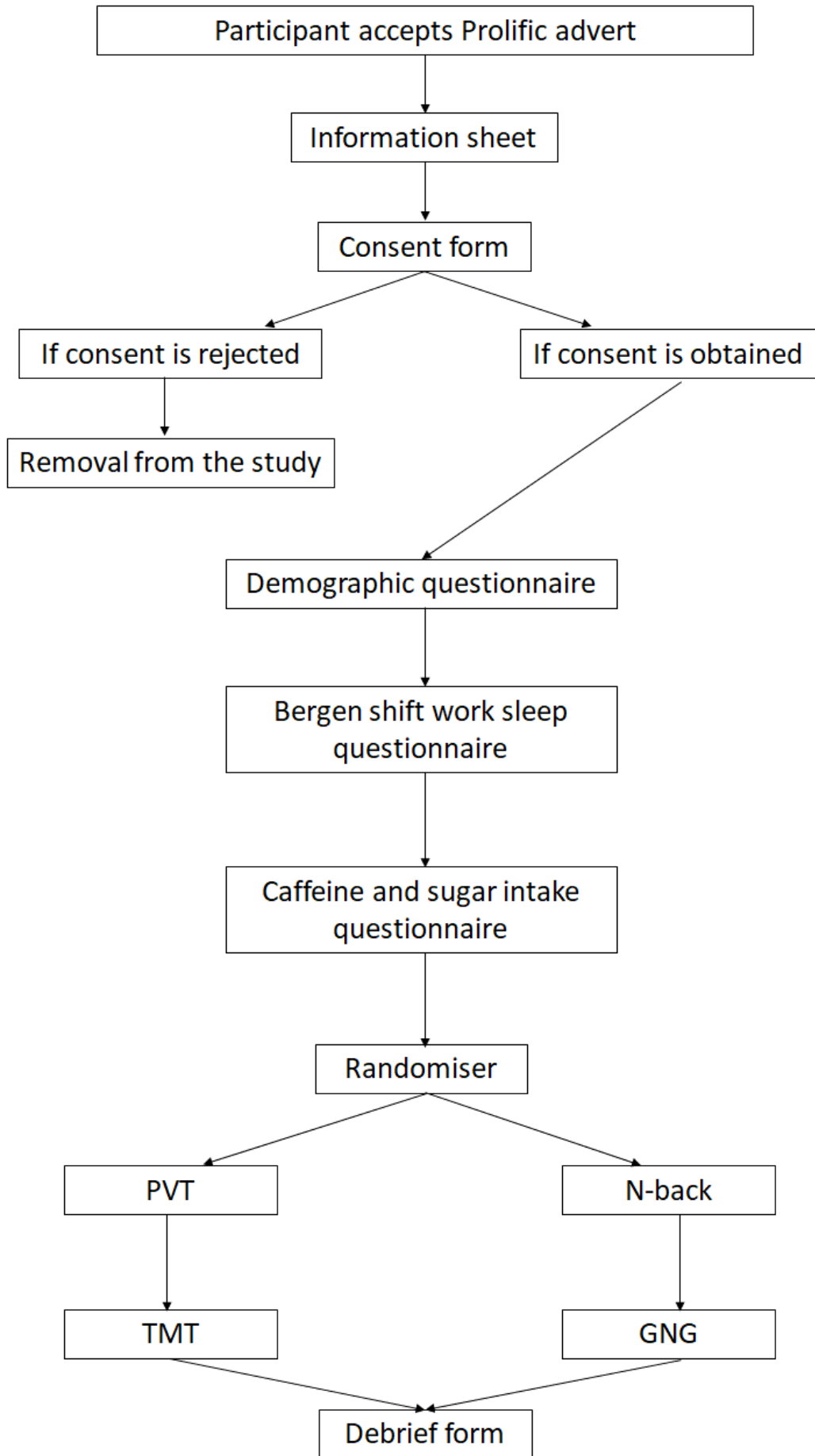


Figure 1 SW1 cohort study design (PVT = Psychomotor Vigilance Task; TMT = Trail Making Task; GNG = Go Nogo task)

All individuals were recruited through Prolific and tested using the Gorilla platform. They received financial payment for the time taken to complete the study (a minimum of £5 per hour in line with Prolific's payment guidelines).

In order to be included in primary analysis participants had to be aged 18+ years, have had no recent head injury, have provided sufficiently detailed and consistent information to enable them to be categorised into one of the shift groups, were on a day off from work and had fully completed the study.

Whole group analysis was run for key demographics to examine potential group differences on the basis of self-reported shift categorisations (night, rotating and day). This contained all participants in this cohort regardless of which cognitive assessments were completed.

No main effect of age ($H(2)=0.38$, $p=0.83$, $\eta_H=0.01$) or sex ($X^2(2, n=147)=1.895$, $p=0.38$, Cramer's $V=0.11$) was observed. There was no significant association between shift group and country of testing ($X^2(4, n=147)=5.26$, $p=0.26$, Cramer's $V=0.13$) or shift group and years worked shifts ($X^2(6, n=149)=7.28$, $p=0.296$, Cramer's $V=0.16$). Time spent awake prior to completing the study was calculated using the self-reported wake time and the time of testing and converted into hours. There were no main effects of time spent awake in any group ($H(2)=1.87$, $p=0.39$, $\eta_H<0.01$).

Whole group demographic analysis was also run using the BSWSQ groupings described in the cognitive chapters. These groupings were made based on the rest component of the BSWSQ. Shift workers were separated into low and high BSWSQ score, as were day workers, creating four groups. These were Low Bergen Shift group, High Bergen Shift group, Low Bergen Control group and High Bergen control group. A main effect of age was observed ($H(3)=9.21$, $p=0.03^*$, $\eta_H=0.05$), with Low Bergen shift group (31.02 ± 9.58) significantly younger than High Bergen shift group (37.58 ± 0.86 , $p=0.02$). No significant differences between groups was found with respect to sex ($X^2(3, n=131)=4.75$, $p=0.19$, Cramer's $V=0.19$), country of testing ($X^2(6, n=131)=10.89$, $p=0.09$, Cramer's $V=0.20$), or time spent awake ($H(3)=2.12$, $p=0.55$, $\eta_H=0.01$). A significant difference was found between the groups in years worked shifts was found ($X^2(9, n=132)=19.93$, $p=0.02^*$, Cramer's $V=0.22$).

Due to secondary exclusion criteria (on the basis of task performance – see data chapters for more details) not all individuals' data were included in both tasks. Further, whilst many participants provided demographic data they did not go on to complete both tasks. Therefore, the demographic characteristics of each group have also been calculated by task. Outlined in Table 1 are the demographic characteristics of the SW1 cohort. Sample size indicates group size prior to outlier analysis.

Table 1 Summary of SW1 demographic data. *1 participant did not provide sex/country of testing information

	Shift group	PVT	TMTA	TMTB	GNG	N-back
Sample size	Night	9	7	9	13	10
	Rotating	37	28	34	40	35
	Day	24	18	22	19	17
Age (mean±SD)	Night	32.89 ± 9.75	32.14 ± 9.99	32.89 ± 9.752	35.31 ± 15.72	35.10±17.75
	Rotating	33.84 ± 10.35	30.5 ± 7.88	32.06 ± 9.247	34.55 ± 10.22	34.83±10.71
	Day	34.48 ± 10.55	33.78 ± 10.14	33.64 ± 10.13	35.11 ± 10.33	34.65±10.84
Sex (M:F)	Night	2:7	1:6	2:7	4:9	3:7
	Rotating	13:23 *	12:15*	13:20*	20:19*	17:17*
	Day	12:15	8:10	10:12	5:14	5:12
Country of testing (%)	Night	UK=77.78 Europe=11.11 Rest of world=11.11	UK=85.71 Europe=14.29 Rest of world=0.00	UK=77.78 Europe=11.11 Rest of world=11.11	UK=53.85 Europe=7.69 Rest of world=38.46	UK=50.00 Europe=10.00 Rest of world=40.00
	Rotating	UK=69.44 Europe=13.89 Rest of world=16.67 *	UK=59.26 Europe=22.22 Rest of world=18.52 *	UK=60.61 Europe=21.21 Rest of world=18.18 *	UK=56.41 Europe=25.64 Rest of world=17.95	UK=61.76 Europe=26.47 Rest of world=11.76
	Day	UK=70.37 Europe=11.11 Rest of world=18.52	UK=77.78 Europe=5.56 Rest of world=16.67	UK=72.73 Europe=9.09 Rest of world=18.18	UK=73.68 Europe=5.26 Rest of world=21.05	UK=70.59 Europe=5.88 Rest of world=23.53
	Night	Desk Based=22.22 Light=22.22	Desk Based=28.57 Light=14.29	Desk Based=22.22 Light=22.22	Desk Based=30.77 Light=15.38	Desk Based=30.00 Light=20.00

Job type (level of exercise) (%)		Moderate=33.33 High=22.22	Moderate=28.57 High=28.57	Moderate= 33.33 High=22.22	Moderate=23.08 High=30.77	Moderate=20.00 High=30.00
	Rotating	Desk Based=29.73 Light=16.22 Moderate=29.73 High=24.32	Desk Based=32.14 Light=14.29 Moderate=28.57 High=25.00	Desk Based=29.41 Light=17.65 Moderate=29.41 High=23.53	Desk Based=30.00 Light=17.50 Moderate=25.00 High=27.50	Desk Based=31.43 Light=17.14 Moderate=22.86 High=28.57
	Day	Desk Based=33.33 Light=25.93 Moderate=11.11 High=29.63	Desk Based=33.33 Light=33.33 Moderate=5.56 High=27.78	Desk Based=36.36 Light=27.27 Moderate=4.55 High=31.82	Desk Based=42.11 Light=26.32 Moderate=26.32 High=5.26	Desk Based=47.06 Light=29.41 Moderate=17.65 High=5.88
Years worked (shifts/day) (%)	Night	0-12 months=11.11 1-5 years=66.67 6-10 years=11.11 10+ years=11.11	0-12 months=0.00 1-5 years=85.71 6-10 years=0.00 10+ years=14.29	0-12 months=11.11 1-5 years=66.67 6-10 years=11.11 10+ years=11.11	0-12 months=15.38 1-5 years=61.54 6-10 years=7.69 10+ years=15.38	0-12 months=10.00 1-5 years=70.00 6-10 years=10.00 10+ years=10.00
	Rotating	0-12 months=24.32 1-5 years=45.95 6-10 years=21.62 10+ years=8.11	0-12 months=25.00 1-5 years=39.29 6-10 years=25.00 10+ years=10.71	0-12 months=26.47 1-5 years=47.06 6-10 years=20.59 10+ years=5.88	0-12 months=12.50 1-5 years=47.50 6-10 years=22.50 10+ years=17.50	0-12 months=8.57 1-5 years=48.57 6-10 years=22.86 10+ years=20.00
	Day	0-12 months=37.04 1-5 years=37.04 6-10 years=7.41 10+ years=18.52	0-12 months=38.89 1-5 years=44.44 6-10 years=0.00 10+ years=16.67	0-12 months=40.91 1-5 years=40.91 6-10 years=0.00 10+ years=18.18	0-12 months=21.05 1-5 years=57.89 6-10 years=10.53 10+ years=10.53	0-12 months=23.53 1-5 years=58.82 6-10 years=5.88 10+ years=11.76

All shift groups in all four tasks had a female majority, with the exception of rotating shift workers in the GNG task and the N-back task. Across the cohort, the average age range was relatively narrow (30.5-35.31). There were no significant differences in age in any group. In all shift groups the largest proportion of participants were based in the UK. This cohort showed a wide range of job type (stratified on the basis of using the degree of physical activity associated with work as a proxy for occupation) though there was no consistent majority job type across the shift groups. All tasks had participants from each job type, with all shift groups reporting at least 4.55% of participants in each category. The number of years working shifts showed 1-5 years of shift work being the most common. However, again there was a variety of shift lengths across all tasks.

2.4.2 Shift worker 2 (SW2)

The SW2 cohort consisted of night and rotating shift workers as well as a day working control. Differing from the SW1 cohort, this day group only consisted of individuals working for an 8 hour period between typical start and end times (i.e. from 8am-4pm; 9am-5pm and 10am-6pm). The control data was collected in a separate experiment (though collected at the same time as the other groups in the SW2 cohort) in order to ensure it only contained individuals who had stated on Prolific that they worked '9-5' jobs.

Following analysis of the data collected from the SW1 cohort, the demographic questionnaire used with SW2 was altered to provide more specific shift related information than that used in the previous cohort.

Responses to the demographic questionnaire were used to sort participants into one of the three groups.

The questions given to the shift working groups were as follows:

1. Which of the following applies to you: I have always worked permanent nights, I have always worked rotating shifts, I have always worked day shifts, I have previously worked a combination of shifts.
2. What shifts have you worked in the last month? Night shifts, Rotating shifts, Day shifts
3. What shift rotation do you currently work? Nights, Rotating, Days
4. Describe your shift pattern. For example 'I work 4 night shifts, then 4 day shifts then I have 4 days off' – free text response.

The following shift group categorisation criteria were applied:

- Night shifts were categorised as any shifts worked past midnight in a stable/permanent shift pattern
- Rotating shifts were categorised as shifts that regularly rotated through day and night
- Day shifts were categorised as shifts that were worked over an 8 hour period between typical start and end times (8am-4pm, 9am-5pm, 10am-6pm)

The study design for this cohort was changed to include branches to account for potential order effect (outlined in Figure 2). Where possible the cognitive data received from these branches were merged (on the basis of no significant difference between testing groups) however this was not always possible therefore for the tasks where merging was not possible the demographics have been separated into 'group A' and 'group B' (GNG and TMTB).

A reduced Morningness-Eveningness Questionnaire (rMEQ) (Adan & Almirall, 1991) was also added to the demographic questionnaire. Details of this can be found below.

As discussed in Chapters 3-6, changes to cognitive assessment task instructions and design were implemented following the analysis of the data collected from SW1. This aimed to reduce the number of participants who were excluded due to lack of understanding, to reduce the dropout rate and where necessary increase task difficulty to account for apparent ceiling effects.

Figure 2 outlines the study design used for the SW2 cohort.

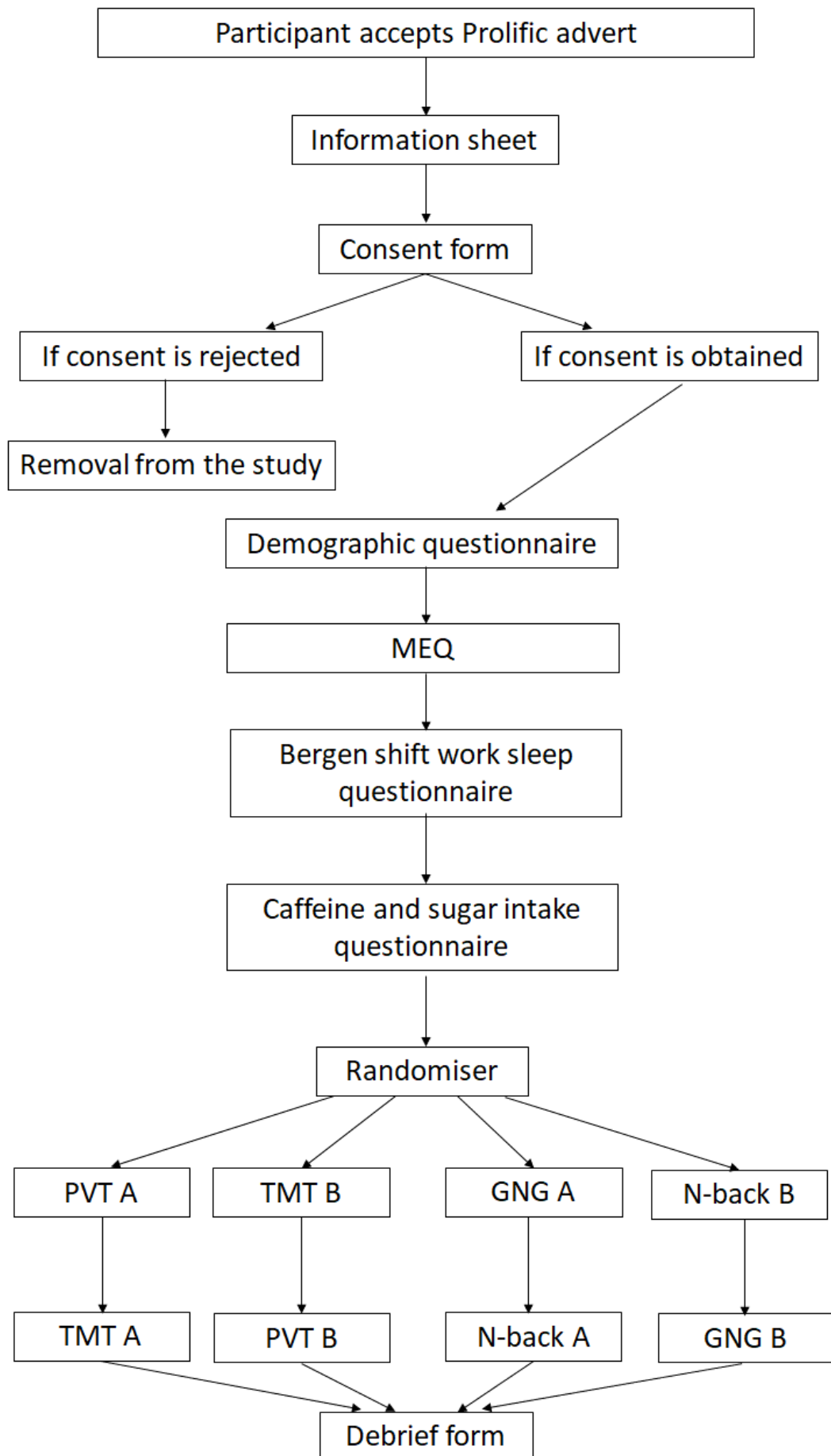


Figure 2 SW2 cohort study design (MEQ = Morningness-Eveningness Questionnaire; PVT = Psychomotor Vigilance Task; TMT = Trail Making Task; GNG = Go Nogo task)

As with the SW1 cohort, all individuals were recruited through Prolific and tested using the Gorilla platform. They received financial payment for the time taken to complete the study (a minimum of £5 per hour in line with Prolific's payment guidelines).

In order to be included in primary analysis participants had to be aged 18+ years, have had no recent head injury severe enough to require medical attention, have provided sufficiently detailed and consistent information to enable them to be categorised into one of the shift groups, were on a day off from work and had fully completed the study.

Whole group analysis was run for key demographics to examine potential group differences on the basis of self-reported shift categorisations (night, rotating and day). This contained all participants in this cohort regardless of which cognitive assessments were completed.

No significant differences were seen in age ($H(2)=3.92$, $p=0.14$, $\eta_H=0.01$) or sex ($\chi^2(2, n=260)=2.28$, $p=0.32$, Cramer's $V=0.09$). A significant difference between groups was found in country of testing ($\chi^2(4, n=260)=59.57$, $p<0.001$, Cramer's $V=0.34$), activity level ($\chi^2(6, n=260)=67.47$, $p<0.001$, Cramer's $V=0.36$) and years worked shifts ($\chi^2(6, n=260)=23.47$, $p<0.001$, Cramer's $V=0.21$). Time spent awake prior to completing the study was calculated using participant's self-reported wake time and the time of testing and converted into hours. There were no main effects of time spent awake in any group ($H(2)=0.39$, $p=0.82$, $\eta_H=0.01$). Time spent asleep during participants last sleep was calculated using self-reported wake and sleep times and converted into hours. There was a main effect ($H(2)=35.18$, $p<0.0001$, $\eta_H=0.13$) with night shift workers reporting significantly less sleep than day workers (7.63 ± 3.58 vs 10.66 ± 4.43 , $p<0.0001$) and rotating shift workers also reporting less sleep than day workers (8.36 ± 3.24 vs 10.66 ± 4.43 , $p<0.0001$).

Whole group demographic analysis was also run using the BSWSQ groupings described in the cognitive chapters. These groupings were made based on the rest component of the BSWSQ. No main effect of age ($H(3)=3.48$, $p=0.32$, $\eta_H=0.00$) or years worked shifts ($\chi^2(9, n=222)=16.58$, $p=0.06$, Cramer's $V=0.16$) was detected. A significant difference between groups with respect to sex ($\chi^2(3, n=222)=9.19$, $p=0.03$, Cramer's $V=0.20$), country of testing ($\chi^2(6, n=222)=65.47$, $p<0.001$, Cramer's $V=0.38$), and activity level ($\chi^2(9, n=222)=77.41$, $p<0.001$, Cramer's $V=0.34$) was detected. Time spent asleep also showed a main effect ($H(3)=21.79$, $p<0.001$, $\eta_H=0.09$), with post hoc analysis showing Low Bergen shift group (8.16 ± 3.04) reporting less time asleep than Low Bergen control group (10.38 ± 4.27 , $p=0.007$) and High Bergen control group (10.64 ± 4.88 , $p=0.007$). High Bergen shift group (8.28 ± 3.56) had also reportedly slept less than Low Bergen control group (10.38 ± 4.27 , $p=0.005$) and High Bergen control group (10.64 ± 4.88 , $p=0.005$). A main effect of

time spent awake was also observed ($H(3)=10.84$, $p=0.01$, $\eta_H=0.04$) with the Low Bergen shift group (3.4 ± 3.8) having been awake for less time than the High Bergen shift group (5.3 ± 4.9 , $p=0.01$).

Due to secondary exclusion criteria (on the basis of task performance – see data chapters for more details) not all individuals' data were included in both tasks. Further, whilst many participants provided demographic data they did not go on to complete both tasks. Therefore, the demographic characteristics of each group have been calculated by task. Outlined in Table 2 are the demographic characteristics of the SW2 cohort. Sample size indicates group size prior to outlier analysis.

Table 2 Summary of SW2 demographic data * For those working a '9-5' job this question referred to how long they had been working this style of job.

	Shift group	PVT	TMTA	TMTB Group A	TMTB Group B	GNG Group A	GNG Group B	N-back
Sample size	Night	24	24	10	15	9	14	22
	Rotating	50	45	26	24	28	33	58
	Day	46	37	22	23	23	18	45
Age (mean±SD)	Night	32.17 ± 10.07	31.58 ± 10.81	30.70 ± 9.57	31.73 ± 10.94	34.56 ± 15.53	31.07 ± 8.18	32.23 ± 11.63
	Rotating	30.40 ± 8.35	29.80 ± 8.19	29.62 ± 7.96	29.79 ± 7.85	30.11 ± 8.51	33.73 ± 9.56	31.47 ± 8.93
	Day	34.50 ± 8.76	34.32 ± 8.17	34.64 ± 8.84	33.35 ± 7.55	29.13 ± 6.897	31.83 ± 4.18	31.49 ± 7.51
Sex (M:F)	Night	13:11	12:12	5:5	9:6	5:4	6:8	11:11
	Rotating	30:20	27:18	17:9	14:10	15:13	21:12	34:24
	Day	31:15	24:13	15:7	15:8	16:7	11:7	28:17
Country of testing (%)	Night	UK= 45.83 Europe= 8.33 Rest of world= 45.83	UK= 41.67 Europe= 8.33 Rest of world= 50.00	UK= 30.00 Europe= 10.00 Rest of world= 60.00	UK= 53.33 Europe= 6.67 Rest of world= 40.00	UK= 88.89 Europe= 0.00 Rest of world= 11.11	UK= 57.14 Europe= 7.14 Rest of world= 35.71	UK= 72.73 Europe= 4.55 Rest of world= 22.73
	Rotating	UK= 50.00 Europe= 22.00 Rest of world= 28.00	UK= 48.89 Europe= 26.67 Rest of world= 24.44	UK= 57.69 Europe= 23.08 Rest of world= 19.23	UK= 41.67 Europe= 29.17 Rest of world= 29.17	UK= 64.29 Europe= 10.71 Rest of world= 25.00	UK= 39.39 Europe= 24.24 Rest of world= 36.36	UK= 50.00 Europe= 17.24 Rest of world= 32.76
	Day	UK= 36.96 Europe= 60.87 Rest of world= 2.17	UK= 32.43 Europe= 64.86 Rest of world= 2.70	UK= 36.36 Europe= 63.64 Rest of world= 0.00	UK= 30.43 Europe= 65.22 Rest of world= 4.35	UK= 34.78 Europe= 56.52 Rest of world= 8.70	UK= 33.33 Europe= 55.56 Rest of world= 11.11	UK= 37.78 Europe= 53.33 Rest of world= 8.89

Job type (level of exercise) (%)	Night	Desk Based= 29.17 Light= 16.67 Moderate= 4.17 High= 50.00	Desk Based= 20.83 Light= 12.50 Moderate= 12.50 High= 54.17	Desk Based= 10.00 Light= 10.00 Moderate= 10.00 High= 70.00	Desk Based= 33.33 Light= 20.00 Moderate= 6.67 High= 40.00	Desk Based= 22.22 Light= 22.22 Moderate= 44.44 High= 11.11	Desk Based= 28.57 Light= 0.00 Moderate= 28.57 High= 42.86	Desk Based= 27.27 Light= 9.09 Moderate= 31.82 High= 31.82
	Rotating	Desk Based= 22.00 Light= 16.00 Moderate= 36.00 High= 26.00	Desk Based= 22.22 Light= 17.78 Moderate= 31.11 High= 28.89	Desk Based= 19.23 Light= 23.08 Moderate= 38.46 High= 19.23	Desk Based= 25.00 Light= 8.33 Moderate= 25.00 High= 41.67	Desk Based= 14.29 Light= 14.29 Moderate= 25.00 High= 46.43	Desk Based= 33.33 Light= 6.06 Moderate= 27.27 High= 33.33	Desk Based= 24.14 Light= 12.07 Moderate= 25.86 High= 37.93
	Day	Desk Based= 67.39 Light= 15.22 Moderate= 13.04 High= 4.35	Desk Based= 59.46 Light= 18.92 Moderate= 18.92 High= 2.70	Desk Based= 68.18 Light= 18.18 Moderate= 9.09 High= 4.55	Desk Based= 56.52 Light= 17.39 Moderate= 21.74 High= 4.35	Desk Based= 73.91 Light= 17.39 Moderate= 4.35 High= 4.35	Desk Based= 77.78 Light= 16.67 Moderate= 5.56 High= 0.00	Desk Based= 73.33 Light= 17.78 Moderate= 6.67 High= 2.22
Years worked (shifts/9- 5) (%)	Night	0-12 months= 29.17 1-5 years= 37.50 6-10 years= 20.83 10+ years= 12.50	0-12 months= 29.17 1-5 years= 41.67 6-10 years= 20.83 10+ years= 8.33	0-12 months= 10.00 1-5 years= 60.00 6-10 years= 20.00 10+ years= 10.00	0-12 months= 40.00 1-5 years= 26.67 6-10 years= 20.00 10+ years= 13.33	0-12 months= 0.00 1-5 years= 55.56 6-10 years= 44.44 10+ years= 0.00	0-12 months= 7.14 1-5 years= 64.29 6-10 years= 21.43 10+ years= 7.14	0-12 months= 4.55 1-5 years=63.64 6-10 years= 27.27 10+ years= 4.55
	Rotating	0-12 months= 24.00 1-5 years= 50.00 6-10 years= 12.00 10+ years= 14.00	0-12 months= 26.67 1-5 years= 48.89 6-10 years= 13.33 10+ years= 11.11	0-12 months= 26.92 1-5 years= 42.31 6-10 years= 11.54 10+ years= 19.23	0-12 months= 20.83 1-5 years= 58.33 6-10 years= 16.67 10+ years= 4.17	0-12 months= 28.57 1-5 years= 46.43 6-10 years= 10.71 10+ years= 14.29	0-12 months= 18.18 1-5 years= 51.52 6-10 years= 12.12 10+ years= 18.18	0-12 months= 24.14 1-5 years= 50.00 6-10 years= 13.79 10+ years= 12.07
	Day *	0-12 months= 6.52 1-5 years= 43.48 6-10 years= 10.87 10+ years= 39.13	0-12 months= 8.11 1-5 years= 48.65 6-10 years= 10.81 10+ years= 32.43	0-12 months= 9.09 1-5 years= 45.45 6-10 years= 9.09 10+ years= 36.36	0-12 months= 4.35 1-5 years= 47.83 6-10 years= 8.70 10+ years= 39.13	0-12 months= 13.04 1-5 years= 56.52 6-10 years= 8.70 10+ years= 21.74	0-12 months= 0.00 1-5 years= 66.67 6-10 years= 16.67 10+ years= 16.67	0-12 months= 6.67 1-5 years= 57.78 6-10 years= 15.56 10+ years= 20.00

A large proportion of shift groups across the tasks had a male majority, with the exception of night shift workers in TMTA, TMTB group A and N-back who had an equal number of males and females and night shift workers in GNG group B who had more females. Across the cohort the average age range was 29.13 – 34.64. TMTA showed a significant difference ($H(2)=7.07$, $p=0.03$) with rotating shift workers (29.80 ± 8.19) being significantly younger than day workers (34.32 ± 8.17 , $p=0.03$). No other task showed a significant difference. The country of testing was very varied in this cohort, with no clear majority being shown across all shift groups. This cohort showed a wide range of job type (stratified on the basis of using the degree of physical activity associated with work as a proxy for occupation) though there was no consistent majority job type across the shift groups. The number of years working shifts (working a '9-5' job for day workers) showed a large proportion of individuals had worked shifts for 1-5 years, however this was not always the majority within each shift group.

2.4.3 Shift worker 3 (SW3)

The SW3 cohort consisted of night and rotating shift workers and a day working control group. As with the SW2 cohort, this day group only consisted of individuals working a '9-5' job. The control data was collected in a separate experiment in order to ensure it only contained individuals who had stated on Prolific that they worked a '9-5' job. In order to aid grouping, night and rotating shift workers were also collected in separate experiments, again each only containing individuals who stated on Prolific they worked either night or rotating shifts. This separation of all three shift groups in Prolific allowed the questionnaires in Gorilla to be tailored to the specific shift type. For example, in the day ('9-5') group no shift related questions were asked, being replaced by questions relating only to day work (e.g. instead of 'how long have you worked shifts' this group received the question 'how long have you worked a 9-5 job'.)

The questions used to determine shift group were the same as those used in the SW2 cohort.

The questions given to the shift working groups were as follows:

1. Which of the following applies to you: I have always worked permanent nights, I have always worked rotating shifts, I have always worked day shifts, I have previously worked a combination of shifts.
2. What shifts have you worked in the last month? Night shifts, Rotating shifts, Day shifts
3. What shift rotation do you currently work? Nights, Rotating, Days
4. Describe your shift pattern. For example 'I work 4 night shifts, then 4 day shifts then I have 4 days off' – free text response.

Further to the Prolific groupings the following shift group categorisation criteria were applied:

- Night shifts were categorised as any shifts worked past midnight in a stable/permanent shift pattern
- Rotating shifts were categorised as shifts that regularly rotated through day and night
- Day shifts were categorised as shifts that were worked over an 8 hour period between typical start and end times (8am-4pm, 9am-5pm, 10am-6pm)

In this cohort two new tasks were used. This was to further explore the cognitive domains of response inhibition and working memory. The tasks used were the Eriksen flanker (for response inhibition) and a modified N-back (N-back (mod)) (for working memory). The rationale for the use of these tasks is further explained in Chapters Four and Five.

Again the study design included branches to account for potential order effects (outlined in Figure 3). Where possible the cognitive data obtained from these branches were merged (on the basis of no significant difference between testing groups). This was possible for all groups in this cohort. Unfortunately, due to a coding error the data from the revised N-back task was not usable (see Chapter Five) and therefore only the demographics for participants included in the Eriksen flanker task are included here.

Figure 3 outlines the study design used for the SW3 cohort.

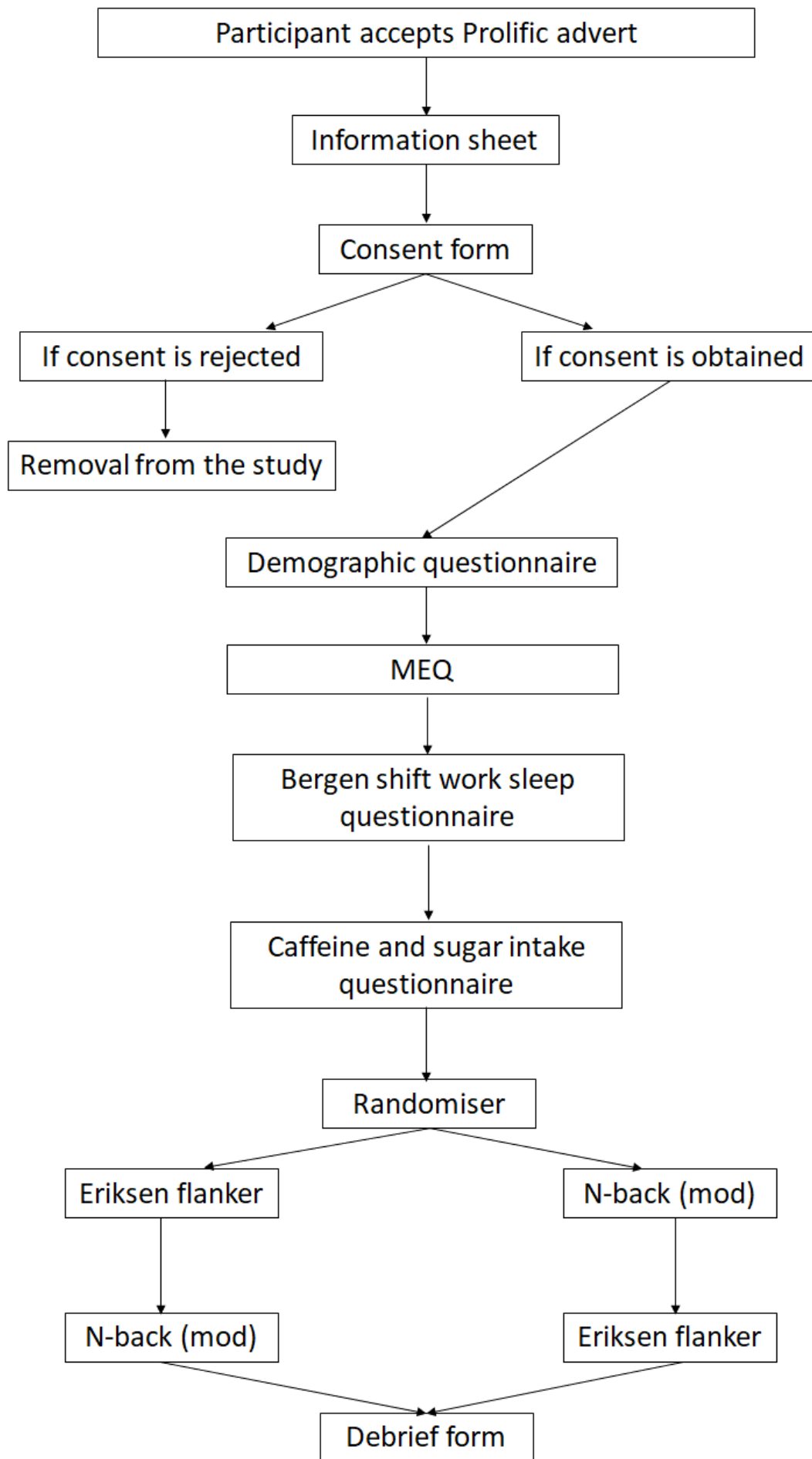


Figure 3 SW3 cohort study design (MEQ= Morningness-Eveningness Questionnaire)

As with the SW1 and SW2 cohorts, all individuals were recruited through Prolific and tested using the Gorilla platform. They received financial payment for the time taken to complete the study (a minimum of £5 per hour in line with Prolific's payment guidelines).

In order to be included in primary analysis participants had to be aged 18+ years, have had no recent head injury severe enough to require medical attention, have provided sufficiently detailed and consistent information to enable them to be categorised into one of the shift groups, were on a day off from work and had fully completed the study. Outlined in Table 3 are the demographic characteristics of the SW3 cohort. Sample size indicates group size prior to outlier analysis.

Whole group analysis was run for key demographics to examine potential group differences on the basis of self-reported shift categorisations (night, rotating and day). This contained all participants in this cohort regardless of which cognitive assessments were completed.

There was a main effect of age ($H(2)=10.85$, $p=0.004$, $\eta_H=0.07$) with the rotating group being significantly younger than day shift workers (31.86 ± 9.29 vs 38.35 ± 10.92 , $p=0.003$). There was a significant difference in sex ($\chi^2(2, n=126)=6.34$, $p=0.04$, Cramer's $V=0.22$). There was a significant association between shift group and country of testing ($\chi^2(4, n=126)=28.65$, $p<0.001$, Cramer's $V=0.34$), between shift group and years worked shifts ($\chi^2(6, n=126)=19.00$, $p=0.004$, Cramer's $V=0.27$) and between shift work and activity levels ($\chi^2(6, n=126)=39.41$, $p<0.001$, Cramer's $V=0.40$). There was no main effect of time spent awake ($H(2)=0.15$, $p=0.93$, $\eta_H=0.02$) or sleep time ($H(2)=3.75$, $p=0.15$, $\eta_H=0.01$).

Whole group demographic analysis was also run using the BSWSQ groupings described in the cognitive chapters. These groupings were made based on the rest component of the BSWSQ. There was a main effect of age ($H(3)=13.21$, $p=0.004$, $\eta_H=0.10$), with Low Bergen shift group (31.96 ± 8.43) being significantly younger than High Bergen control group (41.13 ± 10.66 , $p=0.01$), and High Bergen shift group (33.30 ± 11.04) being significantly younger than High Bergen control group (41.13 ± 10.66 , $p=0.02$). A significant differences between group with respect to country of testing ($\chi^2(6, n=105)=25.81$, $p<0.001$, Cramer's $V=0.35$), activity level ($\chi^2(9, n=105)=33.90$, $p<0.001$, Cramer's $V=0.33$) and years worked shifts were detected ($\chi^2(9, n=105)=25.36$, $p=0.003$, Cramer's $V=0.28$). There was no significant differences between groups with respect to sex ($\chi^2(3, n=105)=7.05$, $p=0.07$, Cramer's $V=0.26$), sleep time ($H(3)=4.13$, $p=0.25$, $\eta_H=0.01$) or time awake ($H(3)=0.64$, $p=0.89$, $\eta_H=0.02$).

Table 3 Summary of SW3 demographic data

	Shift group	Eriksen flanker
Sample size	Night	8
	Rotating	44
	Day	74
Age (mean±SD)	Night	36.13 ± 11.97
	Rotating	31.86 ± 9.29
	Day	38.35 ± 10.92
Sex (M:F)	Night	4:4
	Rotating	21:23
	Day	52:22
Country of testing (%)	Night	UK= 12.50 Europe= 0.00 Rest of world= 87.50
	Rotating	UK= 47.73 Europe= 27.27 Rest of world= 25.00
	Day	UK= 63.51 Europe= 29.73 Rest of world= 6.76
Job type (level of exercise) (%)	Night	Desk Based= 50.00 Light= 0.00 Moderate= 25.00 High= 25.00
	Rotating	Desk Based= 18.18 Light= 25.00 Moderate= 31.82 High= 25.00
	Day	Desk Based= 67.57 Light= 18.92 Moderate= 10.81 High= 2.70
Years worked (shifts/9-5) (%)	Night	0-12 months= 12.50 1-5 years= 62.50 6-10 years= 12.50 10+ years= 12.50
	Rotating	0-12 months= 15.91 1-5 years= 54.55 6-10 years= 20.45 10+ years= 9.09
	Day	0-12 months= 5.41 1-5 years= 32.43 6-10 years= 22.97 10+ years= 39.19

In this cohort, there were an equal number of males and females in the night shift worker group, a female majority in the rotating shift workers and a male majority in the day workers. The average age range was 31.86 to 38.35. There was a significant difference in age ($H(2)=10.85$, $p=0.004$) with rotating shift workers (31.86 ± 9.29) being significantly younger than day workers (38.35 ± 10.92 , $p=0.003$). The country of testing varied amongst the groups however there were no rotating shift workers from Europe in this cohort. This cohort showed variety regarding job type (stratified on the basis of using the degree of physical activity associated with work as a proxy for occupation) with a majority of night shift workers and day workers being desk based compared to the rotating shift group consisting predominantly of people doing a moderate amount of exercise per shift (up to half the shift). Again, there was no clear majority across all three shift groups with regard to years worked shifts or a '9-5' job.

2.4.4 Police (Po)

The analysis of the data collected from cohorts SW1, SW2 and SW3 revealed several disparities with existing studies of shift workers. Given that many published studies recruit from occupationally narrow populations (e.g. nurses), it was decided that the recruitment of a similarly occupationally restricted cohort in this project would provide a useful comparator sample. This led to the generation of the Po cohort.

The Po cohort consisted of rotating shift workers and day working controls recruited from a sample of individuals working in the UK police force (though not all police officers).

Night shift workers were not purposefully excluded from this sample however no participants who completed the experiment were able to be categorised as night shift workers. It is unknown whether this was due to this shift pattern not being commonly used within the UK police force or because (by chance) no one working permanent nights signed up for this study.

Rather than through Prolific, recruitment for this cohort was achieved via advertising through the Open University Centre for Policing Research and Learning leading to direct communication with four UK constabularies.

Similar to that of the SW1 cohort the day shift workers in the PO cohort included individuals working a variety of shifts that were conducted at any time through the day, finishing at 12 midnight or before.

The following shift group categorisation criteria were applied:

- Rotating shifts were categorised as shifts that regularly rotated through day and night

- Day shifts were categorised as shifts that were conducted at any time through the day up until 12 midnight

As with previous cohorts, responses to the demographic questionnaire were used to categorise participants into shift groups. The demographic questionnaire was modified to attempt to provide more specific shift related information than those questionnaires used in the previous cohorts.

The questions were as follows:

1. Which of the following applies to you: I have always worked permanent nights, I have always worked rotating shifts, I have always worked day shifts, I have previously worked permanent nights, I have previously worked rotating shifts, I have previously worked a combination of shifts, I am not a shift worker
2. What shifts have you worked in the last month? – Night shifts, rotating shifts, day shifts, I'm not a shift worker
3. Describe your shift pattern. For example 'In my shift rotation of 12 days I work 4 night shifts, 4 day shifts and have 4 days off' or 'In my shift rotation of 7 days I work 0 night shifts, 5 day shifts and have 2 days off'
4. My night shifts usually start at: (if you don't work night shifts leave these clocks set at 00:00) and end at:
5. My day shifts usually start at: (if you don't work day shifts leave these clocks set at 00:00) and end at:

Gatekeepers distributed the link to the Gorilla study website across each participating constabulary, with participants given the option to enter a prize draw to win a £30 Amazon voucher (10 vouchers were available in total).

In order to be included in primary analysis participants had to be aged 18+ years, have had no recent head injury severe enough to require medical attention, have provided sufficiently detailed and consistent information to enable them to be categorised into one of the shift groups, were on a day off from work and had fully completed the study.

Due to secondary exclusion criteria (on the basis of task performance) not all individuals' data were included. Further whilst many participants provided demographic data they did not go on to complete both tasks. Therefore, the demographic characteristics of each group have been calculated by task, rather than as a whole cohort.

As outlined in Chapter Three, only the Psychomotor Vigilance Task (PVT) was used in this cohort and no further cognitive assessment was attempted. As recruitment occurred through direct contact rather than the Prolific platform (where participants are generally highly motivated to engage with studies) it was deemed more likely that these participants would be less willing to commit to a full cognitive battery assessment which could take up to 30 minutes. Therefore, one cognitive task was used, rather than two as with previous cohorts, in order to minimise time commitment. Figure 4 outlines the study design used for this cohort.

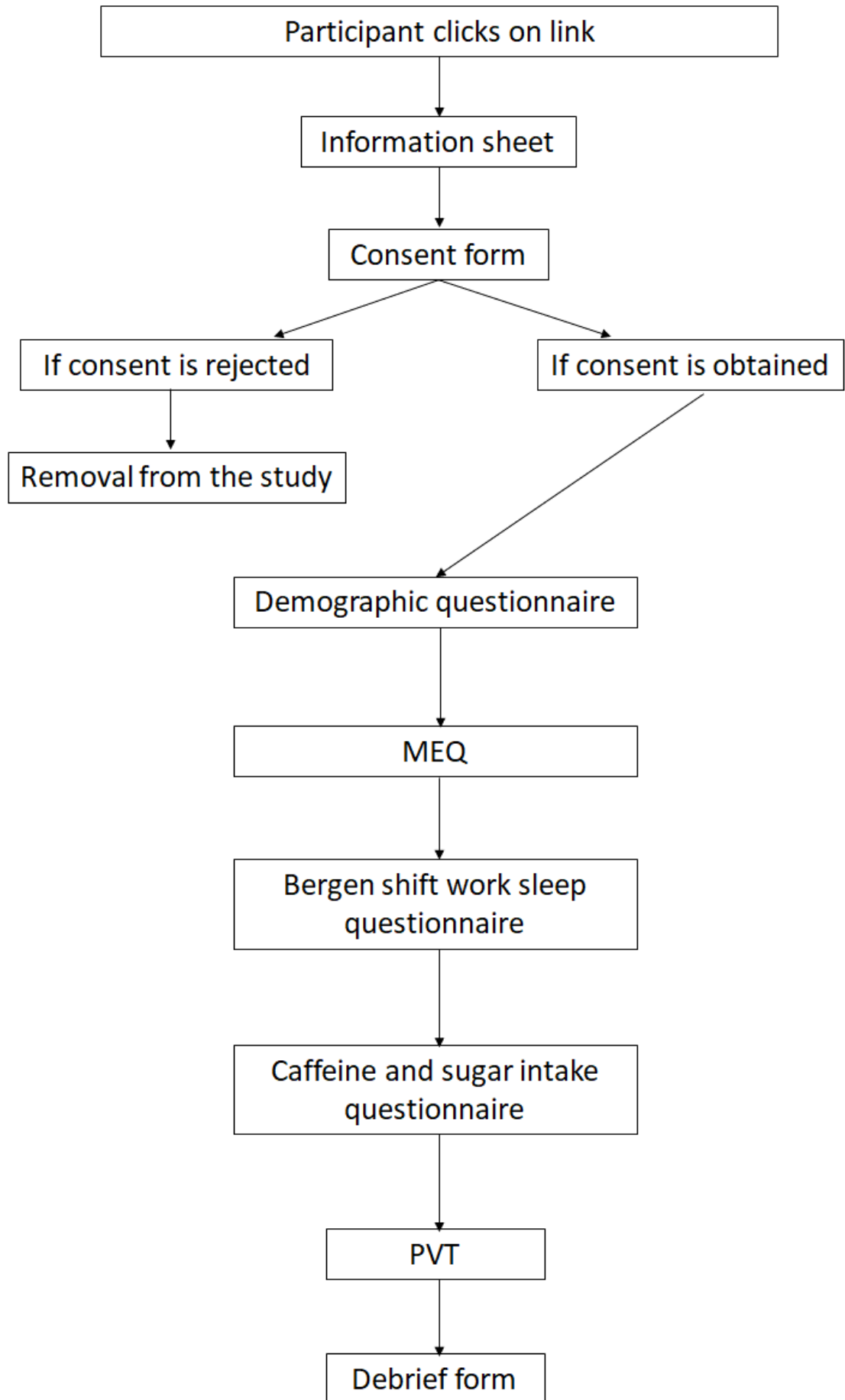


Figure 4 Po cohort study design (MEQ= Morningness-Eveningness Questionnaire; PVT= Psychomotor vigilance task)

Whole group analysis was run for key demographics to examine potential group differences on the basis of self-reported shift categorisations (rotating and day). There was a significant difference in age with day shift workers significantly older than rotating shift workers ($t(44)=2.09$, $p=0.04$, $\eta^2=0.09$). No difference was seen in sex ($X^2(1, n=46)=0.12$, $p=0.72$, Cramer's $V=0.05$).

There was no significant association between shift group and years worked shifts $X^2(3, n=46)=4.35$, $p=0.23$, Cramer's $V=0.31$ or shift group and activity levels ($X^2(3, n=46)=1.42$, $p=0.70$, Cramer's $V=0.18$).

There was no significant difference in time awake ($t(44)=0.44$, $p=0.67$, $\eta^2=0.004$). Sleep time did show a significant difference with day shift workers having slept more than rotating shift workers ($t(44)=2.86$, $p=0.007$, $\eta^2=0.16$).

Whole group demographic analysis was also run using the BSWSQ groupings described in the cognitive chapters. These groupings were made based on the rest component of the BSWSQ. There was no main effect of age ($F(3,36)=2.05$, $p=0.12$, $\eta^2=0.15$), sex ($X^2(3, n=40)=0.61$, $p=0.89$, Cramer's $V=0.12$), activity level ($X^2(9, n=40)=8.66$, $p=0.47$, Cramer's $V=0.27$), years worked shifts ($X^2(9, n=40)=13.64$, $p=0.14$, Cramer's $V=0.34$), sleep time ($H(3)=4.61$, $p=0.20$, $\eta_H=0.04$) or time awake ($F(3,36)=0.15$, $p=0.93$, $\eta^2=0.01$).

Outlined in Table 4 are the demographic characteristics of the Po cohort. Sample size indicated group size prior to outlier analysis.

Table 4 Summary of Po demographic data

	Shift group	PVT
Sample size	Rotating	25
	Day	21
Age (mean±SD)	Rotating	36.6 ± 8.87
	Day	42.19 ± 9.18
Sex (M:F)	Rotating	12:13
	Day	9:12
Country of testing (%)	Rotating	UK= 100
	Day	UK= 100
Job type (level of exercise) (%)	Rotating	Desk Based= 52.00 Light= 20.00 Moderate= 24.00 High= 4.00
	Day	Desk Based= 66.67 Light= 9.52 Moderate= 19.05 High= 4.76
Years worked (shifts/days) (%)	Rotating	0-12 months= 8.00 1-5 years= 32.00 6-10 years= 16.00 10+ years= 44.00
	Day	0-12 months= 19.05 1-5 years= 9.52 6-10 years= 23.81 10+ years= 47.62

There was a significant difference in age, with rotating shift workers being significantly younger than day workers ($t(44)=2.096$, $p=0.042$). Both shift groups contained a majority of females and all were based in the UK. The majority of workers were desk based in both shift groups and a large proportion of both groups had been working in their job type for over 10 years.

2.4.5 New parents (NP)

The NP cohort consisted of new parents and controls. New parents refers to any individuals who have recently become a parent to a newborn child, regardless of whether they have any previous children. Each of these were separated by sex resulting in four groups: NP male, NP female, Control (C) male and C female. New parents were defined as anyone having a child under the age of one year old, regardless of any other children they had. Participants in the control group did not have a child under the age of 1 years old, however were not excluded if they had an older child(ren).

Responses to the demographic questionnaire were used to sort participants into one of four groups. For the new parents these were as follows:

1. Which of the following best describes you? Male, Female, Other, Do not wish to say
2. When was your baby born? Less than 1 month ago, 1-2 months ago, 2-3 months ago, 3-4 months ago, 4-5 months ago, 5-6 months ago, 6-7 months ago, 7-8 months ago, 8-9 months ago, 9-10 months ago, 10-11 months ago, 11-12 months ago
3. If you do have more than one child, please give the age for each child – free text response

The question 'Do you have any children? If so, please give age(s) of each child' was used to determine the control group.

The following group categorisation criteria were applied:

- NP male were categorised as any male who had a child under the age of 1 year
- NP female were categorised as any female who had a child under the age of 1 year
- C male were categorised as any male who did not have a child under the age of 1 year
- C female were categorised as any female who did not have a child under the age of 1 year

Similar to the SW2 and SW3 cohorts, study design included branches to account for potential order effect (outlined in Figure 5). Where possible the cognitive data from these branches were merged (on the basis of no significant difference between testing groups). However this was not

always possible, therefore for the task where significant differences were seen, the demographics have been separated into 'group A' and 'group B' (TMTB).

Figure 5 outlines the study design used for the NP cohort.

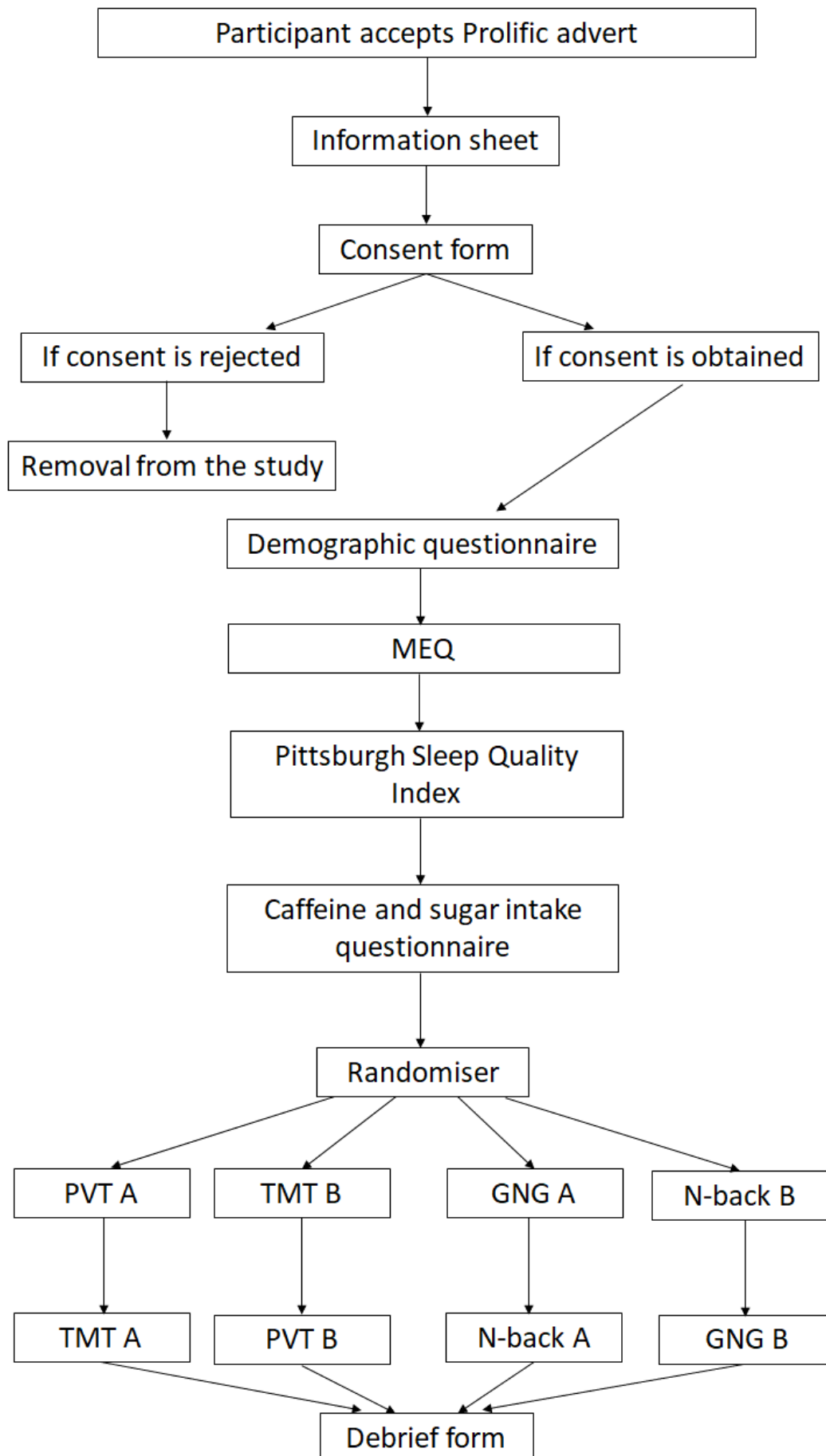


Figure 5 NP cohort study design (MEQ= Morningness-Eveningness Questionnaire; PVT= Psychomotor Vigilance Task; TMT= Trail making task; GNG = Go Nogo task)

As with the SW1, SW2 and SW3 cohorts, all individuals were recruited through Prolific and tested using the Gorilla platform. They received financial payment for the time taken to complete the study (a minimum of £5 per hour in line with Prolific's payment guidelines).

In order to be included in primary analysis participants had to be aged 18+ years, have had no recent head injury severe enough to require medical attention, have provided sufficiently detailed and consistent information to enable them to be categorised into one of the participant groups and had fully completed the study.

Whole group analysis was run for key demographics to examine potential group differences on the basis of self-reported parental categorisations (NP Male, NP Female, Control Male, and Control Female). This contained all participants in this cohort regardless of which cognitive assessments were completed. No significant difference in age was found ($H(4)=7.35$, $p=0.06$, $\eta_H=0.02$). A main effect of country of testing was found ($\chi^2(6, n=280)=72.30$, $p<0.001$, Cramer's $V=0.36$). A main effect was found in time awake prior to study completion ($H(3)=14.29$, $p=0.003$, $\eta_H=0.04$) with NP Male awake for longer than Control Male (5.80 ± 4.40 , 3.02 ± 2.331 , $p=0.02$) and NP Female awake for longer than Control Male (5.43 ± 4.25 , 3.02 ± 2.331 , $p=0.02$). No main effect of sleep time was observed ($H(3)=5.93$, $p=0.12$, $\eta_H=0.01$).

Due to secondary exclusion criteria (on the basis of task performance) not all individuals' data were included in both tasks. Further, whilst many participants provided demographic data they did not go on to complete both tasks. Therefore, the demographic characteristics of each group have been calculated by task. Outlined in Table 5 are the demographic characteristics of the NP cohort. Sample size indicates group size prior to outlier analysis.

Table 5 Summary of NP cohort demographics

	Shift group	PVT	TMTA	TMTB Group A	TMTB Group B	GNG	N-back
Sample size	NP Male	26	27	13	15	31	29
	NP Female	66	62	32	26	61	58
	C Male	29	21	15	13	26	27
	C Female	15	12	7	7	11	14
Age (mean±SD)	NP Male	29.50 ± 4.84	29.37 ± 4.69	30.77 ± 5.48	28.47 ± 3.74	32.06 ± 4.65	32.52 ± 5.21
	NP Female	31.09 ± 4.76	31.27 ± 4.52	30.13 ± 4.05	32.50 ± 4.47	29.57 ± 4.53	29.98 ± 4.399
	C Male	33.45 ± 7.27	33.67 ± 6.87	33.13 ± 6.98	32.62 ± 6.74	29.77 ± 6.15	30.78 ± 7.99
	C Female	37.40 ± 11.1	35.58 ± 9.71	37.86 ± 11.91	33.86 ± 7.27	31.27 ± 5.97	32.93 ± 7.26
Country of testing (%)	NP Male	UK= 30.77 Europe= 30.77 Rest of world= 8.46	UK= 33.33 Europe= 29.63 Rest of world= 37.04	UK= 46.15 Europe= 15.38 Rest of world= 38.46	UK= 20.00 Europe= 40.00 Rest of world= 40.00	UK= 35.48 Europe= 35.48 Rest of world= 29.03	UK= 34.48 Europe= 37.93 Rest of world= 27.59
	NP Female	UK= 60.61 Europe= 15.15 Rest of world= 24.24	UK= 61.29 Europe= 14.52 Rest of world= 24.19	UK= 62.50 Europe= 12.50 Rest of world= 25.00	UK= 61.54 Europe= 15.38 Rest of world= 23.08	UK= 65.57 Europe= 9.84 Rest of world= 24.59	UK= 67.24 Europe= 8.62 Rest of world= 24.14
	C Male	UK= 20.69 Europe= 79.31 Rest of world= 0.00	UK= 19.05 Europe= 80.95 Rest of world= 0.00	UK= 20.00 Europe= 80.00 Rest of world= 0.00	UK= 23.08 Europe= 76.92 Rest of world= 0.00	UK= 23.08 Europe= 61.54 Rest of world= 15.38	UK= 25.93 Europe= 59.26 Rest of world= 14.81

	C Female	UK= 66.67 Europe= 26.67 Rest of world= 6.67	UK= 58.33 Europe= 33.33 Rest of world= 8.33	UK= 71.43 Europe= 28.57 Rest of world= 0.00	UK= 57.14 Europe= 28.57 Rest of world=14.29	UK= 54.55 Europe= 45.45 Rest of world= 0.00	UK= 57.14 Europe= 42.86 Rest of world= 0.00
Do you live alone with your baby/children?	NP Male	Yes= 7.69 No= 88.46 Other= 3.85	Yes= 7.41 No= 88.89 Other= 3.70	Yes= 7.69 No= 92.31 Other= 0.00	Yes= 6.67 No= 86.67 Other= 6.67	Yes= 3.23 No= 96.77 Other= 0.00	Yes= 3.45 No= 96.55 Other= 0.00
	NP Female	Yes= 3.03 No= 96.97 Other= 0.00	Yes= 1.61 No= 98.39 Other= 0.00	Yes= 3.13 No= 96.88 Other= 0.00	Yes= 3.85 No= 96.15 Other= 0.00	Yes= 8.20 No= 91.80 Other= 0.00	Yes= 8.62 No= 91.38 Other= 0.00
Over the last month, has your child slept all the way through the night?	NP Male	Yes= 53.85 No= 46.15	Yes= 55.56 No= 44.44	Yes= 61.54 No= 38.46	Yes= 46.67 No= 53.33	Yes= 45.16 No= 54.84	Yes= 48.28 No= 51.72
	NP Female	Yes= 30.30 No= 69.70	Yes= 29.03 No= 70.97	Yes= 34.38 No= 65.63	Yes= 30.77 No= 69.23	Yes= 36.07 No= 63.93	Yes= 36.21 No= 63.79
How are you currently feeding your baby?	NP Male	BM (breast)= 38.46 BM (bottle)= 11.54 Formula= 38.46 Mixture= 11.54 Other= 0.00	BM (breast)= 37.04 BM (bottle)= 11.11 Formula= 37.04 Mixture= 11.11 Other= 3.70	BM (breast)= 53.85 BM (bottle)= 0.00 Formula= 38.46 Mixture= 7.69 Other= 0.00	BM (breast)= 26.67 BM (bottle)= 20.00 Formula= 33.33 Mixture= 13.33 Other= 6.67	BM (breast)= 38.71 BM (bottle)= 0.00 Formula= 38.71 Mixture= 12.90 Other= 3.23 Prefer not to say= 6.45	BM (breast)= 37.93 BM (bottle)= 0.00 Formula= 37.93 Mixture= 13.79 Other= 3.45 Prefer not to say= 6.90
	NP Female	BM (breast)= 51.52 BM (bottle)= 3.03 Formula= 39.39 Mixture= 3.03 Other= 3.03	BM (breast)= 51.61 BM (bottle)= 3.23 Formula= 37.10 Mixture= 4.84 Other= 3.23	BM (breast)= 53.13 BM (bottle)= 6.25 Formula= 31.25 Mixture= 6.25 Other= 3.13	BM (breast)= 46.15 BM (bottle)= 0.00 Formula= 50.00 Mixture= 0.00 Other= 3.85	BM (breast)= 44.26 BM (bottle)= 0.00 Formula= 39.34 Mixture= 13.11 Other= 3.28	BM (breast)= 43.10 BM (bottle)= 0.00 Formula= 39.66 Mixture= 13.79 Other= 3.45

Across the cohort the average age range was 28.47 – 37.86. There were no significant differences in age within each task, with the exception of participants in the PVT task who showed a main effect of age ($F(3,132)=5.99$, $p=0.0007$), with NP males (29.50 ± 4.84) being significantly younger than control females (37.40 ± 11.1 $p=0.001$) and NP females (31.09 ± 4.76) being significantly younger than control females (37.40 ± 11.1 $p=0.0036$). The country of testing varied throughout this cohort with no clear majority across all groups. The majority of new parents lived with another adult. With regards to whether their baby had slept through the night in the last month, there was no clear majority across groups. Finally, a large proportion of individuals fed their babies' breast milk (directly from the breast) or used formula.

2.4.6 EEG

The EEG cohort consisted of shift workers and non-shift workers. To maximise recruitment, shift workers in this cohort were defined as anyone working shifts, regardless of shift pattern. In this cohort all shift workers were rotating. As this cohort was recruited through direct communication (shift and non-shift workers at a UK higher education institute were approached directly) questionnaires were not needed to determine individuals shift worker status.

Different to the previous cohorts, this group received no cognitive testing, instead they received a basic eyes open-eyes closed EEG protocol twice, as outlined in Chapter Seven. In the shift working group, one testing session occurred at the beginning of a night shift and one at the beginning of a day shift. For the non-shift working controls, both testing sessions occurred at the start of their normal working day. Figure 6 outlines the study design used in this cohort. Here a full MEQ was used instead of the rMEQ used in the previous cohorts. Details of this can be found below.

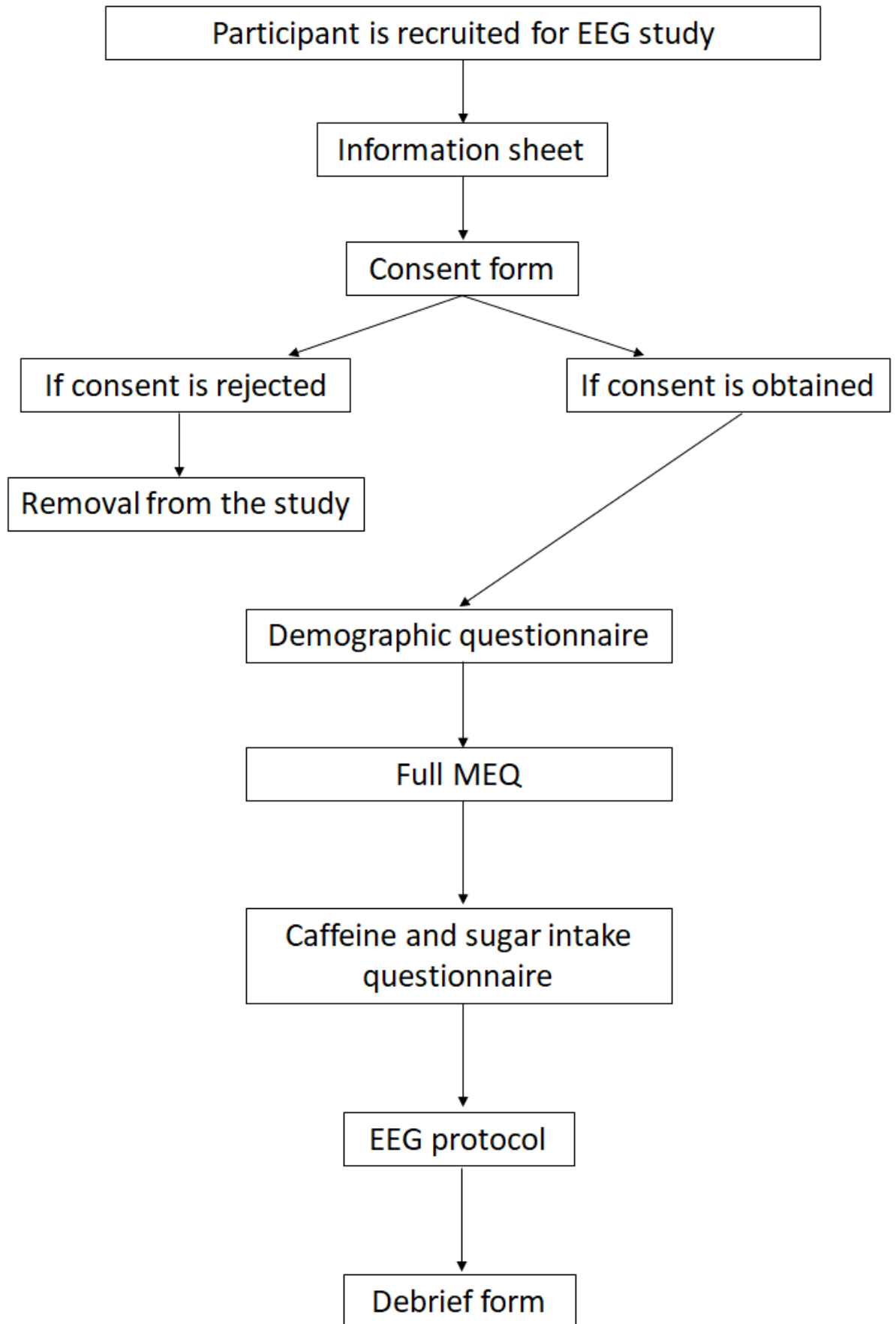


Figure 6 EEG cohort study design (MEQ = Morningness-Eveningness Questionnaire)

Participants received a £5 Amazon voucher for taking part in both EEG testing sessions. As with previous cohorts, in order for participants to be included in primary analysis they had to be aged

18+ years, have had no recent head injury severe enough to require medical attention, have provided sufficiently detailed and consistent information to enable them to be categorised into one of the shift groups and had fully completed the study.

Outlined in Table 6 are the demographic characteristics of the EEG cohort. Sample size indicated group size following signal artefact analysis (see Chapter Seven for more details).

Whole group analysis was also run for key variables to examine potential group confounds.

No significant difference in age was found ($t(15)=1.87$, $p=0.08$, $\eta^2=0.19$). Both groups had a majority of males, with the non-shift workers having no females. All participants were tested in the UK and the majority of shift workers had worked shifts for more than 10 years.

Table 6 Summary of EEG cohort demographics

	Shift group	EEG
Sample size	Shift workers	9
	Non shift workers	8
Age (mean±SD)	Shift workers	52.13 ± 14.04
	Non shift workers	39.22 ± 14.39
Sex (M:F)	Shift workers	8:1
	Non shift workers	8:0
Country of testing (%)	Shift workers	UK= 100 Europe= 0.00 Rest of world= 0.00
	Non shift workers	UK= 100 Europe= 0.00 Rest of world= 0.00
Years worked (shifts/9-5) (%)	Shift workers	0-12 months= 12.50 1-5 years= 0.00 6-10 years= 25.00 10+ years= 62.50

2.5 Questionnaires

Alongside the demographic questionnaire and the caffeine questionnaire (not reported) each cohort received a further set of questionnaires. These included the Bergen Shift Work Sleep Questionnaire, the Morningness-Eveningness Questionnaire (both long and short versions were used) and the Pittsburgh Sleep Quality Index (not reported).

Outlined below are the scores calculated from each of these questionnaires from the respective cohorts, stratified by task. A copy of all the questionnaires used in this thesis can be found in the appendix.

2.5.1 Bergen Shift Work Sleep Questionnaire

The Bergen Shift Work Sleep Questionnaire (BSWSQ) is used to assess sleep issues directly linked to different work shifts (day, evening and night shifts) and rest days (Flo et al., 2012). Consisting of seven questions, the BSWSQ measures insomnia symptoms and tiredness/sleepiness. Each question is asked with respect to each of the three shift types as well as a day off. See Figure 7 for an example.

How often has it taken you more than 30 minutes to fall asleep after the light is switched off? (Tick one option for each question)

a) When you are working day shift/ordinary day work?

Never	Rarely	Sometimes	Often	Always	N/A
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b) When you are working evening shift/evening work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

c) When you are working night shift/ night work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

d) When you are not working (rest days /vacations)?

Never	Rarely	Sometimes	Often	Always	
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Figure 7 Screenshot of an example question from the BSWSQ given to online participants

As seen in Figure 7, each question is answered with a choice of 5 responses, N/A is also used on the shift related sub questions. Each is rated with a score (Never=0, Rarely=1, Sometimes=2, Often=3, Always=4, N/A is marked as missing data) and the reported score indicates the persistence of each symptom. The higher the score the more severe the problem.

Participants are asked to answer all questions in relation to the last 3 months.

Each question relates to a specific insomnia symptom: >30 min sleep onset latency, >30 min wake after sleep onset, >30 min premature awakenings, non-restorative sleep, being sleepy either at work, during free periods on work days, or on rest-days.

Shift related insomnia was defined as participants scoring 'often' or 'always' on at least one of questions 1-4 and on at least one shift specific question relating to being sleepy during work or free periods at work. The BSWSQ has demonstrated good reliability (test-retest coefficients $p < 0.001$) and good convergent and discriminant validity (all coefficients $p < 0.001$) (Flo et al., 2012).

Of the six cohorts described above, four received the BSWSQ (SW1, SW2, SW3 and Po). The scores from each cohort are outlined below. As each cohort contained different shift types not all questions were relevant to all groups, therefore grey squares are used to indicate where

questions were not relevant. Further, not all participants responded to all questions, therefore sample sizes may differ within groups.

2.5.1.1 SW1

As detailed above, this cohort consisted of night and rotating shift workers and a day working control. In total there were 22 night shift workers, 81 rotating shift workers and 46 day workers whose data were used in the analysis of at least one of the four cognitive tasks. However not all participants responded to every question in the BSWSQ and therefore the sample size for each sub question fluctuates. Given that the percentage of group who responded 'often or 'always' is used as a measure of the severity within each shift subgroup, the sample size of each group is also reported. The percentage of group and the sample sizes are summarised in Table 7.

Table 7 BSWSQ summary for the SW1 cohort showing percentage of group who responded 'often' or 'always'

BSWSQ Questions	Shift type	Day (A)		Evening (B)		Night (C)		Rest days (D)	
		%	n	%	n	%	n	%	n
How often has it taken you more than 30 minutes to fall asleep after the light is switched off?	Night					68.42	19	25	20
	Rotating	45.2054795	73	46.77419	62	50	72	27.14286	70
	Day	41.8604651	43	48.57143	35			28.57143	42
How often are you awake for more than 30 minutes within your main sleep period?	Night					42.11	19	25	20
	Rotating	34.246575	73	40.32258	62	30.55556	72	24.28571	70
	Day	18.604651	43	20	35			14.28571	42
How often have you woken up more than 30 minutes earlier than you wished, without being able to fall asleep again?	Night					68.42	19	25	20
	Rotating	39.72603	73	41.93548	62	40.27778	72	28.57143	70
	Day	30.23256	43	34.28571	35			23.80952	42
How often have you not felt adequately rested following sleep?	Night					63.16	19	15	20
	Rotating	53.42466	73	46.77419	62	58.33333	72	32.85714	70
	Day	60.46512	43	51.42857	35			35.71429	42
How often have you been tired/sleepy at work?	Night					52.63	19		
	Rotating	36.9863	73	45.16129	62	51.38889	72		
	Day	44.18605	43	42.85714	35				
How often have you been tired/sleepy on your free time (time out of work) on workdays?	Night					63.16	19		
	Rotating	34.24658	73	37.09677	62	45.83333	72		
	Day	53.48837	43	54.28571	35				
How often have you been tired/sleepy on rest days/on vacation?	Night							45	20
	Rotating							21.42857	70
	Day							38.09524	42

Analysis was run within each work category score (Day, Evening, Night and Rest) to see if any significant differences between shift types were present. For example, for the responses regarding Evening shifts (Evening (B)), all participants who answered this question in the rotating group and the day group were compared to see if there were any significant differences in BSWSQ Evening score. Further, for the Rest (D) score, the two shift types (night and rotating) were collapsed to see if any difference was present between shift and non-shift workers as a whole. This collapsing was not possible for the Day (A), Evening (B) and Night (C) BSWSQ work category score as they did not include both types of shift work (night and rotating). No significant differences were found in any of the comparison groups, suggesting there was no impact of shift type on BSWSQ work category score, and therefore no differences in sleep issues in these shift groups.

Statistical outputs can be found in Table 8.

Table 8 SW1 BSWSQ work category score comparisons

BSWSQ work category score	Comparison group	Statistic
Day (A)	rotating Vs day	t(114)=0.05, p=0.96, $\eta^2=2.42e-005$
Evening (B)	rotating Vs day	t(95)=0.01, p=0.99, $\eta^2=1.67e-006$
Night (C)	night Vs rotating	t(89)=1.13, p=0.26, $\eta^2=0.01$
Rest (D)	night Vs rotating Vs day	F(2,129)=0.004, p=0.996, $\eta^2=5.79e-005$
Rest (D)	Shift workers Vs Non-shift workers	t(130)=0.09, p=0.93, $\eta^2=5.62e-005$

2.5.1.2 SW2

As detailed in the demographics section, this cohort consisted of night and rotating shift workers and a day working control. In total there were 51 night shift workers, 115 rotating shift workers and 94 day shift workers whose data were used in the analysis of at least one of the four cognitive tasks.

For the SW2 cohort an attention check question was added to increase data quality. This was introduced due to internally inconsistent findings being observed in the SW1 cohort. For example, a participant may answer the question ‘Which of the following applies to you’ with ‘I have always worked permanent nights’ however then answer the question ‘What shifts have you worked in the last month?’ with ‘Rotating shifts’. The attention check question instructed participants to make a specific response e.g. ‘Rarely’. If any other answer was given for that question all of the BSWSQ data for that participant was removed. This resulted in the BSWSQ questionnaire data of 8 night shift workers, 11 rotating shift workers and 19 day workers being removed.

As with the SW1 cohort, not all participants responded to all questions causing differences in question samples sizes. Again, the percentage of group who responded 'often' or 'always' was used as a measure of insomnia/sleepiness severity within each shift group. The percentage of group and the sample sizes are summarised in Table 9.

Table 9 BSWSQ summary for the SW2 cohort showing percentage of group who responded 'often' or 'always'

BSWSQ Questions	Shift type	Day (A)		Evening (B)		Night (C)		Rest days (D)	
		%	n	%	n	%	n	%	n
How often has it taken you more than 30 minutes to fall asleep after the light is switched off?	Night					55.81	43	34.88	43
	Rotating	38.83	103	44.33	97	46.53	101	27.88	104
	Day	33.33	75	21.43	28			26.67	75
How often are you awake for more than 30 minutes within your main sleep period?	Night					44.19	43	37.21	43
	Rotating	24.27	103	29.90	97	28.71	101	15.38	104
	Day	22.67	75	14.29	28			14.67	75
How often have you woken up more than 30 minutes earlier than you wished, without being able to fall asleep again?	Night					37.21	43	30.23	43
	Rotating	27.18	103	27.84	97	34.65	101	26.92	104
	Day	28.00	75	10.71	28			20.00	75
How often have you not felt adequately rested following sleep?	Night					53.49	43	32.56	43
	Rotating	50.49	103	39.18	97	49.50	101	20.19	104
	Day	45.33	75	50.00	28			18.67	75
How often have you been tired/sleepy at work?	Night					37.21	43		
	Rotating	44.66	103	35.05	97	49.50	101		
	Day	29.33	75	25.00	28				
How often have you been tired/sleepy on your free time (time out of work) on workdays?	Night					46.51	43		
	Rotating	27.18	103	27.84	97	38.61	101		
	Day	28.00	75	21.43	28				
How often have you been tired/sleepy on rest days/on vacation?	Night							25.58	43
	Rotating							19.23	104
	Day							13.33	75

Analysis was run within each work category score (Day, Evening, Night and Rest) to see if any significant differences between shift types were present. Further, for the Rest score, the two shift types (night and rotating) were collapsed to see if any difference was present between shift and non-shift workers as a whole. No significant differences were found in the Day, Night, Rest comparison groups, suggesting there was no impact of shift type on these BSWSQ work category score, and therefore no differences in sleep issues in these shift groups. There were however significant differences in the Evening comparison with rotating (12 ± 4.5) significantly higher than day (9.5 ± 4.9). This suggests that the rotating shift workers have more sleep issues than the day workers.

Statistical outputs can be found in Table 10.

Table 10 SW2 BSWSQ work category score comparisons

BSWSQ work category score	Comparison group	Statistic
Day (A)	rotating Vs day	$t(176)=1.01, p=0.31, \eta^2=0.01$
Evening (B)	rotating Vs day	$t(123)=2.49, p=0.01^*, \eta^2=0.05$
Night (C)	night Vs rotating	$t(142)=1.49, p=0.14, \eta^2=0.02$
Rest (D)	night Vs rotating Vs day	$H(2)=5.38, p=0.07, \eta_H=0.02$
Rest (D)	Shift workers Vs Non shift workers	$T(220)=1.89, p=0.06, \eta^2=0.02$

2.5.1.3 SW3

As detailed in the demographics section, this cohort consisted of night and rotating shift workers and a day working control. In total there were 8 night shift workers, 44 rotating shift workers and 74 day shift workers whose data were used in the analysis of the Eriksen flanker task.

For the SW3 cohort an attention check question was added to ensure data quality. The attention check question instructed participants to make a specific response e.g. 'Rarely'. If any other answer was given for that question all of the BSWSQ data for that participant was removed. This resulted in the BSWSQ questionnaire data of 1 night shift worker, 6 rotating shift workers and 13 day workers being removed.

As with the SW1 and SW2 cohorts, not all participants responded to all questions causing differences in question samples sizes. Again, the percentage of group who responded 'often' or 'always' was used as a measure of insomnia/sleepiness severity within each shift group. The percentage of group and the sample sizes are summarised in Table 11.

Table 11 BSWSQ summary for the SW3 cohort showing percentage of group who responded ‘often’ or ‘always’

BSWSQ Questions	Shift type	Day (A)		Evening (B)		Night (C)		Rest days (D)	
		%	n	%	n	%	n	%	n
How often has it taken you more than 30 minutes to fall asleep after the light is switched off?	Night					28.57	7	42.86	7
	Rotating	31.58	38	42.86	35	32.43	37	24.32	37
	Day	26.23	61	5.56	18			14.75	61
How often are you awake for more than 30 minutes within your main sleep period?	Night					14.29	7	14.29	7
	Rotating	31.58	38	37.14	35	35.14	37	18.92	37
	Day	16.39	61	5.56	18			13.11	61
How often have you woken up more than 30 minutes earlier than you wished, without being able to fall asleep again?	Night					14.29	7	0.00	7
	Rotating	18.42	38	22.86	35	29.73	37	16.22	37
	Day	21.31	61	11.11	18			16.39	61
How often have you not felt adequately rested following sleep?	Night					28.57	7	0.00	7
	Rotating	52.63	38	40.00	35	54.05	37	24.32	37
	Day	42.62	61	27.78	18			22.95	61
How often have you been tired/sleepy at work?	Night					28.57	7		
	Rotating	44.74	38	34.29	35	37.84	37		
	Day	26.23	61	11.11	18				
How often have you been tired/sleepy on your free time (time out of work) on workdays?	Night					14.29	7		
	Rotating	34.21	38	28.57	35	40.54	37		
	Day	29.51	61	16.67	18				
How often have you been tired/sleepy on rest days/on vacation?	Night							14.29	7
	Rotating							35.14	37
	Day							9.84	61

Analysis was run within each work category score (Day, Evening, Night and Rest) to see if any significant differences between shift types were present. Further, for the Rest score, the two shift types (night and rotating) were collapsed to see if any difference was present between shift and non-shift workers as a whole. No significant differences were found in the Day, Night, Rest comparison groups, suggesting there was no impact of shift type on these BSWSQ work category scores, and therefore no differences in sleep issues in these shift groups. There was however a significant difference in the Evening comparison with rotating (12±4.6) significantly higher than day (8.4±4.8). This suggest that the rotating shift workers have more sleep issues than the day workers.

Statistical outputs can be found in Table 12.

Table 12 SW3 BSWSQ work category score comparisons

BSWSQ work category score	Comparison group	Statistic
Day (A)	rotating Vs day	t(97)=1.67, p=0.097, $\eta^2=0.03$
Evening (B)	rotating Vs day	t(51)=2.998, p=0.004**, $\eta^2=0.15$
Night (C)	night Vs rotating	t(42)=1.66, p=0.11, $\eta^2=0.06$
Rest (D)	night Vs rotating Vs day	F(2,102)=1.51, p=0.23, $\eta^2=0.03$
Rest (D)	Shift workers Vs Non-shift workers	t(103)=0.83, p=0.41, $\eta^2=0.01$

2.5.1.4 Po

As detailed in the demographics section, this cohort consisted of rotating shift workers and a day working control. In total there were 25 rotating shift workers and 21 day shift workers whose data were used in the analysis of the PVT task.

For the SW3 cohort an attention check question was added to ensure data quality. The attention check question instructed participants to make a specific response e.g. 'Rarely'. If any other answer was given for that question all of the BSWSQ data for that participant was removed. This resulted in the BSWSQ questionnaire data of 2 rotating shift workers and 4 day workers being removed.

As with previous cohorts, not all participants responded to all questions causing differences in question samples sizes. Again, the percentage of group who responded 'often' or 'always' was used as a measure of insomnia/sleepiness severity within each shift group. The percentage of group and the sample sizes are summarised in Table 13.

Table 13 BSWSQ summary for the Po cohort showing percentage of group who responded 'often' or 'always'

BSWSQ Questions	Shift type	Day (A)		Evening (B)		Night (C)		Rest days (D)	
		%	n	%	n	%	n	%	n
How often has it taken you more than 30 minutes to fall asleep after the light is switched off?	Rotating	30.43	23	31.82	22	14.29	21	26.09	23
	Day	23.53	17	45.45	11			11.76	27
How often are you awake for more than 30 minutes within your main sleep period?	Rotating	34.78	23	27.27	22	38.10	21	13.04	3
	Day	35.29	17	45.45	11			23.53	17
How often have you woken up more than 30 minutes earlier than you wished, without being able to fall asleep again?	Rotating	43.48	23	22.73	22	71.43	21	13.04	23
	Day	29.41	17	27.27	11			11.76	17
How often have you not felt adequately rested following sleep?	Rotating	78.26	23	59.09	22	76.19	21	39.13	23
	Day	41.18	17	45.45	11			29.41	17
How often have you been tired/sleepy at work?	Rotating	43.48	23	45.45	22	85.71	21		
	Day	58.82	17	45.45	11				
How often have you been tired/sleepy on your free time (time out of work) on workdays?	Rotating	65.22	23	31.82	22	66.67	21		
	Day	47.06	17	27.27	11				
How often have you been tired/sleepy on rest days/on vacation?	Rotating							39.13	23
	Day							35.29	17

Analysis was run within each work category score (Day, Evening, and Rest) to see if any significant differences between shift types were present. As this group contained only one type of shift worker, no merging of the Rest scores was needed. Further, there was no comparison for the Night score. No significant differences were found in any of the comparison groups, suggesting there was no impact of shift type on BSWSQ work category score, and therefore no differences in sleep issues in these shift groups.

Statistical outputs can be found in Table 14.

Table 14 Po BSWSQ work category score comparisons

BSWSQ work category score	Comparison group	Original groups (Rotating Vs Day)
Day (A)	rotating Vs day	t(38)=1.63, p=0.11, $\eta^2=0.07$
Evening (B)	rotating Vs day	t(31)=0.39, p=0.72, $\eta^2=0.004$
Rest (D)	rotating Vs day	t(38)=1.34, p=0.19, $\eta^2=0.05$

2.5.2 The Morningness-Eveningness Questionnaire

The Morningness-Eveningness questionnaire (MEQ) assesses an individual's chronotype – either morning type, evening type or intermediate (J. A. Horne & Östberg, 1976). The MEQ is widely accepted as a valid and reliable questionnaire to examine Morningness-Eveningness (Adan et al., 2012).

This instrument was added following the analysis of the data collected from the SW1 cohort in an attempt to further examine why the observed cognitive data differed from the existing literature. Two versions of the MEQ were used in the cohorts described in this thesis: a short and a long version. Copies of both can be found in the appendix. Due to assessment session duration the short version was used in cohorts SW2, SW3, and NP. As two cognitive tasks were also given to these cohorts it was decided to make the questionnaires as short as possible in order to maximise participant retention. For consistency, the same shortened questionnaire was given to the Po cohort. In the EEG cohort no cognitive testing occurred therefore the long version of the MEQ was used.

The long MEQ consists of 19 questions, with each answer option allocated a number. All answers are combined to create a total score which then dictates respondent chronotype. Scores can range from 16-86 (J. A. Horne & Östberg, 1976; Terman, Rifkin, Jacobs, & White, 2008). Table 15 shows the score ranges and corresponding chronotypes.

Table 15 MEQ categories

MEQ score	16-30	31-41	42-58	59-69	70-86
Chronotype	Definite evening	Moderate evening	Intermediate	Moderate morning	Definite morning

Adan and Almirall (1991) developed a shorter version of the MEQ, called the reduced MEQ (rMEQ) (Adan & Almirall, 1991). The rMEQ consists of 5 questions, with each answer option allocated a number. Similar to the long MEQ, chronotype is calculated using the total score of all questions. Scores range from 4-25. Table 16 shows the score ranges and corresponding chronotypes. Again this version has shown good convergent validity and has been translated and used in several different populations (Randler, 2013).

Table 16 MEQ categories

rMEQ Score	4-7	8-11	12-17	18-21	22-25
Chronotype	Definite evening	Moderate evening	Intermediate	Moderate morning	Definite morning

The scores from each cohort are outlined below.

2.5.2.1 SW2

The SW2 cohort received the rMEQ, following a series of demographic questions. As with the BSWSQ any participant whose data had been included in at least one of the four cognitive tasks was included here. Table 17 outlines the rMEQ categories found in each shift group (%).

Table 17 rMEQ category percentages

Group	n	Definite evening	Moderate evening	Intermediate	Moderate morning	Definite morning
Night	51	21.57	25.49	41.18	9.80	1.96
Rotating	115	8.695	28.695	47.83	13.04	1.74
Day	94	2.13	10.64	60.64	25.53	1.06

In all three groups the largest category was intermediate. In the night and rotating shift group, moderate evening was the next biggest category. In the day group moderate morning was the next biggest category.

2.5.2.2 SW3

The SW3 cohort received the rMEQ following a series of demographic questions. As with the BSWSQ any participant whose data had been included in the Eriksen flanker task was included here. Table 18 outlines the rMEQ categories found in each shift group (%).

Table 18 rMEQ category percentages

Group	n	Definite evening	Moderate evening	Intermediate	Moderate morning	Definite morning
Night	8	25	25	50	0	0
Rotating	44	18.18	31.82	43.18	6.82	0
Day	74	0	17.57	70.27	9.46	2.70

In all three groups the largest category was intermediate. In the night shift group the next biggest categories were definite evening and moderate evening (both at 25%). In both the rotating and day groups moderate evening was the next biggest category.

2.5.2.3 Po

The Po cohort received the rMEQ, following a series of demographic questions. As with the BSWSQ any participant whose data had been included in the PVT was included here. Table 19 outlines the rMEQ categories found in each shift group (%).

Table 19 rMEQ category percentages

Group	n	Definite evening	Moderate evening	Intermediate	Moderate morning	Definite morning
Rotating	25	0.00	24.00	56.00	16.00	4.00
Day	21	0.00	4.76	66.67	23.81	4.76

Both groups had a large proportion of intermediate. Moderate evening was the next largest category in rotating shift workers. Moderate morning was the next biggest category in day shift workers.

2.5.2.4 NP

The NP cohort received the rMEQ, following a series of demographic questions. As with the BSWSQ any participant whose data had been included in at least one of the four cognitive tasks was included here. Table 20 outlines the rMEQ categories found in each group (%).

Table 20 rMEQ category percentages

Group	n	Definite evening	Moderate evening	Intermediate	Moderate morning	Definite morning
NP Male	61	1.64	24.59	59.02	13.11	1.64
NP Female	133	2.26	18.80	57.14	18.80	3.01
C Male	56	3.57	12.50	58.93	25.00	0.00
C Female	30	0.00	10.00	60.00	26.67	3.33

The majority of all four groups were categorised as intermediate, with the next largest group being moderate evening for NP males, moderate evening/moderate morning for NP females, and moderate morning for both C males and C females.

2.5.2.5 EEG

The EEG cohort received the MEQ, following a series of demographic questions. Any participant whose EEG data had been included was included here. Table 21 outlines the MEQ categories found in each shift group (%).

Table 21 MEQ category percentages

Group	n	Definite evening	Moderate evening	Intermediate	Moderate morning	Definite morning
Rotating	8	0.00	0.00	62.50	37.50	0.00
Day	9	0.00	0.00	44.44	33.33	22.22

Both groups had a large proportion of intermediate, with moderate morning being the next biggest category.

2.5.3 Pittsburgh Sleep Quality Index

The Pittsburgh Sleep Quality Index (PSQI) assesses sleep quality and disturbances over a one month period (Buysse, Reynolds, Monk, Berman, & Kupfer, 1988). It is comprised of 10 questions with 19 individual items, which combined create seven 'component' scores; subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. The sum of these scores produces a global score. This global score has a possible range of 0-21. A global score above 5 indicates poor sleep quality. The scoring guide for the PSQI can be found in the appendix. If individuals fail to answer any part of the questionnaire they are removed from analysis.

The new parents (NP male and NP female) in the NP cohort received this questionnaire however due to an issue with transposition of the questionnaire instrument and the method by which the global score is calculated this data was unusable.

2.6 Cognitive assessments

Five different cognitive tasks were used to assess four domains of cognition. These were a PVT (to assess attention), a GNG and Eriksen flanker (to assess response inhibition), an N-Back (to assess working memory) and a TMT (to assess visuomotor coordination). Information on the specific tasks can be found in the related chapters (Chapters 3-6). Instructions given to participants at the start of each task can be found in the appendix.

As described in each of the related chapters, outlier analysis was conducted on each group before the groups were merged for order effect. For example, outlier analysis was conducted on both night A and night B in the SW2 cohort before the groups were merged due to no significant differences between them. The number of participants removed through outlier analysis is outlined in the sample tables for each variable. In the majority of cases very few participants (less than 3) were removed from each group. Indeed, these removed cases were likely a result of the mode of cognitive assessment delivery. The online assessment approach used here resulted in participants completing the assessments without the presence of a researcher. In the absence of a researcher, some participants attempted to finish studies as fast as possible, or left them running with little to no interaction. Further details on the approaches used to identify such participants can be found in the data chapters.

3.1 Introduction

Attention is a complex cognitive domain consisting of multiple elements including sustained, divided and selective attention (defined in Chapter One). Elements such as these underpin a variety of cognitive processes, including response inhibition and memory. As a result of both its complexity and its key role in other cognitive domains, attention is one of the most well researched areas of human cognition. This domain is vital for normal functioning and therefore understanding if/how attentional performance can be compromised by disturbances to sleep is important.

As with all cognitive domains, multiple tests can be used to measure the elements of attention. As detailed in Chapter One, these include the Psychomotor Vigilance Task (PVT) (Basner & Dinges, 2011), choice signal detection tasks such as the 5-Choice Serial Reaction Time Task (Leonard, 1959) and the Stroop task (Stroop, 1935). This chapter focuses on data collected using the PVT task. The PVT is one of the most commonly used tasks to assess behavioural alertness (Basner & Dinges, 2011) and is relatively simple to administer to participants. Popularised within sleep deprivation studies by Dinges and Powell, the PVT is a reaction time task that measures how fast a participant can respond to a given stimulus (Dinges & Powell, 1986). Assessing sustained attention, the task itself takes between 3-10 minutes on average. However this variation in test length has led to the wide range of test durations used in sleep deprivation literature. Basner and Dinges (2011) suggested a ten minute PVT is most optimised to detect sleep deprivation related changes in attention (Basner & Dinges, 2011). The 10 minute version of this task has been shown to be highly reliable (Dorrian, Rogers, & Dinges, 2005). Further, it has proved to be resistant to practise effects (Lim & Dinges, 2008, Basner et al., 2018). In particular, a 3 minute PVT has been shown to produce a stable performance across repeated administrations (Basner et al., 2018).

Laboratory based sleep deprivation studies have shown attention to be particularly vulnerable to sleep deprivation. Doran, Van Dongen and Dinges (2001) recruited healthy male participants who were allocated to a nap group, in which participants received a 2 hour nap opportunity every 12 hours, or a total sleep deprivation group, in which participants were required to stay awake throughout the 88 hour sleep deprivation protocol. Assessed using a 10 minute PVT, they found increasingly greater performance variability as a function of time on task following just 18 hours of wakefulness in the total sleep deprivation group, compared to the nap group (Doran et al., 2001). Similar findings were observed by Lim and Dinges (2010) who conducted a meta-analysis of the short term sleep deprivation literature. They concluded that significant impairments are seen

across most cognitive domains, including attention, following less than 48 hours of sleep deprivation (Lim & Dinges, 2010).

Together these studies suggest the possibility that any disruption to sleep could impair attention in terms of vigilance or maintaining focus. However these studies were conducted in a laboratory environment and consisted of long periods of forced wakefulness, therefore are not particularly ecologically relevant. One group of individuals who naturally experience long periods of wakefulness as well as a disturbed sleep pattern, are new parents. Altered sleep patterns, lack of adequate sleep duration/quality and increased fatigue are common amongst new parents (Rudzik & Ball, 2016). Specifically, new parents have been shown to have more sleep disruption following the birth of a child, with mothers experiencing less sleep during the night but more sleep during the day compared to the last month of pregnancy (Gay et al., 2004). These are all factors which would likely lead to impaired attention (Lim & Dinges, 2010). Given the unpredictable periods of wakefulness and disturbed sleep experienced by these individuals it is vital to assess whether the findings of similar but artificial laboratory sleep deprivation studies are replicated in this population. Insana et al. (2013) found that over the course of 12 weeks postpartum, women experienced a worsening PVT performance, though not until week 2 (Insana et al., 2013). The cumulative effect of sleep deprivation was suggested to have influenced this decline.

However the impact of new parenthood on attention may be reversible. Wilson et al. (2019a) looked at postpartum women and their children during a residential early parenting program (Wilson et al., 2019a). Following five days of increased sleep opportunities, supervised practise of infant settling strategies and psychological support, PVT reciprocal mean reaction times were significantly faster than at the beginning of the course. It is likely that 5 days of recovery from sleep disruption linked with new motherhood was enough to recover attention. Of note, transformed lapses and early presses did increase at discharge, though the authors state that these responses represented a very small proportion of overall responses. Further, the number of lapses here were lower than those seen in community samples of postpartum woman (Insana et al., 2013) suggesting a lasting positive impact on attentional performance.

An issue with much of the current postpartum cognition literature is that it often focuses on mothers, omitting the consideration of the potential impact on fathers. Different sleep patterns have been observed in new mothers compared to new fathers (Gay et al., 2004). It is therefore vital to understand the impact of new parenthood on the fathers' cognition, specifically attention, given their role in the care of an infant. Shared parental leave was introduced in the UK in 2015 (Gov.uk, 2015; Peachey, 2015), and has likely led to an increase in fathers taking a more active role in the early postpartum days. Many UK based companies have seen an increase in fathers taking more than 2 weeks leave, for example Aviva saw 95% of fathers taking more than 2 weeks

and 67% taking six months leave, a year after shared parental leave was offered (Usborne, 2019). Insana and Montgomery-Downs (2013) looked at sustained attention in both mothers and fathers postpartum. They found that whilst both new mothers and new fathers had worse PVT performances compared to their sex matched controls, new mothers PVT performance was worse than new fathers (Insana & Montgomery-Downs, 2013). Therefore the findings of previous new parent attention literature that focuses on mothers may not be applicable to fathers. While both parents experience sleep deprivation (and as such are likely to experience attention impairment), the difference in the nature of the SD experiences may lead to differences in the magnitude of attentional impairment.

Findings from sleep deprivation research and studies of new parents suggest that any alterations to an individual's sleep pattern can result in impaired attention. Modern society contains another large group of individuals who routinely experience another form of sleep disruption – shift workers. Shift workers, whilst having less sleep and worse quality sleep (Harrington, 2001; Monk et al., 2013), generally get a predictable period of time within each 24 hour period in which to sleep. This is unlike the sleep disruption experienced by new parents: shift workers have the additional disruption associated with routine circadian mismatching, such that their only opportunity to sleep in a 24 hour period may be during daylight hours. Unlike many other areas of cognition, attention is fairly well researched within the shift working community, potentially due to concerns about the safety implications of poorly functioning attention in many shift worker occupations e.g. doctors, machine operators, pilots. However there is a high degree of divergence amongst the existing findings.

For example, Wilson et al. (2019b) tested nurses at the beginning, middle and end of a shift on four occasions (Wilson et al., 2019b). This was done to account for potential illness or absence in any one testing day. Each participant worked six 12 hour shifts within a two week period. These were either day shifts or night shifts, with no rotation present in any participant. Whilst daily sleep duration showed no difference between day and night shifts, PVT performance did. Day shift workers showed stable performance across the three time points, however nights shift workers' performance worsened across the shift. This suggests that the circadian mismatching associated with night shift work unmasked an impairment not observed under day shift conditions. The night shift group also showed more performance variability between the testing days and within group at each testing point. This increased variability is likely a result of systematic inter-individual differences in homeostatic and circadian inputs to fatigue (Van Dongen, Bender, & Dinges, 2012).

Similarly Chellappa, Morris and Scheer (2019) found impaired PVT performance during a night shift relative to that seen in a day shift (Chellappa, Morris, & Scheer, 2019). This impairment

appeared to be exacerbated by more than 10 hours of wakefulness. However, it is important to note here that whilst a shift working population were used, the study was conducted in a simulated shift environment (lab-based). These studies suggest that circadian misalignment alone (i.e. working a night shift) has an impact on attention that is not otherwise apparent in day workers. In contrast to these studies are the findings of Geiger-Brown et al. (2012) who found that nurses on a 12 hour night shift did not show any difference in PVT reaction time compared to day shift working colleagues. Night shift nurses also reported higher levels of sleepiness towards the end of the shift. PVT testing was performed at the beginning and end of each 12 hour shift during a work rotation of three or more consecutive 12 hour shifts (either night or days shifts, no rotation) followed by two days off.

All of the aforementioned studies have utilised a PVT to assess sustained attention, and whilst the task is relatively simple to complete, there are multiple variations of PVT design that can be administered to participants. These variations could have an impact upon results and make comparison between studies challenging. For example, as this task measures sustained attention, the degree of distraction present in the assessment environment could have an impact. While this is a factor that can be controlled in individual studies, consistency in the degree of distraction present in the assessment environment cannot necessarily be guaranteed between studies. Another variable to consider is that most studies conduct tests at the beginning and end of a shift. This is subject to fatigue accumulated during the work period and goal driven attention has been shown to be particularly susceptible to this (Boksem, Meijman, & Lorist, 2005). Finally, the group in which sustained attention is tested is often extremely occupationally homogenous. Many studies use nurses or doctors as participants. This is an issue when the findings are generalised to other occupations in which workers do not experience the same levels of stress nor have the same education levels as these groups.

However, to the best of our knowledge, no work has been done to systematically examine the effects of these variables on PVT performance. Further, it is unclear whether any attentional impairments persist after one night of recovery sleep. Given Doran et al.'s (2001) findings of better PVT performance in individuals who were allowed to nap, compared to those in a total sleep deprivation protocol, it suggests the effects on attention may not be chronic. Overall these factors highlight the need to test a range of current shift workers, drawn from a range of occupations, using a standardised PVT.

The neurobiological constructs underpinning attention have been examined closely. Drummond et al. (2005), found that, when individuals were well rested, optimal PVT performance (on the basis of fastest reaction times) involved the typical frontoparietal sustained attention system and a variety of cortical and sub-cortical motor-related structures (Drummond et al., 2005). Following

a period of SD that resulted in impaired PVT performance, correlations with activity in a different range of structures were detected. These included structures associated with the default mode network (consisting of brain regions including the medial frontal, superior frontal, and ventral anterior cingulate gyri) that show more activity when at rest but awake (Glass et al., 2014). However, whilst these data offer predictions as to what may occur in shift workers and new parents experiencing sleep disruption, the findings cannot be directly extrapolated due to the different characteristics of the sleep deprivation experienced in the laboratory compared to that experienced by new parents and shift workers.

Whilst there is clearly a negative relationship between attention and sleep disruption, the precise nature of this relationship calls for further investigation. Whilst some evidence suggests that naturalistic sleep deprivation experienced by new parents results in impaired attention, there is a lack of research on new fathers. The inconsistent findings regarding the impact of shift work on attention suggest that fatigue may play a key role. However, the extent to which fatigue accounts for this pattern is unclear. Further, the occupational specificity of the impairments seen in shift workers remains unexplored, given the occupationally homogenous samples employed in many of the studies, particularly nurses. Finally, the duration of any attentional impairment caused by new parenthood and shift work is unknown; it remains possible that a single period of recovery sleep is sufficient to rescue any such impairment. This chapter aims to provide further insight into these issues.

3.2 Specific aims

1. Evaluate the impact of circadian mismatching on attention with the use of shift workers
2. Evaluate the impact of naturalistic sleep deprivation on attention with the use of new parents
3. Investigate whether previously reported effects of shift work are still detectable after rest, and therefore potentially dissociable from fatigue

3.3 Method

Research presented in this chapter has received ethical approval following review by The Open University's Human Research Ethics Committee (HREC/2016/2444/Breese/2 and HREC/2017/2549/Breese/1) and adheres to all BPS ethics standards (The British Psychological Society, 2018).

A full information sheet and debrief form were provided and each participant was required to provide informed consent before being enrolled. Participants were informed of their right to withdraw at any point prior to data anonymisation and aggregation. Contact details of the research team were provided at the beginning and end of testing, should participants wish to ask any questions. A copy of the information sheet, debrief form and consent form can be found in the Appendix.

3.3.1 Recruitment approach

Data presented in this chapter is an amalgamation of several recruitment drives. Data from the SW1, SW2 and NP cohorts were collected using the online participant platform Prolific (www.prolific.co). The Gorilla Experiment Builder (www.gorilla.sc) was used to create and host all experiments (Anwyl-Irvine et al., 2018). The SW1, SW2 and NP cohorts received financial payment for taking part in the study. Unlike the previous cohorts, the Po sample was not collected through the use of Prolific and therefore could not be paid in the same way. Instead, the Po cohort had the option to be entered into a prize draw.

3.3.2 Participants

Four cohorts of participants were approached in the collection of this data. An in-depth explanation of the differences between sample groups as well as the rationale for each can be found in Chapter Two.

1. Shift worker one (SW1): the PVT task (online) was used to assess shift and non-shift workers.
2. Shift worker two (SW2): following data analysis of SW1, a larger sample of shift workers and non-shift working controls were collected.
3. Police (Po): Due to varied results found in previous cohorts, a more occupationally homogenous cohort of participants working for the police were assessed using the PVT. No night shift workers were collected in this sample.
4. New parents (NP): Parents of a child under one year old were asked to complete the PVT. This task had the same parameters as SW2, and therefore a control group (individuals who were not currently new parents or shift workers) was extracted from the SW2 non-shift working participant sample.

No individuals were permitted to take part in testing more than once, however some data from SW2 was used as a control in NP.

Prior to outlier analysis the sample sizes for each cohort (including controls) were as follows:

- SW1 PVT: 73 participants (5 removed following exclusion criteria)
- SW2 PVT: 120 participants (47 removed following exclusion criteria)
- Po PVT: 46 participants (16 removed following exclusion criteria)
- NP PVT: 136 participants (12 removed following exclusion criteria)

3.3.3 Exclusion criteria

For all cohorts participants were excluded from analysis if any of the following applied: they stated they had had a recent head injury that required medical assistance; were under the age of 18; it was not possible to put them in a shift group due to conflicting/absent/uninterpretable description of their work pattern; they were not on a day off from work or did not fully complete the task.

Specifically relating to task performance, if the participant had more than one instance of a string of early presses (2 or more in one trial) they were excluded as this suggested the participant was no longer meaningfully engaging with the task.

3.3.4 Design

As explained in Chapter Two, SW1, SW2 and NP participants were recruited through Prolific and tested using Gorilla Experiment Builder. Po were recruited through the Open University Centre for Policing Research and Learning and tested using Gorilla Experiment Builder. Participants were tested once, for the SW1, SW2 and Po participants they were asked to complete on a day off from work, for NP cohort participants were asked to complete the study after they had woken up in the morning. This was to reduce any direct impacts of work-related fatigue or acute tiredness on cognition.

3.3.5 Testing procedure

Once participants had read the information sheet and given informed consent, each individual received the full questionnaire battery to complete (outlined in Chapter Two). Following this, SW1, SW2 and NP participants completed a PVT and a TMT (Chapter Six). For SW2 and NP this was given in a randomised order, however SW1 received the PVT task first. The randomisation of task order was introduced following SW1 in order to counter any effect of order. Po received only a PVT task.

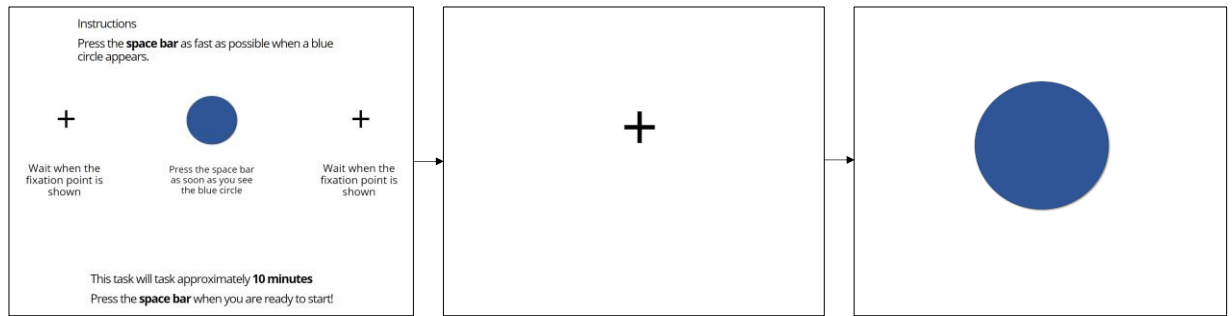


Figure 8 Screen presentation sequences of PVT for all testing groups

The PVT task requires participants to press the space bar when the stimulus is shown (blue circle) (Figure 8). The duration of fixation point display for each trial was selected at random from a list of values ranging between 100 – 10,000 ms and participants had 10,000 ms to respond before the next trial began. In total there were 100 trials and the task took approximately 10 minutes to complete. Initial task design was based on Basner and Dinges (2011) but modifications were made based on preliminary evaluation of the task. These modifications involved using different stimuli and a more varied inter trial stimulus presentation duration (100ms longer).

Basner and Dinges (2011) state that what differentiates the PVT from a simple reaction time task is the sampling of multiple responses to stimuli that appear with random inter trial stimulus lengths, over a period of time. In contrast, a simple reaction time task contains only a few trials. It is these characteristics of the task that challenge vigilance, a key element of the PVT. Whilst these key features are present in the task used in the present study, one element that does differ from that suggested by Basner and Dinges is the lack of reaction time feedback following each trial (although it should be noted that participants were instructed to respond as fast as possible). This may have impacted results in that the task did not give any incentive to the participant to ‘beat’ their previous reaction time. There is evidence to suggest that a lack of feedback during a computerised reaction time task leads to a reduction of motivation (Eckner, Chandran, & Richardson, 2011). Whilst the computerised reaction time task used in Eckner et al., consisted of fewer trials (40) than the task used in the present study, it still contained the key characteristics of a PVT. Therefore, it is possible that the lack of feedback in the present study led to demotivation in the participants, which could have been reflected in longer reaction times and more early presses. Indeed, when compared to the mean reaction times of feedback (301ms) vs no feedback (327ms) seen in Eckner et al (2011), the median reaction times found in the SW1, SW2, NP and Po cohorts were higher (between 350m and 400ms). This difference may indicate a lack of motivation.

As described above, the cohorts described here who took part in the PVT were subject to outlier removal and task performance review. Any participant who had more than one instance of a string of early presses was excluded. Whilst there were other exclusion criteria based on

questionnaire data 80 participants were removed across all four cohorts, approximately 17.5% of participants. This may be evidence of disengagement, though without separating the precise reasons for exclusion it remains unclear whether a lack of feedback did lead to more early presses in the reported cohorts.

3.3.6 Output variables

The variables extracted for analysis are summarised below and are based on those previously used by Basner and Dinges (2011) in a study of current and former shift workers (Basner & Dinges, 2011).

1. Median reaction time: A reaction time was considered valid if it was over 100ms. Any trial reaction times under this threshold value were removed from all analysis.
2. Number of lapses: the number trials in which a reaction time of over 500ms was recorded
3. Number of early starts: the number of trials where a response was recorded whilst the fixation point was being shown, this included any trials where a reaction time of less than 100ms was recorded. For trials where multiple early presses were recorded this was counted as one.
4. Binned reaction time: separated into four bins of 25 trials each, average reaction time was calculated for each group to determine any task related fatigue effects. Responses under 100ms were removed.

3.3.7 Statistical analysis

Data was downloaded from Gorilla and prepared for statistical analysis using Microsoft Excel 2013 (Microsoft, 2013). Descriptive statistics (mean, standard deviation and range) were generated for demographic data, including age, sex, years working shifts and sleep disorder frequency using GraphPad Prism (version 8.2.1) (GraphPad Software, La Jolla California USA, n.d.) and StatsCloud (www.statscloud.app) and are outlined in Chapter Two.

Cognitive assessment data were analysed using frequentist statistics with JASP (www.jasp-stats.org, version 0.11.1) and GraphPad Prism (version 8.2.1). Data was first screened for normality using the D'Agostino and Pearson test. Outliers were identified with box plots and points identified as being outside the whiskers (set to 1.5 x interquartile range above/below the 75th/25th percentile) were removed. If data were normally distributed parametric tests were used (ANOVA and t-test), if normality was not achieved non-parametric tests were employed (Kruskal-Wallis, Mann-Whitney, Wilcoxon). To address multiple comparisons, Tukey post hoc analyses were performed as appropriate. Significance was given by a p-value of less than 0.05.

Bayesian analysis was conducted using JASP and conclusions based on the thresholds found in Van Doorn et al (2019). These can be found in Table 22.

Table 22 Bayesian thresholds

BF10	Evidence	In favour of
>100	Decisive	Alternative hypothesis
30 to 100	Very strong	Alternative hypothesis
10 to 30	Strong	Alternative hypothesis
3 to 10	Moderate	Alternative hypothesis
1 to 3	Anecdotal	Alternative hypothesis
1	No evidence	Neither
1 to 0.33	Anecdotal	Null hypothesis
0.33 to 0.1	Moderate	Null hypothesis
0.1 to 0.033	Strong	Null hypothesis
0.033 to 0.01	Very strong	Null hypothesis
<0.01	Decisive	Null hypothesis

3.4 Results

For the SW2 and NP cohorts, in order to control for any potential order effect the design contains sub-groups A and B (see Figures 2 and 5 in Chapter Two). Where possible the two testing order conditions were merged, in order to maximise power. All testing groups in all samples were able to be merged.

3.4.1 Median reaction time showed no evidence of group dependant differences

Median reaction time was calculated after the removal of any trials in which a reaction time of less than 100ms was recorded. There was no main effect of group on median reaction time in the SW1 cohort ($F(2,63)=0.792$, $p=0.457$, $\eta^2=0.02$) (Figure 9a), the SW2 cohort ($H(2)=0.746$, $p=0.689$, $\eta_H=0.01$) (Figure 9b), the Po cohort ($t(43)=0.957$, $p=0.344$, $\eta^2=0.02$) (Figure 9c), or the NP cohort ($H(3)=2.847$, $p=0.416$, $\eta_H=0.00$) (Figure 9d). This analysis was also run using Bayesian statistics to explore the degree of support within the data for the null or alternative hypothesis. The null hypothesis proposed there is an absence of an effect of group in median reaction time. The alternative hypothesis proposed that there is an effect of group on median reaction time. The thresholds used to determine the level of support for a hypothesis can be found in Van Doorn et al., (2019) and are described above in Section 3.3.7.

There was moderate evidence for the null hypothesis in the SW1 cohort ($BF_{10}=0.26$), the SW2 cohort ($BF_{10}=0.24$), and the NP cohort ($BF_{10}=0.18$). There was anecdotal evidence for the null hypothesis in the Po cohort ($BF_{10}=0.43$).

The sample size of each cohort and number of participants removed following outlier analysis is detailed in Table 23.

Table 23 Sample sizes for PVT median RT

Cohort	Groups	n	Removed through outlier analysis
SW1	Night	8	1
	Rotating	33	4
	Day	25	2
SW2	Night	23	1
	Rotating	48	2
	Day	45	1
Po	Rotating	25	0
	Day	20	1
NP	NP male	25	1
	NP female	64	2
	C male	29	0
	C female	15	0

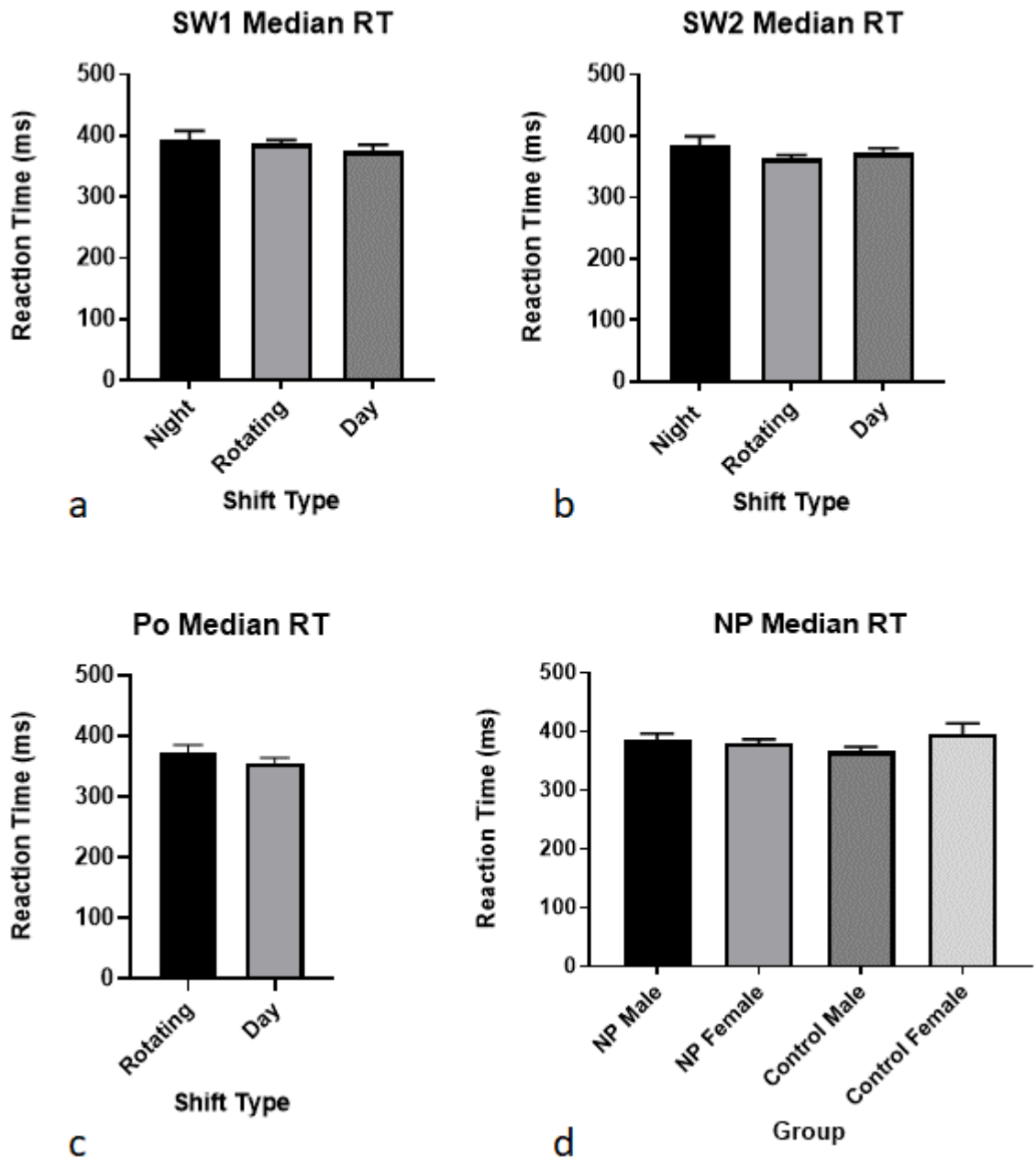


Figure 9 PVT median RT a) SW1 cohort b) SW2 cohort c) Po cohort d) NP cohort. Error bars indicate SEM.

Based on BSWSQ analysis revealing no impact of shift type on BSWSQ work category score, and therefore no differences in sleep issues in these shift groups, the samples were regrouped on the basis of high or low BSWSQ scores. As there is no precedent in the literature that defines the exact thresholds of a ‘high’ or ‘low’ BSWSQ score these were calculated on an individual basis using a median split. If participants had scored the median number they were included in the group that had the least number of participants, in order to even out group sizes. This is supported by DeCoster et al (2011) who examined the best practises when using median splits (DeCoster, Gallucci, & Iselin, 2011). Median RT analysis was then run again. Table 24 details the statistical analysis for each BSWSQ score and sample. Where data did not pass a normality test it

was transformed. The transformation applied is indicated in the table. Where data could not be made normal, nonparametric analysis was used.

Table 24 PVT median RT BSWSQ score grouping

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	H(3)=2.70, p=0.44, $\eta_H=0.01$	F(3,37)=1.98, p=0.13, $\eta^2=0.14$ (Log transformed)	U=190, p=0.66, r=0.07	H(3)=9.04, p=0.03*, $\eta_H=0.10$ High Bergen shift group (407.4 ± 55.09) vs High Bergen control group (362.0 ± 70.59, p=0.03)
SW2	F(3,79)=1.67, p=0.18, $\eta^2=0.06$ (1/ Transformed)	t(40)=0.08, p=0.94, $\eta^2=0.0001$	t(64)=0.32, p=0.75, $\eta^2=0.002$ (1/Transformed)	H(3)=2.43, p=0.49, $\eta_H=0.01$
Po	H(3)=0.84, p=0.84, $\eta_H=0.06$	F(3,29)=0.52, p=0.67, $\eta^2=0.05$	t(19)=0.48, p=0.64, $\eta^2=0.01$	H(3)=0.42, p=0.94, $\eta_H=0.07$

A main effect group was seen in the SW1 cohort in the Rest BSWSQ score, with High Bergen shift group being significantly slower than High Bergen control group. No other main effects of shift were seen.

Further, correlation analysis was run between BSWSQ score and median reaction times. No significant effects were found. Table 25 details the statistical analysis for each BSWSQ score and sample.

Table 25 PVT median RT correlations

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	$r_s(58)=-0.05$, p=0.69, observed power=0.12	$r_s(39)=0.26$, p=0.10, observed power=0.08	$r_s(39)=-0.07$, p=0.69, observed power=0.03	$r_s(61)=0.09$, p=0.50, observed power=0.11
SW2	$r_s(81)=-0.1$, p=0.36, observed power=0.12	$r(40)=0.04$, p=0.82, observed power=0.04	$r_s(64)=0.04$, p=0.74, observed power=0.17	$r_s(101)=-0.03$, p=0.77, observed power=0.05
Po	$r_s(38)=-0.12$, p=0.46, observed power=0.06	$r_s(31)=-0.06$, p=0.74, observed power=0.03	$r_s(19)=-0.01$, p=1.00, observed power=0.041.	$r_s(38)=-0.02$, p=0.90, observed power=0.04

In order to further explore the impact of demographic variables on this sample, ANCOVAs were run using the BSWSQ rest score groupings. Any demographic variable that had shown a significant

difference was included in the analysis. No significant differences were found in any of the Po demographic variables therefore ANCOVAs were not run on that sample.

In the SW1 cohort the covariate, age, was not significantly related to median RT ($F(1,58)=0.007$, $p=0.93$, $\eta^2<0.001$). There was also no effect of BSWSQ group on median RT after controlling for age ($F(3,58)=0.95$, $p=0.43$, $\eta^2=0.05$). The covariate ‘years worked shifts’ was not significantly related to median RT ($F(1,58)=1.92$, $p=0.17$, $\eta^2=0.03$). There was also no effect of BSWSQ group on median RT after controlling for years worked shifts ($F(3,58)=0.83$, $p=0.49$, $\eta^2=0.04$).

In the SW2 cohort none of the demographics tested significantly related to median RT. Further there was no effect of group on median RT when demographic variables were controlled for. ANCOVA statistics can be found in Table 26.

Table 26 PVT median RT x demographic variable ANCOVAs

Demographic variable	Main effect	Effect of group when demographic controlled for
Sex	$F(1,98)=1.02$, $p=0.31$, $\eta^2=0.01$	$F(3,98)=0.72$, $p=0.55$, $\eta^2=0.02$
Country	$F(1,98)=0.14$, $p=0.71$, $\eta^2=0.001$	$F(3, 98)=0.93$, $p=0.43$, $\eta^2=0.03$
Activity level	$F(1,98)=0.37$, $p=0.55$, $\eta^2=0.004$	$F(3,98)=0.99$, $p=0.40$, $\eta^2=0.03$
Sleep time	$F(1, 96)=1.64$, $p=0.20$, $\eta^2=0.02$	$F(3,96)=0.50$, $p=0.68$, $\eta^2=0.02$
Time awake	$F(1,95)=1.25$, $p=0.27$, $\eta^2=0.01$	$F(3,95)=0.44$, $p=0.73$, $\eta^2=0.01$

3.4.2 Number of lapses indicated no differences in attention failure

In the PVT, the variable ‘number of lapses’ can be used as a proxy measure of attentional failure. Analysis of lapses showed no main effect of group in the SW1 cohort ($H(2)=3.73$, $p=0.16$, $\eta_H=0.03$) (Figure 10a), the SW2 cohort ($H(2)=0.03$, $p=0.98$, $\eta_H=0.02$) (Figure 10b), the Po cohort ($t(38)=1.72$, $p=0.09$, $\eta^2=0.07$) (Figure 10c) or the NP cohort ($H(3)=3.75$, $p=0.29$, $\eta_H=0.01$) (Figure 10d).

Bayesian statistics showed there was anecdotal evidence for the null hypothesis in the SW1 cohort ($BF_{10}=0.38$), the NP cohort ($BF_{10}=0.55$) and the Po cohort ($BF_{10}=0.98$). There was moderate evidence for the null hypothesis in the SW2 cohort ($BF_{10}=0.17$). The null hypothesis proposed there is an absence of an effect of group on number of lapses.

The sample size of each cohort and number of participants removed following outlier analysis is detailed in Table 27.

Table 27 Sample sizes of PVT Lapses

Cohort	Groups	n	Removed through outlier analysis
SW1	Night	8	1
	Rotating	34	3
	Day	25	2
SW2	Night	23	1
	Rotating	47	3
	Day	43	3
Po	Rotating	22	3
	Day	18	3
NP	NP male	25	1
	NP female	62	4
	C male	28	1
	C female	15	0

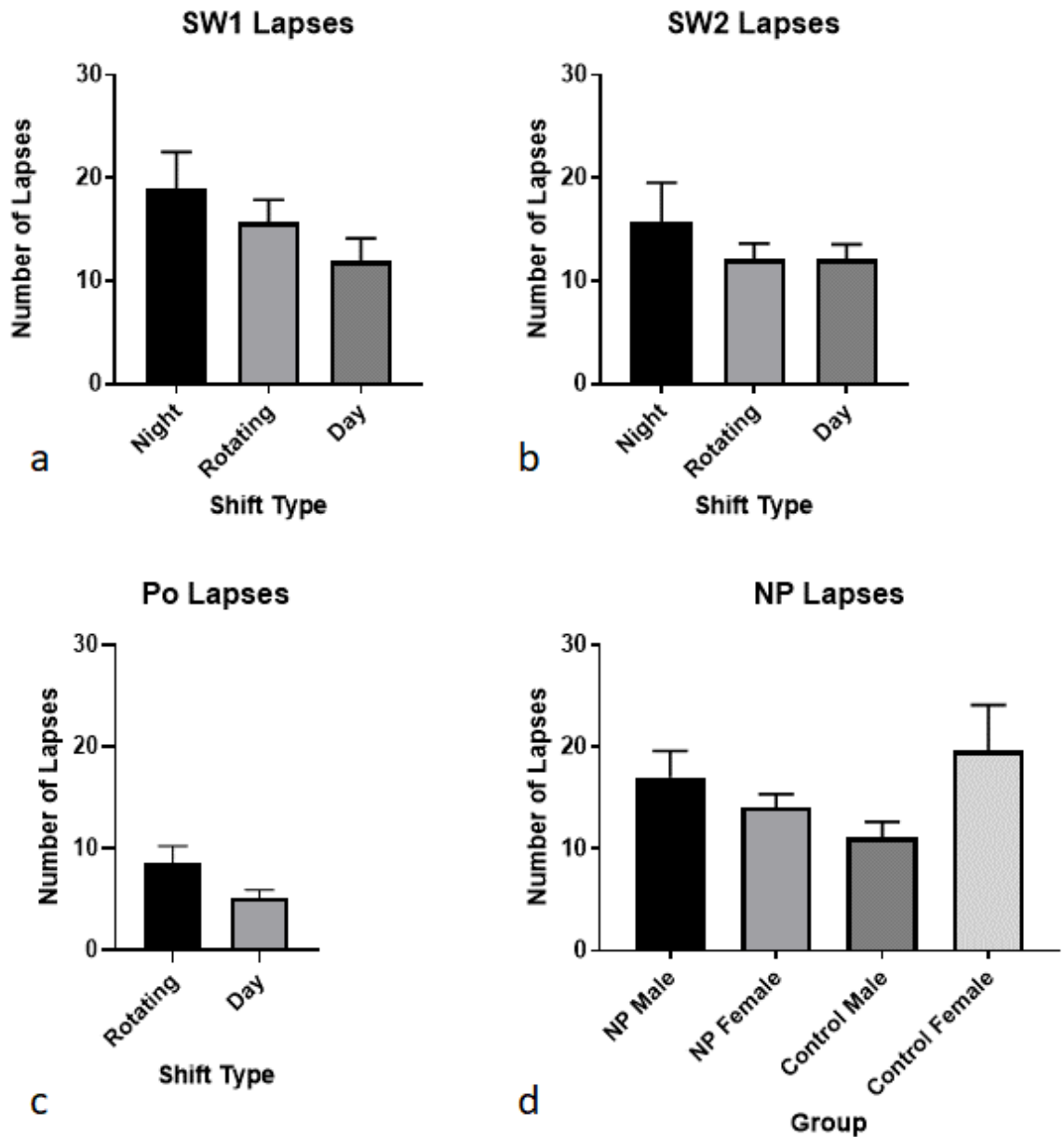


Figure 10 PVT Number of lapses a) SW1 cohort b) SW2 cohort c) Po cohort d) NP cohort. Error bars indicate SEM.

As with the previous variable, analysis was run again with shift groups split by BSWSQ score. Table 28 details the statistical analysis for each BSWSQ score and sample. Where data did not pass a normality test it was transformed. The transformation applied is indicated in the table. Where data could not be made normal, nonparametric analysis was used. A significant difference was seen in the SW1 Rest analysis, with High Bergen control group producing significantly fewer lapses than both High and Low Bergen shift groups. No other analyses showed significant differences.

Table 28 PVT Number of lapses BSWSQ score grouping

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	F(3,56)=0.73, p=0.54, $\eta^2=0.04$ (SQRT Transformed)	F(3,37)=2.24, p=0.099, $\eta^2=0.15$ (SQRT transformed)	U=205, p=0.96, r=0.01	H(3)=8.02, p=0.046*, $\eta_H=0.09$, Low Bergen Shift group (21.23 ± 22.40) vs High Bergen control group (10.18 ± 20.45 , p=0.02) High Bergen shift (19.82 ± 15.56) vs High Bergen control group (10.18 ± 20.45 , p=0.01)
SW2	F(3,79)=1.08, p=0.36, $\eta^2=0.04$ (SQRT Transformed)	t(40)=0.15, p=0.89, $\eta^2=0.0005$	t(64)=0.73, p=0.47, $\eta^2=0.008$ (SQRT transformed)	F(3,99)=0.99, p=0.40, $\eta^2=0.03$ (SQRT transformed)
Po	H(3)=2.01, p=0.57, $\eta_H=0.03$	F(3,29)=0.80, p=0.50, $\eta^2=0.08$ (SQRT Transformed)	t(19)=0.71, p=0.49, $\eta^2=0.03$ (SQRT Transformed)	H(3)=1.51, p=0.68, $\eta_H=0.04$

A main effect of group was seen in the SW1 cohort in the Rest BSWSQ score, with Low Bergen shift group and High Bergen shift group having significantly more lapses than the High Bergen Control group. No other main effects of shift were seen.

Further correlation analyses were run between BSWSQ score and number of lapses. No significant correlation between BSWSQ score and number of lapses was found. Table 29 details the statistical analysis for each BSWSQ score and sample.

Table 29 PVT Number of lapses correlations

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	$r_s(58)=0.20$, p=0.12, observed power=0.32	$r_s(39)=0.17$, p=0.28, observed power=0.04	$r_s(39)=-0.01$, p=0.97, observed power=0.05	$r_s(61)=0.02$, p=0.87 Observed power=0.07
SW2	$r_s(81)=0.02$, p=0.83, observed power=0.1	$r_s(40)=-0.12$, p=0.46, observed power=0.11	$r_s(64)=0.22$, p=0.07, observed power=0.58	$r_s(101)=0.08$, p=0.40, observed power=0.13
Po	$r_s(38)=-0.02$, p=0.88, observed power=0.04	$r_s(31)=0.03$, p=0.88, observed power=0.04	$r_s(19)=0.24$, p=0.29, observed power=0.13	$r_s(38)=0.05$, p=0.74, observed power=0.08

As with the previous variable, ANCOVAs were run using the BSWSQ rest score groupings. In the SW1 cohort the covariate, age, was not significantly related to Lapses ($F(1,58)=0.16$, $p=0.69$, $\eta^2=0.003$). There was also no effect of BSWSQ group on Lapses after controlling for age ($F(3,58)=0.89$, $p=0.45$, $\eta=0.04$). The covariate ‘years worked shifts’ was not significantly related to Lapses ($F(1,58)=1.39$, $p=0.24$, $\eta^2=0.02$). There was also no effect of BSWSQ group on Lapses after controlling for years worked shifts ($F(3,58)=0.81$, $p=0.49$, $\eta^2=0.04$).

In the SW2 cohort none of the demographics tested significantly related to number of lapses. Further there was no effect of group on number of lapses when demographic variables were controlled for. ANCOVA statistics can be found in Table 30.

Table 30 PVT Number of lapses x demographic variable ANCOVAs

Demographic variable	Main effect	Effect of group when demographic controlled for
Sex	$F(1,98)=1.80$, $p=0.18$, $\eta^2=0.02$	$F(3,98)=0.74$, $p=0.53$, $\eta^2=0.02$
Country	$F(1,98)=0.42$, $p=0.52$, $\eta^2=0.004$	$F(3,98)=1.11$, $p=0.35$, $\eta^2=0.03$
Activity level	$F(1,98)=0.11$, $p=0.74$, $\eta^2=0.001$	$F(3,98)=1.12$, $p=0.35$, $\eta^2=0.03$
Sleep time	$F(1,96)=1.74$, $p=0.19$, $\eta^2=0.02$	$F(3,96)=1.16$, $p=0.33$, $\eta^2=0.03$
Time awake	$F(1,95)=0.61$, $p=0.44$, $\eta^2=0.01$	$F(3,95)=1.14$, $p=0.34$, $\eta^2=0.03$

3.4.3 Number of early starts indicated differing impulsivity within cohorts

The variable ‘early starts’ provides a proxy measure of impulsivity. Analysis of early starts revealed no main effect of group in the SW1 cohort ($H(2)=4.127$, $p=0.127$, $\eta_H=0.03$) (Figure 11a). A main effect of group was seen in the SW2 cohort ($H(2)=11.67$, $p=0.0029$, $\eta_H=0.09$) (Figure 11b) with night shift workers (0.773 ± 0.813) being significantly less impulsive than rotating (1.756 ± 1.598) and day shift workers (2.295 ± 1.924). The Po cohort showed no significant differences ($U=207$, $p=0.278$, $r=0.16$) (Figure 11c). Finally the NP cohort showed a main effect of group ($H(3)=15.25$, $p=0.0016$, $\eta_H=0.10$) (Figure 11d) with NP males (0.917 ± 0.881) being significantly less impulsive than NP females (2.219 ± 1.713), Control males (2.214 ± 1.833) and Control females (3.067 ± 2.658).

Bayesian statistics showed there was anecdotal evidence for the null hypothesis in the SW1 cohort ($BF_{10}=0.64$) and the Po cohort ($BF_{10}=0.83$). The null hypothesis proposed there is an absence of an effect of group in number of early starts. There was strong evidence for the alternative hypothesis in the SW2 cohort ($BF_{10}=13.39$) and the NP cohort ($BF_{10}=13.54$). The alternative hypothesis states there is an effect of group in number of early starts.

The sample size of each cohort and number of participants removed following outlier analysis is detailed in Table 31.

Table 31 Sample sizes of PVT Early starts

Cohort	Groups	n	Removed through outlier analysis
SW1	Night	8	1
	Rotating	32	5
	Day	26	1
SW2	Night	22	2
	Rotating	45	5
	Day	44	2
Po	Rotating	24	1
	Day	21	0
NP	NP male	24	2
	NP female	64	2
	C male	28	1
	C female	15	0

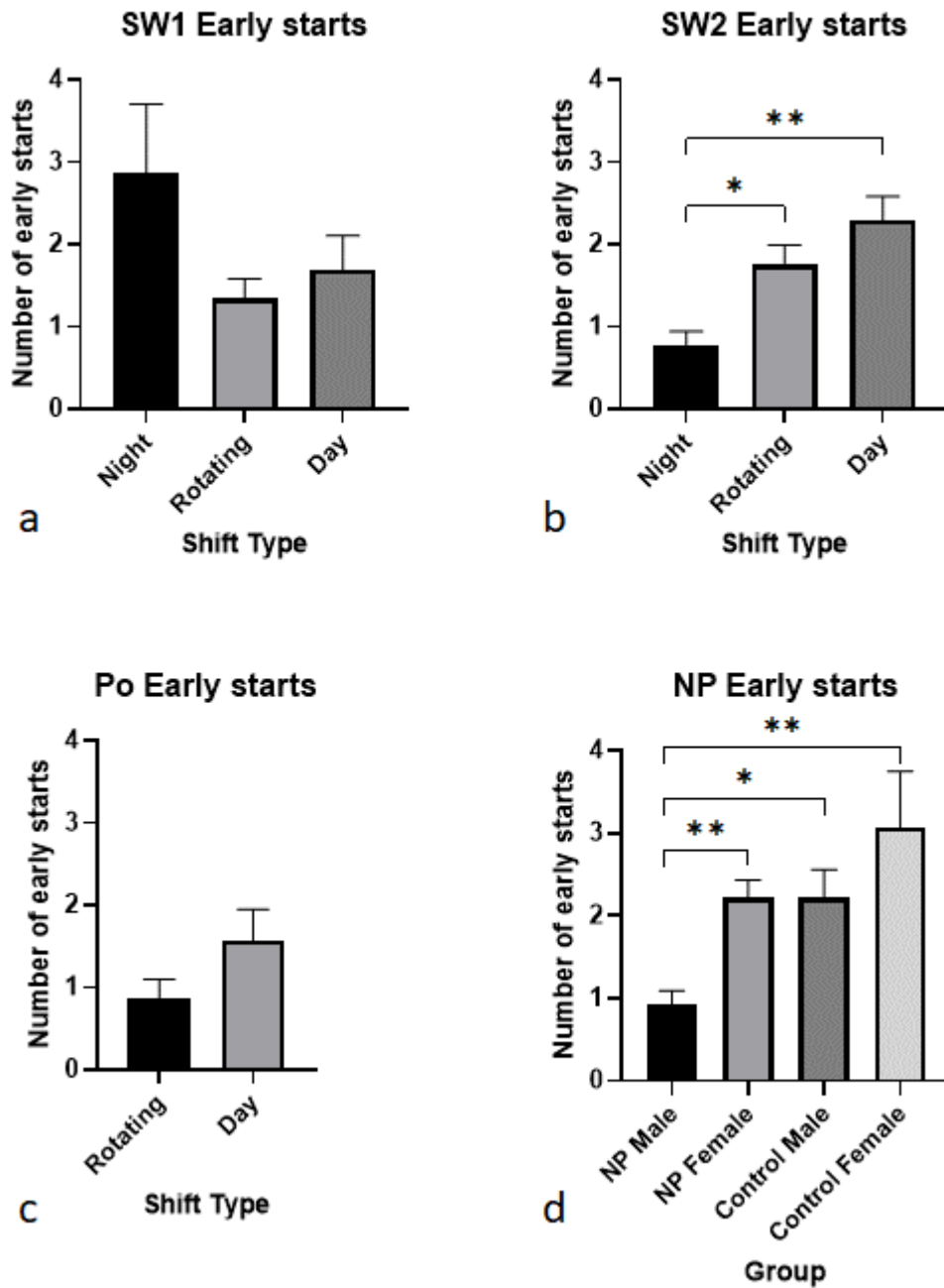


Figure 11 PVT Number of early starts a) SW1 cohort b) SW2 cohort c) Po cohort d) NP cohort * refers to a p value <0.05 , ** refers to a p value of <0.01 . Error bars indicate SEM.

As with previous variables, analysis was run again with shift groups split by BSWSQ score. Table 32 details the statistical analysis for each BSWSQ score and sample. Where data did not pass a normality test it was transformed. The transformation applied is indicated in the table. Where data could not be made normal, nonparametric analysis was used.

Table 32 PVT Number of early starts BSWSQ score grouping

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	F(3,56)=1.26, p=0.297, $\eta^2=0.06$ (SQRT Transformed)	H(3)=8.62, p=0.03*, $\eta_H=0.15$ High Bergen shift group (3.2 \pm 2.35) vs Low Bergen control group (2.67 \pm 2.81) p=0.04	T(38)=0.15, p=0.88, $\eta^2=0.001$ (SQRT transformed)	F(3,59)=0.52, p=0.67, $\eta^2=0.03$ (SQRT Transformed)
SW2	F(3,79)=4.05, p=0.0099**, $\eta^2=0.13$ Low Bergen control group (0.87 \pm 0.66) vs High Bergen control group (1.78 \pm 0.94) p=0.01 (SQRT Transformed)	t(40)=1.27, p=0.21, $\eta^2=0.04$ (SQRT Transformed)	t(64)=1.77, p=0.08, $\eta^2=0.05$ (SQRT Transformed)	F(3,99)=1.95, p=0.13, $\eta^2=0.06$ (SQRT Transformed)
Po	F(3,36)=0.79, p=0.51, $\eta^2=0.06$ (SQRT Transformed)	F(3,29)=0.58, p=0.63, $\eta^2=0.06$ (SQRT Transformed)	t(19)=1.14, p=0.27, $\eta^2=0.06$ (SQRT Transformed)	H(3)=8.41, p=0.04*, $\eta_H=0.15$ No further interactions

A main effect of group was seen in the SW1 cohort in the Evening BSWSQ score, with High Bergen shift group having significantly more early starts than Low Bergen control group. A main effect of group was found in the SW2 cohort in the Day BSWSQ score, with Low Bergen control group having significantly less early starts than the High Bergen control group. A main effect of group was also found in the Po cohort in the Rest BSWSQ score, however no further interactions were found. No other main effects of group were seen.

Further correlation analyses was run between BSWSQ score and number of early starts. Table 33 details the statistical analysis for each BSWSQ score and sample.

Table 33 PVT Number of early starts correlations

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	$r_s(58)=0.04$, $p=0.75$, observed power=0.18	$r_s(39)=0.55$, $p<0.001^{***}$, observed power=0.98	$r_s(39)=<0.01$, $p=0.98$, observed power=0.06	$r_s(61)=0.04$, $p=0.78$, observed power=0.27
SW2	$r_s(81)=0.1$, $p=0.37$, observed power=0.41	$r_s(40)=-0.10$, $p=0.55$, observed power=0.21	$r_s(64)=0.13$, $p=0.29$, observed power=0.17	$r_s(101)=0.12$, $p=0.21$, observed power=0.61
Po	$P(38)=-0.37$, $p=0.02^*$, observed power=0.63	$P(31)=-0.55$, $p<0.001^{***}$, observed power=0.94	$P(19)=-0.15$, $p=0.50$, observed power=0.08	$P(38)=-0.23$, $p=0.16$, observed power=0.36

A significant positive correlation was found between BSWSQ score and number of early starts in the SW1 cohort in the Evening BSWSQ score, and in the Po cohort in the Evening BSWSQ score. No other significant correlations were seen.

As with the previous variable, ANCOVAs were run using the BSWSQ rest score groupings. In the SW1 cohort the covariate, age, was not significantly related to early starts ($F(1,58)=0.49$, $p=0.49$, $\eta^2=0.008$). There was also no effect of BSWSQ group on early starts after controlling for age ($F(3,58)=0.26$, $p=0.85$, $\eta^2=0.01$). The covariate ‘years worked shifts’ was not significantly related to early starts ($F(1,58)=0.33$, $p=0.57$, $\eta^2=0.006$). There was also no effect of BSWSQ group on Lapses after controlling for years worked shifts ($F(3,58)=0.024$, $p=0.87$, $\eta^2=0.012$).

In the SW2 cohort none of the demographics tested significantly related to number of early starts. Further there was no effect of group on number of early starts when demographic variables were controlled for. ANCOVA statistics can be found in Table 34.

Table 34 PVT Number of early starts x demographic variable ANCOVAs

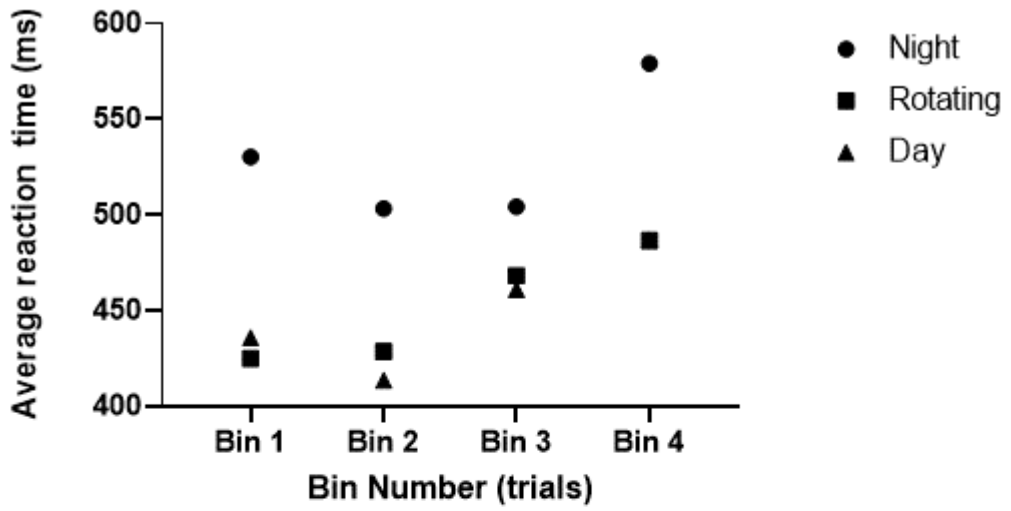
Demographic variable	Main effect	Effect of group when demographic controlled for
Sex	$F(1,98)=1.51$, $p=0.22$, $\eta^2=0.01$	$F(3,98)=1.58$, $p=0.20$, $\eta^2=0.05$
Country	$F(1,98)=0.90$, $p=0.35$, $\eta^2=0.01$	$F(3,98)=1.57$, $p=0.20$, $\eta^2=0.05$
Activity level	$F(1,98)=1.48$, $p=0.23$, $\eta^2=0.01$	$F(3,98)=2.10$, $p=0.11$, $\eta^2=0.06$
Sleep time	$F(1,96)=1.44$, $p=0.23$, $\eta^2=0.01$	$F(3,96)=1.60$, $p=0.20$, $\eta^2=0.05$
Time awake	$F(1,95)=0.001$, $p=0.97$, $\eta^2=<0.001$	$F(3,95)=1.69$, $p=0.18$, $\eta^2=0.05$

3.4.4 Within session performance analysis indicated attentional decrements over time. Reaction times across the task were separated into four bins of 25 trials each to provide a degree of insight into session performance as time on task increased. Average reaction time for each bin was calculated for each group to determine any task related fatigue effects.

The SW1 cohort showed a decrease in reaction times towards the middle of the task, possibly indicating participants had an increased task familiarity. There was then an increase in reaction times for all three groups, suggesting task related fatigue. This was more pronounced in night shift workers (Figure 12a).

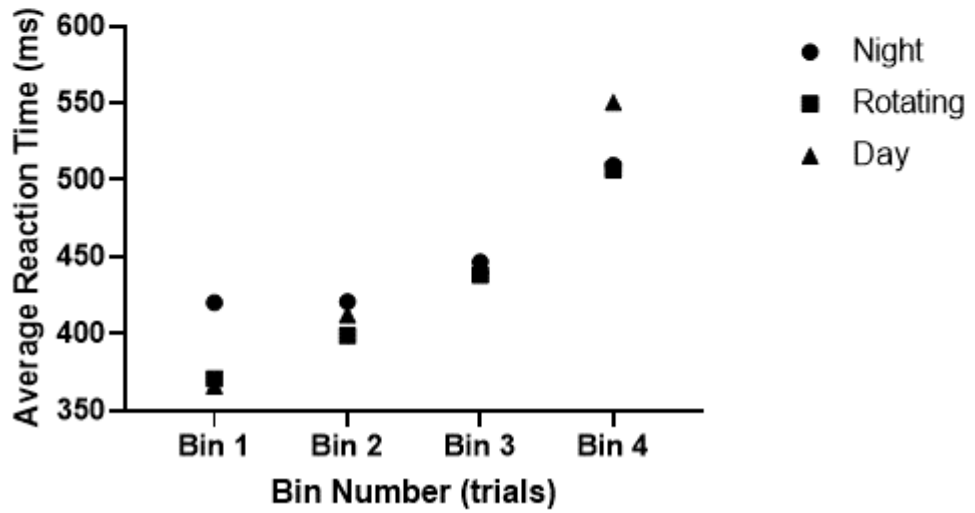
The SW2 cohort also showed an increase in reaction time towards the end of the task (Figure 12b). The Po cohort participants showed a flatter curve than the SW1 cohort however again the increase in reaction times towards the end of the task remained (Figure 12c). The NP cohort reactions times followed a similar pattern to the SW2 cohort (Figure 12d).

SW1 Binned RT



a

SW2 Binned RT



b

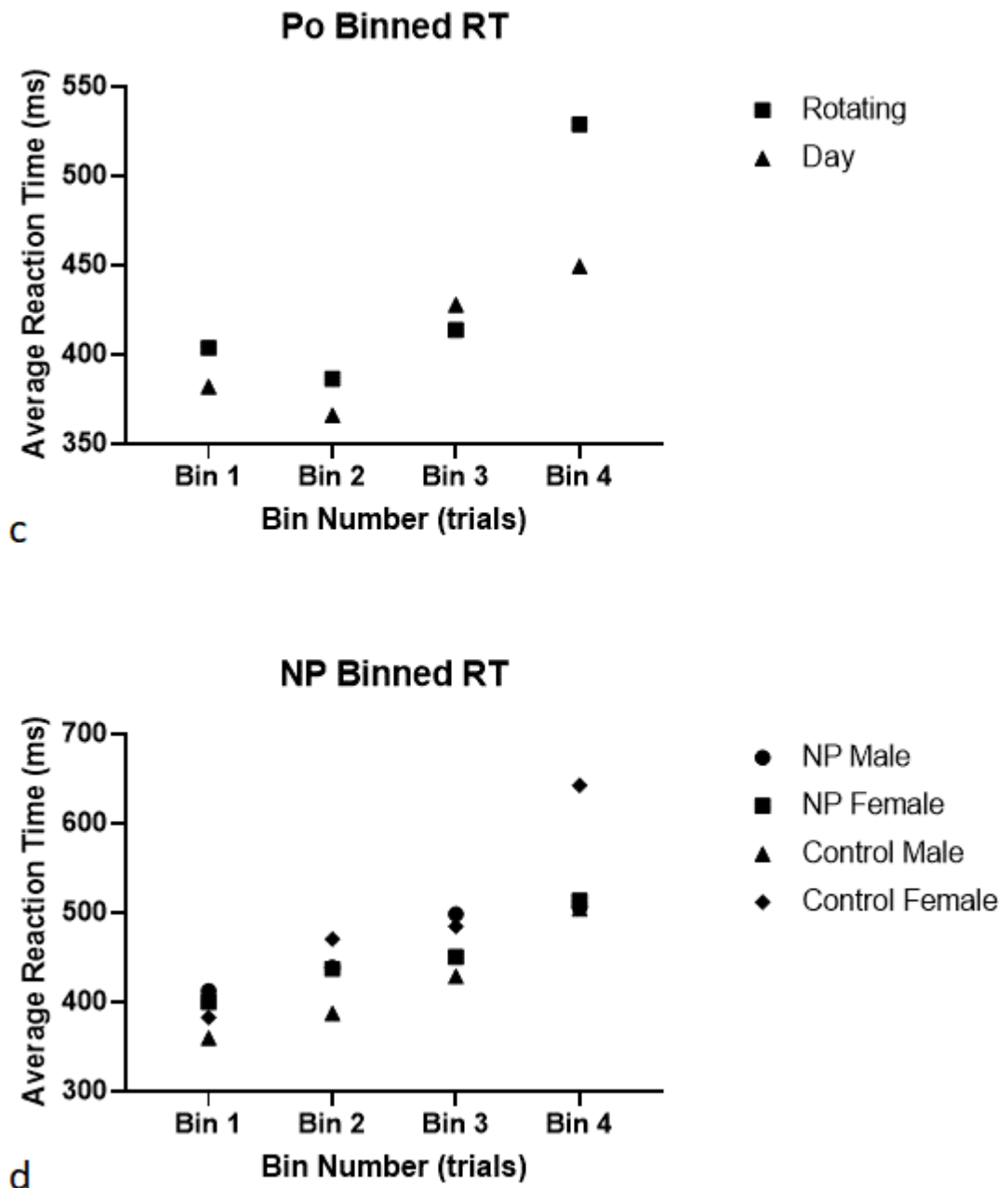


Figure 12 PVT Binned RT a) SW1 cohort b) SW2 cohort c) Po cohort d) NP cohort

3.4.5 Sensitivity measures

Due to the online nature of this task and lack of significant differences in the majority of variables/samples it was important to examine task sensitivity. Increases in reaction time across task indicated task fatigue. This is a pattern of responding that would be expected from a sensitive PVT. However it was also important to establish if the task used in the presented studies was impacted by confounds such as age in the way shown in the current literature.

Indeed, reaction time has been shown to be susceptible to age, with performance decline shown to start as early as the thirties (Blatter et al., 2006; Parasuraman, Nestor, & Greenwood, 1989; Wilkinson & Allison, 1989).

Therefore correlation analysis was conducted on the SW2 population, using median reaction times, to examine the impact of age. This cohort was used as, due to the size of the SW1 and Po cohorts, it is likely they would not produce meaningful results due to a lack of power. Due to the recruitment specifications of the NP cohort, the age range is more restricted and so again was unlikely to provide meaningful analysis. As no significant differences between the three groups (night, rotating and day) were found on this variable, all three groups were collapsed. There was no significant relationship found between age and median RT ($r_s(118)=0.18$, $p=0.051$, observed power=0.24). In contrast to the time on task variable, this suggests that the PVT used in these samples was lacking in the sensitivity needed to examine age effects on attention. However it is important to note that this sample contained an outlier (a reaction time of over 600ms), which when that participant was removed, revealed a significant relationship between age and median RT ($r_s(117)=0.19$, $p=0.03$, observed power=0.40)(Figure 13). As detailed above, this sample was collected using online methods and is therefore more susceptible to distractions and lack of focus. In order to combat this outlier analysis has been employed to remove extreme values that may not be a true representation of the sample.

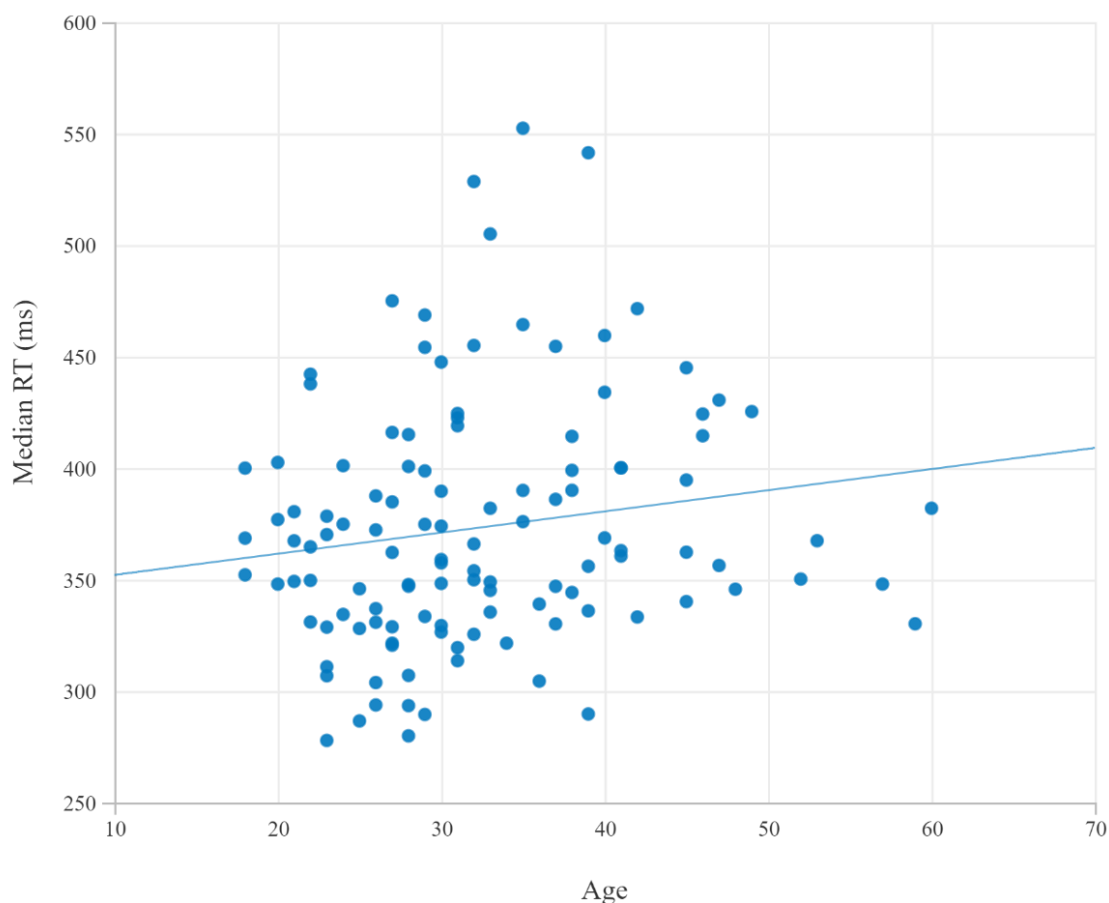


Figure 13 SW2 correlation between age and PVT median RT

Comparisons between the data presented here and that in the literature is more difficult in this task given the differences in the task design (lack of feedback described in Section 3.3.6). However in order to explore the sensitivity of the task used, further comparisons were made between the

day workers in SW1, SW2 and NP and control participants in the sleep disruption literature. median RT and number of lapses were extracted from each of the control cohorts presented here and compared with those from Drummond et al (2005) who also used a 10 minute PVT. Reaction times in the SW1, SW2 and NP cohorts were slower than those reported for the control participants in Drummond et al. Similarly, more lapses were found in the online version of the task compared to that used in Drummond et al. There was also more variation in the online version of the task in both lapses and reaction time, as evidenced by the larger standard deviations.

Outputs are detailed in Table 35.

Table 35 PVT comparisons

Cohort	Average median RT (SD)	Mean number of lapses (SD)
SW1	375.0 (49.17)	11.92 (11.09)
SW2	373.1 (50.00)	12.09 (9.63)
NP	376.40 (52.18)	14.09 (12.63)
Drummond	269 (33)	1.55 (2.62)

Taken together this comparison suggests that there is evidence of differential sensitivity between the cohorts presented here and the control sample in Drummond et al. This may be due to the task differences discussed previously, namely a lack of feedback leading to a lack of motivation. Further, the lack of control regarding the testing environment may have led to more distractions during testing. Indeed, more lapses would be expected in an online study, compared to an offline study. This is further supported by the increase in variation in average reaction time and number of lapses seen in the online study. This needs to be taken into account when drawing conclusions from this work.

3.5 Discussion

The studies reported in this chapter aimed to measure the effect of shift work and sleep disruption associated with new parenthood on attention with the use of the PVT. Overall the data suggests no impairment in attention in any shift worker or new parent cohort tested, indicating a possible rapid recovery effect following sleep. As explained below some evidence of altered impulsivity was observed. These frequentist findings were supported by Bayesian statistics that showed moderate to anecdotal evidence arguing against a significant relationship in the majority of variables. The one exception to this was strong evidence in support of a significant relationship between shift group/parental status and the number of early starts.

Attention has been shown to be negatively impacted by sleep deprivation and disruption, in the case of laboratory based sleep deprivation protocols (Doran, Van Dongen, & Dinges, 2001, Lim &

Dinges, 2010). However the precise impact of more naturalistic forms of sleep deprivation and circadian misalignment remains unclear. Establishing the exact relationship between shift work and attention is vital, given its importance in other cognitive domains. As outlined above, whilst being the most well researched area of cognition within the shift working population, the findings remain ambiguous and contradictory. Where sleep deprivation and new parent studies show a clear detriment to attention following long periods of wakefulness and disturbed sleep patterns, shift working studies appear to show both impairment and resilience. The data presented here attempts to provide clarity regarding these populations by collecting data from both occupationally homogeneous (Po) and heterogeneous (SW1 and SW2) groups, from a new parent and non-shift working comparisons group as well as using a standardised 10 minute PVT across all samples. Further, attempts to minimise work-related fatigue have been implemented by testing on a day off from work.

The PVT has been shown to be a reliable and sensitive measure of sustained attention, susceptible to the effect of sleepiness (Basner & Dinges, 2011). Further, many studies within the area of sleep deprivation and shift work have previously used variants of this task. Here a 10 minute PVT was used for online computerised assessment of remote participants with no synchronous (live) contact with the investigator. Four output variables were extracted from the PVT: median reaction time, lapses, early presses and binned reaction time profile. The first three are metrics often employed within the attention literature. Reaction time and lapses (where a reaction time of over 500ms was recorded) were used to assess sustained attention failures. Early presses examined impulsivity within the cohorts. The final variable was used to see if any task related fatigue was occurring and to establish if there were any differences in the response profiles of participants.

3.5.1 The impact of circadian mismatching on attention in a study of shift workers

Three shift working cohorts were examined to explore the effect of shift work on sustained attention. No significant differences were observed in any of the three shift working cohorts when median reaction times were examined. Further, there was moderate to anecdotal evidence in support of the null hypothesis (Bayesian thresholds used can be found in Table 22). This suggests there was no difference in sustained attention as a result of being a shift worker.

These findings are discordant with much of the current literature that states shift working has a negative impact on attention (Chellappa, Morris, & Scheer, 2019; Wilson, Permitt, English, Albritton, Coogler, & Dongen, 2019). However, the biggest methodological difference between the reported study and those in the literature is that here shift working participants were tested on a day off from work, thereby minimising the effect of work-related fatigue.

This methodological difference may mean that impairments seen in previous shift working studies were in fact due to fatigue that naturally accumulates during wakefulness and is thus eliminated when participants have been able to sleep. However, there is evidence to suggest that the effects of shift work may be persistent. Studies assessing other cognitive domains have suggested that the effects of shift work can remain for up to 5 years (Titova et al., 2016). Within the study of sustained attention, Chellappa et al. (2019) suggested that circadian misalignment experienced by chronic shift workers (participants had a range of 1.5-25.1 years of lifetime cumulative shift work experience) increased cognitive vulnerability on sustained attention, particularly after more than 10 hours of wakefulness. However this study had a very small sample size (7 shift working participants) and no control. Circadian misalignment (a simulated night shift) was compared to circadian alignment (a simulated day shift) within this sample, therefore limiting the comparability of these findings to the present data set.

These findings were further supported when participants were regrouped based on their Bergen Shift Work Sleep Questionnaire. With the exception of the SW1 cohort Evening group, all other groups showed no main effect of group on median reaction time. This suggests that even when grouped based on sleep issues, with a higher score indicating more severe problems, there were no significant differences between shift workers and non-shift workers in these cohorts. This was further confirmed with a lack of correlation between SW2 Bergen Rest scores and median RT.

There are many possible reasons why a significant difference was not seen in this sample, including the impact of demographic variables such as age, years worked shifts and time spent awake prior to testing. Therefore analysis was run on the demographic variables that had been shown to be significantly different within the cohort. However there was no impact of these demographic variables on median RT.

Overall, the findings described here suggest that sustained attention in shift workers (as measured by median reaction time) may be unaffected by the circadian misalignment experienced once a period of recovery sleep has occurred.

Basner and Dinges suggest that median reaction time should not be used as a primary metric, and that lapses should instead be used given 'their superior conceptual and statistical properties and high sensitivity to sleep deprivation' (Basner & Dinges, 2011). Yet, analysis of this metric across the three shift working cohorts here revealed no significant differences. Bayesian analysis showed anecdotal (the SW1 and Po cohorts) and moderate (the SW2 cohort) support for the null hypothesis (lack of any difference). The concordance between median reaction time and number of lapses in this study, with the latter parameter suggested to have a higher sensitivity, suggests that no meaningful impact on attention was present in shift workers who were otherwise free of fatigue. Again, this was further supported by a lack of significant differences when the

participants were regrouped based on BSWSQ scores, with the exception of the SW1 Rest group. This BSWSQ work category showed the High Bergen control group had significantly fewer lapses than both the High and Low Bergen shift groups. Contrary to the conclusions drawn above, this suggests that even with sleep issues (as indicated by a high BSWSQ score), control participants were less impaired than shift workers. However, despite the moderate effect size of this relationship, this was not replicated when examining any of the other BSWSQ work categories, indicating the difference only existed when relating to rest days. Further, there was no correlation between BSWSQ scores and number of lapses nor any significant contribution of demographic factors to the outcomes seen.

When examining response inhibition within this task, using the variable of early presses, some significant differences between shift groups were seen. Within the SW2 cohort, night shift workers displayed less early starts than rotating or day shift workers, with strong Bayesian evidence in support of this finding. This suggests that there are differences in response inhibition across shift groups which manifest as differences in impulsivity.

As outlined further in Chapter Four, impaired impulsivity has been linked to sleep deprivation. Assessed in a home environment, both Demos et al. (2016) and Saksvik-Lehouillier et al. (2020) found partial sleep deprivation was associated with increased impulsivity (Demos et al., 2016; Saksvik-lehouillier et al., 2020). Increased impulsivity has also been linked with shift work, with shift workers being significantly more impulsive than daytime workers (Selvi, Karakaş, Boysan, & Selvi, 2015).

Yet the robustness of this finding in the SW2 cohort here is uncertain, given that no significant differences were seen in either the SW1 cohort or the Po cohort. The findings from the SW2 cohort are also inconsistent with the other response inhibition findings outlined later in this thesis. In Chapter Four, 2 response inhibition tasks were used (GNG and Eriksen flanker) to explore response inhibition within three shift working cohorts different to those used here. However no impairment as a result of shift group was found using these tasks.

Indeed, when participants were re-grouped based on BSWSQ scores, only the SW1 Evening group and the SW2 Day group showed significant differences, with the differences seen between the control groups in the SW2 cohort. This suggests that even when re-grouped on the basis of sleep quality (as assessed by the BSWSQ) there appears to be very little impact of shift work on impulsivity.

It is also important to note that in both the significant findings for the SW2 cohorts, and the non-significant findings for the SW1 and Po cohorts, the number of early starts was relatively low overall (between 0 and 4 early starts in a PVT with 100 trials). Therefore, whilst the difference

between shift groups in the SW2 cohort is statistically significant, it is not necessarily behaviourally relevant.

Given the significant differences seen in the SW2 cohort, the significant differences seen when participants were re-grouped in the SW1 Evening and SW2 Day groups, and the few correlations seen between BSWSQ score and number of early starts, it suggests that the conclusions drawn from these data sets regarding impulsivity may need to be more nuanced and warrants further exploration.

The final output metric that was assessed was binned average reaction time. By binning average reaction times into equal groups of 25 trials it was possible to evaluate if a fatigue effect, where participants perform worse towards the end of the task due to fatigue and/or boredom, was present. SW1 showed a decrease towards the middle of the task, suggesting an optimisation of performance due to an increased experience with the task: as the novelty of the task requirements wore off this may have enhanced understanding and decreased reaction time. However RT then rose in bin 4, suggesting a fatigue effect. SW2 showed a similar peak towards bin 4 however no peak was seen at the beginning. Instead a steady increase in reaction time was seen throughout the task, again suggesting a boredom/fatigue effect. Po showed a similar profile to SW1 however the curve was much flatter. The curve demonstrated in all three shift working cohorts suggests a possible fatigue effect in this task. Sustained attention is known to be affected by age, with children having a less stable attention construct than adults (Tao, Wang, Fan, Gao, & Shi, 2017). However whilst the average duration of sustained attention in adult students is predicted to be between 10-20 minutes, there is little empirical evidence to support this duration expressed across a range of ages (Wilson & Korn, 2007). In order to assess any deficit in attention the deterioration of performance during the task must exceed the natural decline of attentional performance (Tucha et al., 2017). These findings suggest that a ten minute PVT may therefore be optimal for assessing sustained attention in adults of working/parenthood age, given that by the last 25 trials of the task all cohorts were showing time on task dependant reaction time slowing.

Of note, the Po cohort consisted of individuals working within the UK police force, though not all were police officers. This cohort was included to provide an occupationally homogenous cohort, similar to those that are typically published, against which the more occupationally heterogeneous SW1 and SW2 cohorts could be compared. Significantly, it would appear, that even in this more occupationally similar group, likely to experience similar stress levels, shift rotations and to have similar education levels, performance is consistent with the conclusion that attention is not chronically impaired due to shift work.

3.5.2 The impact of naturalistic sleep deprivation on attention in the new parent cohort

One cohort was used to examine the effects of new parenthood and the associated sleep disruption on sustained attention. No significant differences were seen in the median reaction time nor the number of lapses, with moderate and anecdotal Bayesian evidence for the null hypothesis. This would suggest no impairment in sustained attention was evoked by this naturalistic form of sleep deprivation.

This finding is consistent with findings by Wilson et al. (2019a) who suggested that PVT reaction time performance could be improved in new parents following a 5 day residential intervention period including recovery sleep. However, they did see a small increase in the number of lapses, following the end of the intervention, unlike the findings presented here. As individuals in the present study were asked to complete the PVT task as soon after waking as possible, it is plausible that no impairments were seen as fatigue had not yet built up.

Sex has been shown to influence PVT performance. Blatter et al. (2006) found significantly slower reaction times in females than males, independent of age (Blatter et al., 2006). This became more pronounced the further into a 40 hour sleep deprivation protocol the participants went. The authors stated that the responses seen represented a similar level of motivation in both groups however a difference in strategies to achieve the best performance, with women avoiding errors and men attempting to respond as fast as possible. Such sex effects were not detected in the NP cohort here.

However, when assessing response inhibition within this cohort, new parent males showed significantly fewer early starts than all other groups within the NP cohort. This suggests that new parenthood, specifically in males, somewhat paradoxically reduces impulsivity. Bayesian analysis showed strong support for the alternative hypothesis. As described in Chapter Four, there is currently debate over the precise impact sex has on response inhibition, with some suggesting that males are more vulnerable to impairment in inhibitory control and have higher levels of impulsivity compared to females (Petry, Kirby, & Kranzler, 2002) and others showing no behavioural differences (Li, Huang, Constable, & Sinha, 2006). It appears that impulsivity differences related to sex may be due to the task used.

The final variable to be assessed in the NP cohort was the binned reaction time. Over the four bins the NP cohort showed increasing reaction times, similar to that seen in the SW2 cohort. This increased reaction time towards bin 4 is indicative of a fatigue effect. As explained above, sustained attention is limited, so it is not unexpected to see this increase across all four groups, regardless of sleep status.

Overall, the findings here contrast with that of the sleep deprivation literature and a large proportion of the new parent and shift working literature. However, there are considerations to take into account which may explain the disparity. Whilst a standardised 10 minute PVT was used in all four cohorts, many other studies use variations of the PVT (Geiger-Brown et al., 2012; Insana et al., 2013). Therefore it is possible that differences in task length, stimulus presentation time, response time and feedback may have influenced results. As discussed previously, the lack of feedback in this task may have led to a demotivation in participants and an increase in reaction times and lapses.

Further, the demographic characteristics of the sample groups may be a factor. Here a wide range of occupations in SW1 and SW2 was tested (outlined in Chapter Two). This is distinct from much of the shift working literature, which often assesses one group, particularly nurses. Differences seen between these two cohorts (for example the SW2 showed differences in impulsivity where the SW1 cohort did not) further highlight the issue with applying findings from one group of shift workers to the whole work force. Additionally, both male and female new parents were examined here as well as all shift working cohorts assessing both male and female shift workers (though this was not a controlled variable). It is possible therefore that any attentional impairments seen in previous studies were due to a sex difference. For example, in the shift working studies of Wilson et al. (2019b) and Geiger-Brown et al. (2012) the nurses assessed were predominantly female.

Much of the current literature looks at attention in one small occupationally homogenous sample, in which participants experience the same shift patterns, stress conditions and recovery days. Here an attempt was made to replicate these findings with the use of the Po cohort. As explained above, this sample consisted of those working for the UK police force (though not all were police officers) and as such were more likely to have similar stress levels, education levels and shift rotations. However no attentional differences were seen between the rotating and day shift workers. This further supports the argument that shift working studies that look at just one group cannot be applied to the global shift working population.

3.5.3 Limitations and future directions

One key limitation of the present study is the use of online testing. With all tasks completed online at distance there is a lack of control in terms of how much the participant is focussing on the task. For attentional tasks, such as the PVT, a non-distracting environment is key to getting valid results. Future studies conducted online should incorporate attentional checks during the PVT task to ensure a participant is still actively engaged, as well as test a similar sample group in person.

Relating to lack of control with online testing, one of the key components of this study was the alleviation of work related fatigue. With this testing design it is not possible to control exactly how

long individuals had been awake prior to completing the study. Attempts were made to ensure participants were on a day off from work but given the self-reported nature of the study this is not a strictly controlled factor. Future work should collect further data regarding wake times and group participants accordingly in order to further examine the impact of fatigue.

Task sensitivity was also a potential limitation of these findings. As discussed in 3.4.5, whilst reaction time did increase with task duration and a positive correlation was seen between age and reaction time (once an outlier was removed), when compared to a control sample from the literature the reaction times were slower in these samples with more lapses.

Finally, whilst the design used had a strong rationale, it does present limitations in terms of data applicability. This is because participants were only tested once due to testing restrictions and sample retention issues. Future studies should work towards implementing multiple testing conditions in order to establish if these individuals developed attentional impairment following a shift, and compare the scores to those collected on a day off to establish what a well-rested baseline level of attention was for each individual. This will provide a broader picture of the impact of a shift working lifestyle.

3.5.4 Conclusions

In conclusion, these findings present an opportunity to obtain further insight into the exact impact of a shift working lifestyle in the absence of work related fatigue, as well as a comparison group of ecologically sleep deprived individuals, new parents.

The data indicates that there is no impairment in attention in two groups of occupationally heterogeneous shift workers, a more occupationally homogenous group of UK police force staff or in new parents, both mothers and fathers. This therefore suggests that any decline seen over the course of a shift/night of child care as reported in the literature can be recovered with a single period of recovery sleep.

4.1 Introduction

Shift workers are 2.7 times more likely to be involved in an accident at work than non-shift workers (Ryu et al., 2017) and are at a higher risk of drowsiness related car accidents following night shift work (Lee et al., 2016). One contributor to this could be an inappropriate modulation of response inhibition. This ability to suppress an action is vital for normal goal-driven behaviour, including tasks such as driving (Casco et al., 2015; Lee & Hsieh, 2017). Mental fatigue, a feeling of tiredness or reduced cognitive capabilities following a long period of cognitive activity, has been suggested as one of the main contributors to a decline in response inhibition. This is exemplified by Guo et al. (2018) who showed that after a 90 minute fatigue manipulation task, participants had increased reaction times and miss rates on a GNG task.

The neurobiology underpinning response inhibition is well understood. As detailed in Chapter One, performance on cognitive assessments known to involve response inhibition has been linked predominantly to activation in frontal (including prefrontal cortex) and inferior parietal regions (Aron, Robbins, & Poldrack, 2014; Chambers, Garavan, & Bellgrove, 2009; McNab et al., 2008; Simmonds, Pekar, & Mostofsky, 2008, prefrontal cortex: Bari & Robbins, 2013; Rae, Hughes, Anderson, & Rowe, 2015; Ridderinkhof, Van Den Wildenberg, Segalowitz, & Carter, 2004; Rubia, Smith, Brammer, & Taylor, 2003). Further areas that have been associated with response inhibition include the subthalamic nucleus (Aron & Poldrack, 2006; Ray et al., 2009), superior temporal gyrus and cingulate gyrus (Horn et al., 2003).

Many brain regions have shown to be negatively impacted by fatigue. Specifically, frontal regions have shown to be susceptible, with frontal theta and alpha frequencies decreasing following induced fatigue. These changes in frequency are associated with performance impairment (Baumeister et al., 2012). There is also a global impact of fatigue, with slow wave activity shown to increase across the entire cortex following a simulated driving task (Craig, Tran, Wijesuriya, & Nguyen, 2012). Sleep deprivation also leads to impaired brain functioning, with significant reductions in brain activation following sleep deprivation in the fronto-parietal attention network (Ma et al., 2015) and altered connectivity in the dorsal attention network, the DMN and in hippocampal networks (Kaufmann et al., 2016). Taken together, it is plausible that fatigue would impact performance on tests designed to assess response inhibition, due to the brain regions relied upon for this cognitive domain.

There are multiple tests used to assess response inhibition. These include the Go Nogo (GNG) task (Donders, 1969), the Eriksen flanker task (Eriksen & Eriksen, 1974), the Stop Signal reaction time

task (Congdon et al., 2012), Simon task (Simon & Wolf, 1963) and the Stroop task (Stroop, 1935). Many of these tasks have been utilised to assess response inhibition in sleep deprivation (C. Anderson & Platten, 2011b; Drummond et al., 2006), shift work (Kaliyaperumal et al., 2017; Shwetha & Sudhakar, 2012) and new parent studies (Bannbers et al., 2013).

This chapter focuses on data collected using the GNG task and the Eriksen flanker task. The GNG task assesses task-relevant response inhibition, processing speed and sustained attention. It requires individuals to respond to a target stimulus and withhold response to the other stimuli presented (Bender et al., 2016; Donders, 1969). Outcome metrics such as reaction time for correct trials and miss/false positive rate for Go/Nogo trials are used as behavioural performance indicators. The Eriksen flanker task involves a target stimulus flanked by non-target stimuli, with participants required to identify and respond to the target stimulus only. First published by Eriksen and Eriksen (1974), the Eriksen flanker task is used to assess information processing, response inhibition and selective attention (Eriksen & Eriksen, 1974). Reaction time and accuracy within congruent and incongruent trials are extracted as performance indicators. Congruent trials are where the flanking stimuli match the central target stimulus, in incongruent trials they do not match. Participants perform faster on congruent trials as the flanking stimuli are less distracting (as they match the target stimulus and so cause less interference)(Eriksen & Eriksen, 1974), and it is probable that the effect of fatigue would only increase this difference.

Whilst both of these tasks are widely used, well validated (Wöstmann et al., 2013) and the underpinning neurobiology is largely understood, they look at different components of response inhibition, as explained in Chapter One. Therefore, both have been utilised in this project to ensure that a thorough, multi-faceted evaluation of RI and its component processes has been completed. Specifically, the GNG task assesses the suppression of behavioural responses whereas the Eriksen flanker task evaluates interference suppression (the active prevention of interference due to stimulus competition) (Brydges et al., 2012). Brydges et al. (2012) used a hybrid flanker GNG task and found different brain activations during interference suppression and response inhibition conditions. Specifically, the topography and latency of N2 amplitudes differed. In the GNG element of the task, the Nogo condition (where response inhibition is engaged) was associated with greater frontal activity. In the flanker element of the task, the incongruent condition (where interference suppression is engaged) was associated with more central activity. They propose that this provides further evidence to suggest that response inhibition is dissociable into distinct cognitive and neurobiological elements.

As outlined in Chapter One, impaired response inhibition has been observed in the context of sleep deprivation (SD). Following one night of SD, 32 healthy individuals displayed increased failure to inhibit a response and faster incorrect responses to negative stimuli in an emotional

GNG (Anderson & Platten, 2011). This task involved responding and inhibiting responses to neutral or emotional words, with target stimulus changing (i.e. neutral or emotional) throughout the 6-9 minute task. Similar findings have been reported following two consecutive nights of SD (Drummond, Paulus, & Tapert, 2006) and 38 hours of continuous wakefulness (Mander et al., 2010), all assessed using some form of GNG task. However, the rate of decline across different performance metrics varies. Drummond et al. (2006) found hit rates were significantly impaired only after two nights of SD, whereas hit reaction times were slower after both 31 and 55 hours. False positive rates were elevated during all testing sessions (21, 31 and 55 hours of SD). Mander et al. (2010) found significant differences in the percentage of correct inhibitions and correct responses following 38 hours of continuous wakefulness, although as these individuals were only tested at the beginning and end of the sleep deprivation protocol it is not possible to pinpoint exactly when these impairments occurred. Overall, these findings suggest that an impairment in response inhibition is seen after sleep deprivation. Though, which components deteriorate fastest and the rate at which response inhibition failure develops remain unclear.

Comparable outcomes have been found using the Eriksen flanker task, with slower reaction times, increased response errors and omissions observed after one night of sleep deprivation (Tsai, Young, Hsieh, & Lee, 2005). However, in a later study of a sample taken from the same population (university undergraduates), Hsieh et al. (2007) found that there were no effects on performance of the Eriksen flanker task following one night of sleep deprivation (Hsieh, Cheng, & Tsai, 2007). The performance metrics evaluated were comprehensive and included mean response accuracy, error rate, error correction rate, omission rate, correct RT, error RT, error with correct RT, error without correction RT and correction time. The authors stipulate that this finding is inconsistent with their previous study (Tsai, Young, Hsieh, & Lee, 2005) and state it is unclear why the studies vary. The contradiction in these results could suggest that the effect of sleep deprivation of response inhibition (particularly interference suppression) as measured using the Eriksen flanker task is not robust, although this seems unlikely given the compelling GNG data noted previously. Participant sample size may be a contributor to this difference, both papers having a relatively small sample size (16 participants) and are therefore likely lacking in power. Further, this small sample size may have led to a biased sample (all participants were undergraduate students). Given that task design and testing procedure were the same in both studies this is unlikely to have contributed to the difference in findings, however whether participants had previously taken part in an Eriksen flanker task or similar cognitive assessment and therefore be potentially experiencing a practise effect is unknown.

There is also evidence to suggest that there is potential retrieval of normal response inhibition following recovery sleep, though it may not return immediately to baseline. Following 36 hours of total sleep deprivation Jin et al. (2015) found an 8 hour recovery sleep period was enough to

partially restore response inhibition (Jin et al., 2015). Similarly, Drummond et al. (2006) observed a complete recovery with response inhibition returning to baseline after one night of recovery sleep (following two nights of total SD) (Drummond et al., 2006). In addition, Mander et al. (2010) found one night of recovery sleep (after 38 hours of sleep deprivation) resulted in recovered response inhibition (Mander et al., 2010). All studies used a GNG task.

Taken together, laboratory sleep deprivation studies indicate an overall negative effect of SD on response inhibition, which suggests that this cognitive domain would also be sensitive to ecologically valid forms of sleep deprivation, such as shift work. Despite the potential dangers associated with impaired response inhibition, there appear to be a lack of studies conducted, using a GNG task or an Eriksen flanker task, in this population.

However, as noted earlier, a range of response inhibition tasks exist and a small number of these have been applied to the shift working population. Using a Stroop task, Kaliyaperumal et al. (2017) found 71% of shift working nurses scored less accurately on the Stroop's colour naming test during a night shift, compared to a day shift, suggesting an impairment in response inhibition (Kaliyaperumal et al, 2017). The Stroop task has further been utilised to evaluate response inhibition failure in male office workers, specifically business process outsourcing employees (Shwetha & Sudhakar, 2012). Comparison of shift and non-shift working individuals in this study revealed an impairment in response inhibition in those undertaking shifts. Together these studies suggest a response inhibition deficiency associated with shift work.

It is important to note that both these shift working cohorts often experience high levels of stress and are occupationally homogenous, therefore may not be fully representative of the global shift working population, given the variety of occupations who work shifts and the variations in shift lengths, number and duration of breaks and overall shift pattern. Further, it is essential to highlight that the cognitive assessment of these shift working participants occurred at the end of a shift, therefore is likely to be impacted by work-related fatigue as well as or as opposed to circadian misalignment. Fatigue is suggested to be a key contributor to response inhibition failure (Z. Guo et al., 2018). Reaction times, miss and false alarm rates have been shown to increase with time on task, indicating a negative impact of mental fatigue on response inhibition (Guo, Ren, Wang, & Zhu, 2015; Kato et al., 2009). Assessment of response inhibition in a wider community sample of shift workers is needed. Specifically, it is important to establish if there are any persistent negative effects of a shift working lifestyle, in the absence of work-related fatigue.

Beyond shift workers, another cohort of individuals who frequently experience relatively unpredictable sleep deprivation in more naturalistic conditions than the laboratory is new parents. New parents have shown an increase in SD following the birth of a child (Gay, Lee, & Lee, 2004). However, unlike laboratory studies of SD, this is often the result of disturbed sleep and

unpredictable sleep patterns (Hunter, Rychnovsky, & Yount, 2009), rather than one long period of wakefulness. Given that recovery sleep has been shown to partially restore response inhibition (Drummond et al., 2006; Jin et al., 2015; Mander et al., 2010), it is plausible that the effect of new parenthood on this cognitive domain may be less than that seen in chronic laboratory sleep deprivation studies.

Bannbers et al. (2013) assessed response inhibition in postpartum women at 48 hours after delivery and at 4-6 weeks after delivery, as well as non-postpartum controls. They found no differences in GNG performance between groups or across time points (Bannbers et al., 2013). This is in contrast to the laboratory SD literature and supports the view that the sleep disruption associated with being a new parent is not sufficient to impact response inhibition. However, the authors highlight the lack of generalisability of these findings due to the small sample of highly motivated, educated woman evaluated, as well as the absence of any physically or psychologically traumatic births and postpartum periods. This limited sample highlights the need for more research in this area to provide a better picture of the potential impact on response inhibition in a broader sample of new parents. It is important to assess this impact given new parent's responsibility in looking after a newborn, whilst caring for themselves and operating safely in the outside world, for example when driving.

To the best of our knowledge, Bannbers et al. is the only study of response inhibition in new parents. Whilst informative, by only testing women, this approach excludes the new fathers. It is important to assess both parents, given their differing experiences surrounding the birth of a child. For example, females experience hormonal changes during/following labour that fathers would not experience with possible consequences for mood and cognition.

Given the findings in the existing sleep deprivation and new parent literature, as well as the limited number of assessments performed on occupationally homogenous shift workers, it is likely that variation will be seen in any one sample of shift workers. These individuals, similar to new parents, experience sleep deprivation unlike the one long period of wakefulness seen in SD protocols. Instead it is linked with disturbance to normal circadian rhythm (Åkerstedt, 2003). Current literature suggests that there is an impact of shift work on response inhibition, however, as discussed previously, there are issues with generalising these conclusions. It remains unclear if the findings can be extrapolated due to task difference and sample homogeneity.

This chapter reports some of the first response inhibition data in these ecologically valid groups, specifically using the GNG and Eriksen flanker tasks. In the present study we aimed to assess the impact of new parenthood and shift work on response inhibition, without the confound of work-related/mental fatigue. Healthy response inhibition is vital for both shift workers and new parents, given the responsibilities involved in looking after a newborn child and in many shift

working roles (operating heavy machinery, delivering medical treatment, responding to an emergency).

4.2 Specific aims

1. To determine if response inhibition is impacted in shift workers and new parents
2. To determine if either shift workers and new parents exhibited a differential profile of impairment – behavioural suppression (measured using the Go Nogo) and interference suppression (measured using the Eriksen flanker)
3. To evaluate the utility of the Go Nogo task and Eriksen flanker task for online assessment

4.3 Method

All research presented in this chapter has received ethical approval following review by The Open University's Human Research Ethics Committee (HREC/2016/2444/Breese/2 and HREC/2017/2549/Breese/1). This study also adheres to all BPS ethics standards (The British Psychological Society, 2018).

A full information sheet and debrief form were provided and each participant was required to provide informed consent before being enrolled. Participants were informed of their right to withdraw at any point and contact details of the research team were provided at the beginning and end of testing, should participants wish to ask any questions.

4.3.1 Recruitment approach

Data presented in this chapter is an amalgamation of several recruitment drives. All data were collected using the online participant platform Prolific (www.prolific.co) and the Gorilla Experiment Builder (www.gorilla.sc) to create and host all experiments (Anwyl-Irvine et al., 2018). All received financial payment for taking part in the study.

4.3.2 Participants

Four different cohorts were recruited. An in-depth explanation of the differences between the cohorts as well as the rationale for each can be found in Chapter Two.

1. Shift worker one (SW1): the first instance of using the GNG task online assessing shift and non-shift workers.
2. Shift worker two (SW2): following data analysis of the SW1 cohort, changes were made in order to reduce ceiling effect (the amount of time the stimuli were presented was reduced and two new target stimuli were added, so as to increase the number of Go trials) and improve understanding (clearer instructions were given). Again, data were collected from both shift workers and non-shift working controls.

3. New parents (NP): Parents of a child under one year old were asked to complete the GNG. This task had the same parameters as the SW2 cohort, and therefore a control group (individuals who were not currently new parents or shift workers) was extracted from the SW2 non-shift working participant sample.
4. Shift worker three (SW3): The Eriksen flanker task was used to collect data from shift workers and non-shift working controls.

No participants were permitted to take part in more than one of these recruitment drives, however some data from the SW2 cohort was used as a control in NP.

Prior to outlier analysis the sample sizes for each cohort (including controls) were as follows:

- SW1: 72 participants (3 removed following exclusion screening)
- SW2: 125 participants (44 removed following exclusion screening)
- SW3: 138 participants (33 removed following exclusion screening)
- NP: 129 participants (11 removed following exclusion screening)

4.3.3 Exclusion criteria

For both tasks, participants were excluded from analysis if they stated they had had a recent head injury that required hospitalisation, were under the age of 18, if it was not possible to put them in a shift group due to conflicting/absent/uninterpretable description of their work pattern, they were not on a day off from work or did not fully complete the task.

For the GNG task a threshold based on signal detection theory was developed in order to remove individuals who were not meaningfully engaging with the task. This was based on a participant's responses, and aimed to exclude those who were continuously pressing without any selectivity of response, and those who left the task to run without any engagement. In the GNG there are two target types: S+ (participant is required to press) and S- (participant is required to withhold). Each of these have two possible outcomes as outlined in Table 36. If an individual got more than 80% 'press responses' or <80% 'do not press responses' they were excluded from further analysis because this profile of responding implied that the participant was responding to every trial, regardless of the stimulus presented or letting the task run without any engagement. This was also modelled at 90% to check for participant dropout. However, the change in sample size was not deemed large enough to impact results. Similar accuracy exclusion criteria have been used previously in human and animal cognitive studies (Hedge, Powell, & Sumner, 2018; Young, Light, Marston, Sharp, & Geyer, 2009).

Table 36 Signal detection theory grid All possible outcomes from both target types

Target / Response	Press	Do not press
S+	Hit	Miss
S- (small triangle)	False positive	Correct reject

For the Eriksen flanker task, it was not possible to use the same thresholding approach as every stimulus requires a response. However initial review of the data indicated that several participants were displaying behaviour indicative of non-engagement, including consecutive emissions and multiple presses within a single trial.

Therefore, the following exclusion criteria were applied to remove these individuals. Participants were removed if they failed to respond for more than four trials in a row as this was counted as the end of meaningful engagement. Similarly, if a participant had four or more trials where they pressed more than twice in a given trial (triple+ presses) they were excluded as this marked the end of meaningful engagement. Finally, if an individual did not respond to at least 75% of trials (450 trials) they were excluded. This led to the removal of 33 participants.

4.3.4 Design

As explained above, participants were recruited through Prolific and tested using Gorilla Experiment Builder. Participants were all tested once: for the SW1, SW2 and SW3 cohorts, participants were asked to complete on a day off from work; for the NP cohort, participants were asked to complete the assessment after they had woken up in the morning. This was to reduce any direct impacts of work-related fatigue or acute tiredness on cognition.

4.3.5 Testing procedure

Once participants had read the information sheet and given informed consent, each individual received the full questionnaire battery to complete (outlined in Chapter Two). Following this, SW1, SW2 and NP participants completed a GNG and an N-back (Chapter Five). For the SW2 and NP cohorts this was given in a randomised order, however the SW1 cohort received the N-back task first. The randomisation of task order was introduced following SW1 to counter any effect of order.

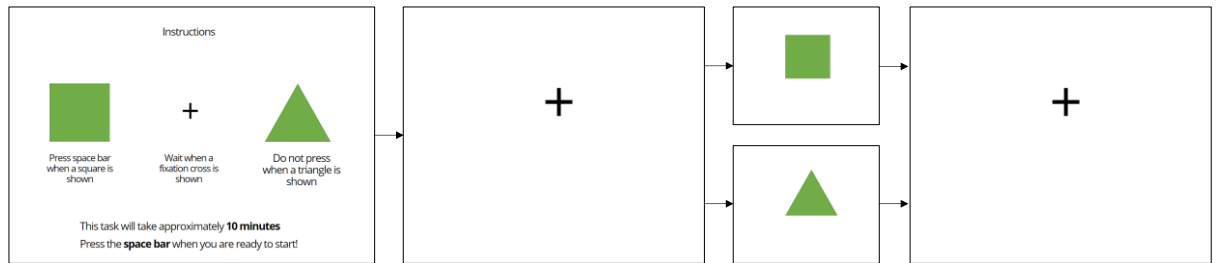


Figure 14 Screen presentation sequence of GNG for SW1

The SW1 GNG task (Figure 14) required participants to view a single visual stimulus presented on the screen for 1000ms. Participants were required to press the space bar as soon as they recognised one stimulus (S+), and to withhold responding to the other stimulus (S-). 181 trials were completed, 72 of which were S+, over a period of approximately 10 minutes. The fixation cross was shown for a randomised period of time (1000-4000ms). Initial task design (trial number) was based on Drummond et al. (2006) but modifications were made based on preliminary evaluation of the task by the research team.

Due to a ceiling effect, changes were made to the GNG to make it more difficult. These included reducing the stimulus presentation time, increasing the number of Go stimuli (from one the same size as the Nogo stimulus to three of varying sizes) and increasing the ratio of S+ to S-.

The SW2 and NP GNG task (Figure 15) required participants to view a single visual stimulus, from a choice of four, presented on the screen for 200ms. Three of the stimuli (S+) required participants to press the space bar, and one (S-) required response withholding. Participants completed a total of 186 trials, 126 of which were S+, over a period of approximately 5 minutes. The fixation point was shown for a fixed amount of time of 1300ms. The trial length and stimulus used were based on Drummond et al. (2006) however more trials were included.

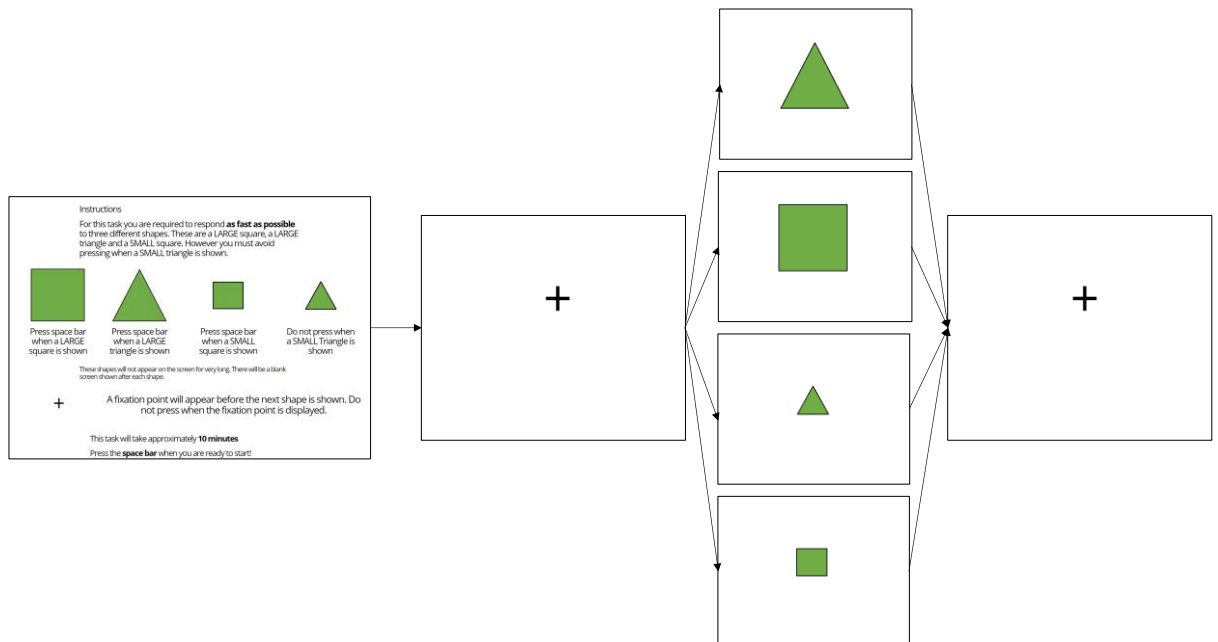


Figure 15 Screen presentation sequence of GNG for SW2 and NP

SW3 participants received an information sheet and, once informed consent was obtained, were given a questionnaire battery to complete (outlined in Chapter Two). Following this, participants completed the Eriksen flanker task and one of two possible N-back tasks (Chapter Five). This was given in a randomised order, to counter any effect of testing sequence.

The Eriksen flanker task (Figure 16) required participants to view an array of five letters presented on the screen for 200 ms, followed by a fixation point shown for a randomised period of time ranging between 1000 and 4000 ms. The aim of the task is for participants to correctly identify the middle letter, ignoring the distracter letters either side. Trials could be either congruent (all the letter were the same, 200 trials) or incongruent (the outside letters (distractors) were different to the target letter, 400 trials). Participants received a practice session, where feedback was given for 6 trials. This was based on the task design used by Renn and Cote (2013).

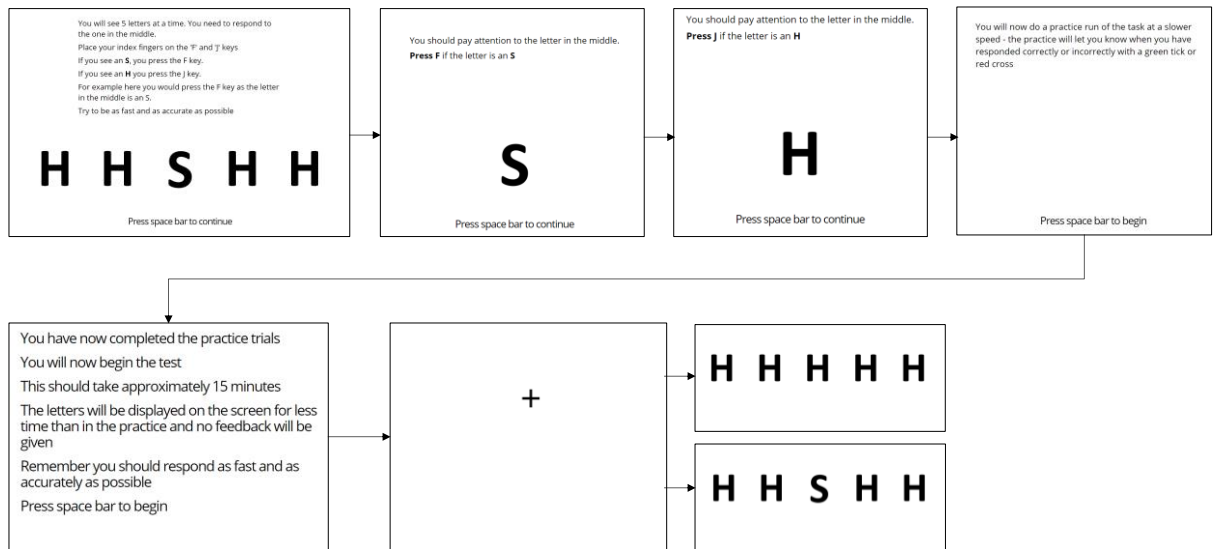


Figure 16 Screen presentation sequence of Eriksen flanker task

4.3.6 Output variables

The variables extracted for analysis of each task are summarised below.

4.3.6.1 Go Nogo

1. Overall correct performance (%) – percentage of 'correct' response types (hits and correct rejects combined)
2. Total false positives (%) – percentage of total false positives as a percentage of total possible (SW1=109 trials, SW2/NP=60 trials)
3. Mean reaction time (for hit and false positive trials) (ms)
4. Within group correct VS incorrect reaction times (ms) – comparison of hit and false positive reaction times within participant sub-groups (participants were removed if they did not have a full data set following outlier analysis)
 - i. Night
 - ii. Rotating
 - iii. Day
 - iv. New parent Male
 - v. New parent Female
 - vi. Control Male
 - vii. Control Female

4.3.6.2 Eriksen flanker

1. Overall correct performance (%) – percentage of correct responses as a % of total trials presented to participant (600)
2. Percentage of incorrect responses (%) - Percentage of total congruent/incongruent trials that were responded to incorrectly (incorrect press)
3. Missing trials – number of trials individuals did not respond to

4. Reaction time for congruent/incongruent responses (ms)
 - i. Congruent Hits
 - ii. Congruent Incorrect presses
 - iii. Incongruent Hits
 - iv. Incongruent Incorrect presses
5. Reaction time comparisons within group (ms) - comparison of hits and incorrect press reaction times for congruent and incongruent trials within participant group (participants were removed if they did not have a full data set following outlier analysis)
 - i. Night
 - ii. Rotating
 - iii. Day

4.3.7 Statistical analysis

Data was downloaded from Gorilla and prepared for statistical analysis using Microsoft Excel 2013 (Microsoft, 2013). Descriptive statistics (mean, standard deviation and range) were generated for demographic data, including age, sex, years working shifts and sleep disorder frequency using GraphPad Prism (version 8.2.1) (GraphPad Software, La Jolla California USA, n.d.) and StatsCloud (www.statscloud.app) and are outlined in Chapter Two.

Cognitive assessment data were analysed using frequentist statistics with JASP (www.jasp-stats.org, version 0.11.1) and GraphPad Prism (version 8.2.1). Data was first screened for normality using the D'Agostino and Pearson test. Outliers were identified with box plots, and points identified as being outside the whiskers (set to 1.5 x interquartile range above/below the 75th/25th percentile) were removed. If data were normally distributed parametric tests were used (ANOVA and t-test), if normality was not achieved non-parametric tests were employed (Kruskal-Wallis, Mann-Whitney, Wilcoxon). To address multiple comparisons, Tukey post hoc analyses were performed as appropriate. Significance was given by a p-value of less than 0.05. Bayesian analysis was conducted using JASP and conclusions based on the thresholds found in Van Doorn et al (2019). These can be found in Table 22.

4.4 Results

4.4.1 GNG task

For SW2 and NP cohorts, in order to control for any potential order effect, the design contains group A and B (see Figure 2 and 5 in Chapter Two). Effects of assessment order were controlled by running two testing sequences. Data from both assessment sequences was compared to determine if there was an order effect. Where no significant effect of order was detected, the two sub-groups were merged to increase group size and statistical power. However it was not always

possible to merge groups and as a result, some variables have group A and group B. This suggests that in some variables an order effect may be present.

4.4.1.1 Overall correct performance (%) showed no evidence of response inhibition differences dependant on group

Overall correct performance was calculated on the basis of total trials presented, 181 trials for the SW1 cohort and 186 trials for the SW2 and NP cohorts. The sample size of each cohort and the number of participants removed following outlier analysis is detailed in Table 37.

In the SW1 cohort there was no main effect of group on overall correct performance ($H(2)=0.830$, $p=0.661$, $\eta_H=0.02$). All participants achieved at least 90% correct with a mean score of 95.16% correct for night shift workers, 96.41% for rotating shift workers and 96.01% for day workers, suggesting a ceiling effect, with all participants getting between 90-100% correct (Figure 17a). Therefore the task was made more difficult (as outlined in the Methods section above). No significant main effect of group was found in the SW2 cohort ($H(3)=7.400$, $p=0.060$, $\eta_H=0.04$) or in the NP cohort ($H(3)=1.998$, $p=0.573$, $\eta_H=0.01$) (Figure 17b and 17c). There was also a reduction in mean score suggesting the changes to task design employed to increase task difficulty and reduce ceiling effect worked. For the SW2 and NP cohort the mean overall correct performance scores can be found in Table 38.

Bayesian statistics showed there was moderate evidence for the null hypothesis in the SW1 cohort ($BF_{10}=0.19$). The null hypothesis proposed there is an absence of an effect of group on overall correct performance. There was anecdotal evidence for the alternative hypothesis in the SW2 cohort ($BF_{10}=1.46$). The alternative hypothesis proposed there is an effect of group on overall correct performance. There was anecdotal evidence for the null hypothesis in the NP cohort ($BF_{10}=0.92$).

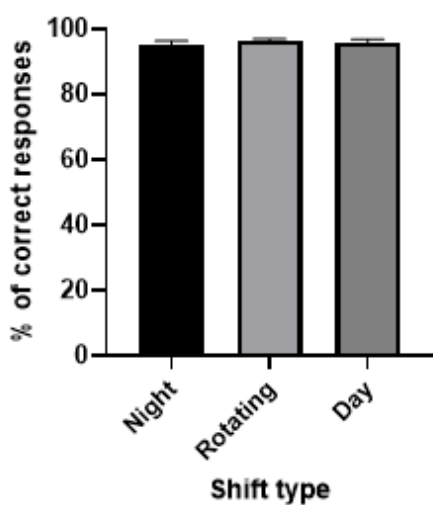
Table 37 Sample sizes for GNG overall correct performance (%)

Cohort	Groups	n	Removed through outlier analysis
SW1	Night	13	0
	Rotating	36	4
	Day	18	1
SW2	Night	23	0
	Rotating A	28	0
	Rotating B	31	2
	Day	41	0
NP	NP male	31	0
	NP female	59	2
	C male	26	0
	C female	11	0

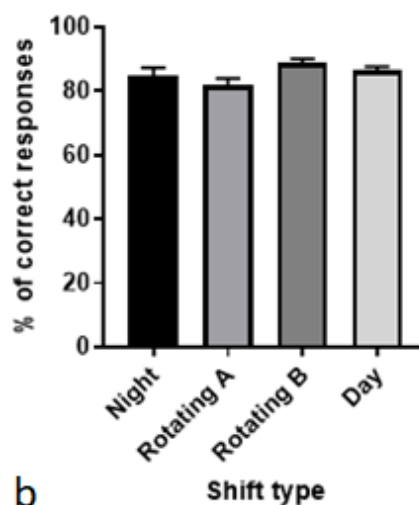
Table 38 Mean overall correct performance scores

Cohort	Groups	Mean overall correct performance scores (%)
SW2	Night	84.99
	Rotating A	81.93
	Rotating B	88.92
	Day	86.43
NP	NP male	79.10
	NP female	85.15
	C male	87.03
	C female	84.26

SW1 Overall correct performance



SW2 Overall correct performance



NP Overall correct performance

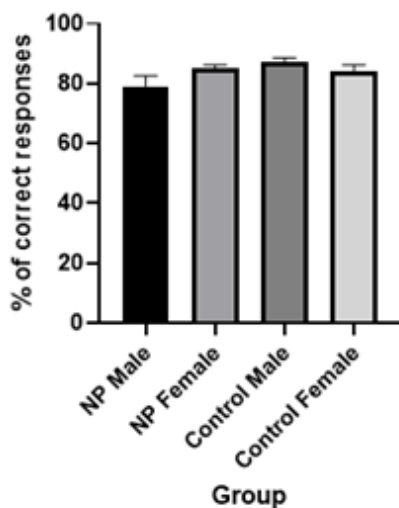


Figure 17 GNG Overall correct performance a) SW1 cohort b) SW2 cohort c) NP cohort. Error bars indicate SEM.

As with the previous task, analysis was run again with shift groups split by BSWSQ score. Table 39 details the statistical analysis for each BSWSQ score and sample. Where data did not pass a normality test it was transformed. The transformation applied is indicated in the table. Where data could not be made normal, nonparametric analysis was used.

Table 39 GNG Overall correct performance BSWSQ score grouping

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	H(3)=0.11, p=0.99, $\eta_H=0.06$	H(3)=0.20, p=0.98, $\eta_H=0.06$	U=240, p=0.79, r=0.04	H(3)=3.11, p=0.38, $\eta_H<0.01$
SW2	H(3)=1.80, p=0.61, $\eta_H=0.01$	H(3)=1.64, p=0.65, $\eta_H=0.02$	U=632, p=0.71, r=0.04	H(3)=2.35, p=0.50, $\eta_H=0.01$

No significant differences were seen between High and Low Bergen shift and control groups when examining overall correct performance.

Further correlation analyses was run between all BSWSQ score and overall correct performance. Table 40 details the statistical analysis for each BSWSQ score and sample

Table 40 GNG Overall correct performance correlations

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	$r_s(50)=-0.12$, p=0.39, observed power=0.09	$r_s(50)=-0.14$, p=0.32, observed power=0.12	$r_s(44)=-0.07$, p=0.62, observed power=0.03	$r_s(63)=-0.20$, p=0.10, observed power=0.11
SW2	$r_s(85)=0.01$, p=0.90, observed power=0.05	$r_s(76)=-<0.01$, p=0.99, observed power=0.04	$r_s(71)=-0.10$, p=0.38, observed power=0.09	$r_s(106)=-0.04$, p=0.67, observed power=0.05

No significant correlations between BSWSQ score and overall correct performance were found in either cohort.

ANCOVAs were run using the BSWSQ rest score groupings. In the SW1 cohort the covariate, age, was not significantly related to overall correct performance ($F(1,60)=0.09$, $p=0.76$, $\eta^2=0.002$). There was also no effect of BSWSQ group on overall correct performance after controlling for age ($F(3,60)=0.14$, $p=0.94$, $\eta^2=0.007$). The covariate 'years worked shifts' was not significantly related to overall correct performance ($F(1,60)=0.71$, $p=0.40$, $\eta^2=0.01$). There was also no effect of BSWSQ group on overall correct performance after controlling for years worked shifts ($F(3,60)=0.18$, $p=0.91$, $\eta^2=0.009$).

In the SW2 cohort country of testing, activity level and sleep time were not significantly related to overall correct performance. Further, in these demographic variables, there was no effect of group on overall correct performance when demographic variables were controlled for.

The covariate sex was significantly related to overall correct performance ($F(1,103)=4.02$, $p=0.05$, $\eta^2=0.04$), however the small effect size seen suggests this relationship may not be strong. There was no effect of BSWSQ group on overall correct performance after controlling for sex ($F(3,103)=0.26$, $p=0.86$, $\eta^2=0.01$). The covariate 'Time awake' was significantly related to overall correct performance ($F(1,100)=4.90$, $p=0.03$, $\eta^2=0.05$). There was no effect of BSWSQ group on overall correct performance after controlling for time awake ($F(3,100)=0.20$, $p=0.89$, $\eta^2=0.01$).

ANCOVA statistics can be found in Table 41.

Table 41 GNG Overall correct performance x demographic variable

Demographic variable	Main effect	Effect of group when demographic controlled for
Sex	$F(1,103)=4.02$, $p=0.05^*$, $\eta^2=0.04$	$F(3,103)=0.26$, $p=0.86$, $\eta^2=0.01$
Country	$F(1,103)=0.62$, $p=0.43$, $\eta^2=0.01$	$F(3,103)=0.41$, $p=0.74$, $\eta^2=0.01$
Activity level	$F(1,103)=0.10$, $p=0.76$, $\eta^2=0.001$	$F(3,103)=0.36$, $p=0.78$, $\eta^2=0.01$
Sleep time	$F(1,100)=0.72$, $p=0.40$, $\eta^2=0.01$	$F(3,100)=0.47$, $p=0.70$, $\eta^2=0.01$
Time awake	$F(1,100)=4.9$, $p=0.03^*$, $\eta^2=0.05$	$F(3,100)=0.20$, $p=0.89$, $\eta^2=0.01$

4.4.1.2 Total false positives (%) showed no indication of group dependant differences

The total number of false positives as a percentage of total possible Nogo trials showed no main effect of group on percentage of total false positive in the SW1 cohort ($H(2)=1.710$, $p=0.425$, $\eta_H<0.01$), the SW2 cohort ($F(2,120)=0.067$, $p=0.935$, $\eta^2=0.001$) or the NP cohort ($H(3)=1.110$, $p=0.775$, $\eta_H=0.02$) (Figure 18). The changes made to task design following the ceiling effect observed in SW1 appear to have increased difficulty as the percentage of false positives increased approximately tenfold in the SW2 and NP cohorts.

Bayesian statistics showed there was anecdotal evidence for the null hypothesis in the SW1 cohort ($BF_{10}=0.92$). There was strong evidence for the null hypothesis in the SW2 cohort ($BF_{10}=0.09$) and the NP cohort ($BF_{10}=0.1$). The null hypothesis proposed there is an absence of an effect of group in total false positives.

The sample size of each cohort and the number of participants removed following outlier analysis is detailed in Table 42.

Table 42 Sample sizes for GNG total false positives (%)

Cohort	Groups	n	Removed through outlier analysis
SW1	Night	12	1
	Rotating	37	3
	Day	18	1
SW2	Night	23	0
	Rotating	60	1
	Day	40	1
NP	NP male	30	1
	NP female	61	0
	C male	25	1
	C female	11	0

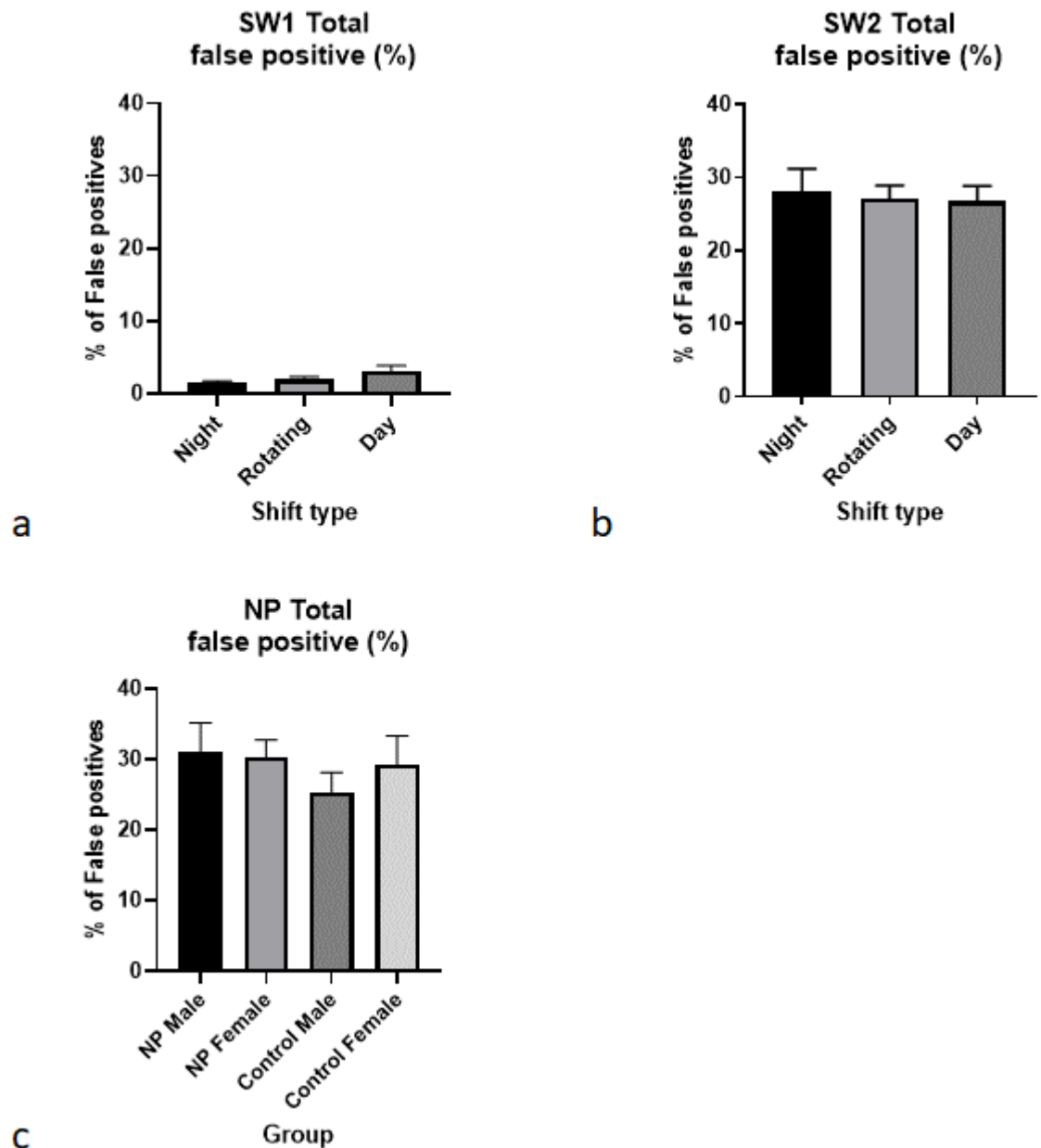


Figure 18 GNG Percentage of false positives a) SW1 cohort b) SW2 cohort c) NP cohort. Error bars indicate SEM.

As with previous variables, analysis was run again with shift groups split by BSWSQ score. Table 43 details the statistical analysis for each BSWSQ score and sample. Where data did not pass a normality test it was transformed. The transformation applied is indicated in the table. Where data could not be made normal, nonparametric analysis was used.

Table 43 GNG Percentage of false positives BSWSQ score grouping

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	H(3)=1.39, p=0.71, $\eta_H=0.03$	H(3)=1.29, p=0.73, $\eta_H=0.04$	U=249, p=0.95, r=0.01	H(3)=3.53, p=0.32, $\eta_H=0.01$
SW2	F(3,83)=1.12, p=0.34, $\eta^2=0.04$	F(3,74)=0.29, p=0.83, $\eta^2=0.01$	t(71)=1.11, p=0.27, $\eta^2=0.02$	F(3,104)=1.19, p=0.32, $\eta^2=0.03$

No significant differences were seen between High and Low Bergen shift and control groups when examining percentage of false positives.

Further correlation analysis was run between BSWSQ score and total false positives. Table 44 details the statistical analysis for each BSWSQ score and sample

Table 44 GNG Percentage of false positives correlations

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	$r_s(50)=0.09$, $p=0.54$, observed power=0.05	$r_s(50)=0.07$, $p=0.65$, observed power=0.17	$r_s(44)=-0.16$, $p=0.299$, observed power=0.05	$r_s(63)=0.09$, $p=0.47$, observed power=0.18
SW2	$r(85)=0.13$, $p=0.22$, observed power=0.24	$r_s(76)=0.02$, $p=0.89$, observed power=0.07	$r(71)=0.19$, $p=0.10$, observed power=0.38	$r_s(106)=0.16$, $p=0.12$, observed power=0.24

No significant correlations between BSWSQ score and percentage of false positives were found in either cohort.

ANCOVAs were run using the BSWSQ rest score groupings. In SW1 the covariate, age, was not significantly related to total false positives ($F(1,60)=0.12$, $p=0.74$, $\eta^2=0.002$). There was also no effect of BSWSQ group on total false positives after controlling for age ($F(3,60)=0.36$, $p=0.78$, $\eta^2=0.02$). The covariate 'years worked shifts' was not significantly related to total false positives ($F(3,60)=0.33$, $p=0.57$, $\eta^2=0.01$). There was also no effect of BSWSQ group on total false positives after controlling for years worked shifts ($F(3,60)=0.30$, $p=0.83$, $\eta^2=0.02$).

In the SW2 cohort sex, country of testing, activity level and time awake were not significantly related to total false positives. Further, in these demographic variables, there was no effect of group on total false positives when demographic variables were controlled for.

The covariate sleep time was significantly related to total false positives ($F(1,100)=6.69$, $p=0.01$, $\eta^2=0.06$). There was no effect of BSWSQ group on total false positives after controlling for sleep time ($F(3,100)=1.28$, $p=0.29$, $\eta^2=0.04$).

ANCOVA statistics can be found in Table 45.

Table 45 GNG Percentage of false positives x demographic variable ANCOVAs

Demographic variable	Main effect	Effect of group when demographic controlled for
Sex	$F(1,103)=2.12$, $p=0.15$, $\eta^2=0.02$	$F(3,103)=1.04$, $p=0.38$, $\eta^2=0.03$
Country	$F(1,103)=0.35$, $p=0.55$, $\eta^2=0.003$	$F(3,103)=1.15$, $p=0.33$, $\eta^2=0.03$
Activity level	$F(1,103)=0.04$, $p=0.83$, $\eta^2<0.001$	$F(3,103)=1.19$, $p=0.32$, $\eta^2=0.03$
Sleep time	$F(1,100)=6.69$, $p=0.01^{**}$, $\eta^2=0.06$	$F(3,100)=1.28$, $p=0.29$, $\eta^2=0.04$
Time awake	$F(1,100)=1.63$, $p=0.21$, $\eta^2=0.02$	$F(3,100)=1.03$, $p=0.38$, $\eta^2=0.03$

4.4.1.3 Mean reaction times showed no differences between group

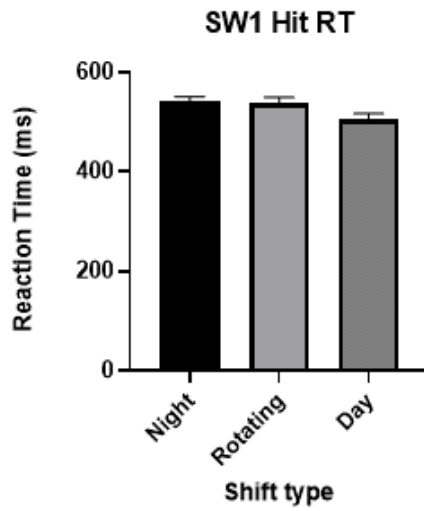
The sample size of each cohort and the number of participants removed following outlier analysis is detailed in Table 46. The average reaction times for each response type (hit or false positive) were calculated for each group. Statistical analysis outcomes are reported in Table 47, with no significant differences found in any group. Again, changes to task design intended to increase difficulty appear to have impacted performance, with reaction times for both hit and false positive responses becoming faster in the SW2 and NP cohorts (Figure 19).

Table 46 Sample sizes for GNG mean reaction time

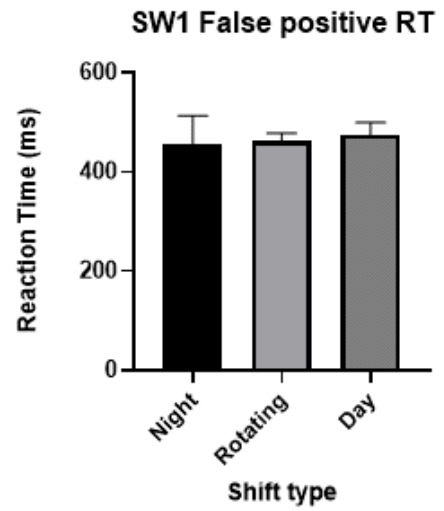
Cohort	Groups	Hit n	Removed through outlier analysis	False positive n	Removed through outlier analysis
SW1	Night	11	2	12	0
	Rotating	37	2	30	2
	Day	18	1	15	1
SW2	Night	21	2	21	2
	Rotating	60	1	60	1
	Day	38	3	40	1
NP	NP male	30	1	30	1
	NP female	57	4	56	4
	C male	25	1	25	1
	C female	11	0	11	0

Table 47 Statistical findings for outcome measure mean hit and false positive reaction times

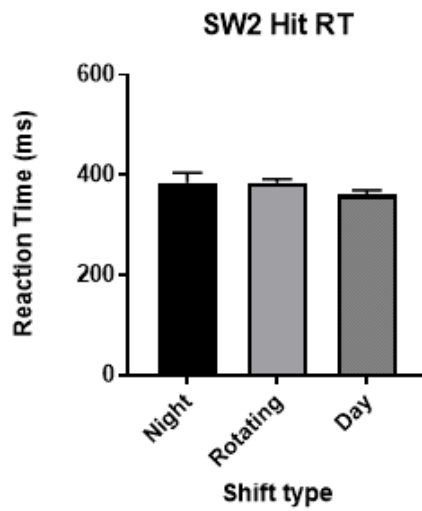
Outcome variable	ANOVA /Kruskal Wallis statistic	p value	Effect size
SW1 Hit	H(2)=5.289	0.071	$\eta_H=0.05$
SW1 False positive	H(2)=0.206	0.902	$\eta_H=0.03$
SW2 Hit	H(2)=3.162	0.206	$\eta_H=0.01$
SW2 False positive	H(2)=1.230	0.541	$\eta_H=0.01$
NP Hit	F(3,119)=0.790	0.502	$\eta^2=0.02$
NP False positive	F(3,118)=0.576	0.632	$\eta^2=0.01$



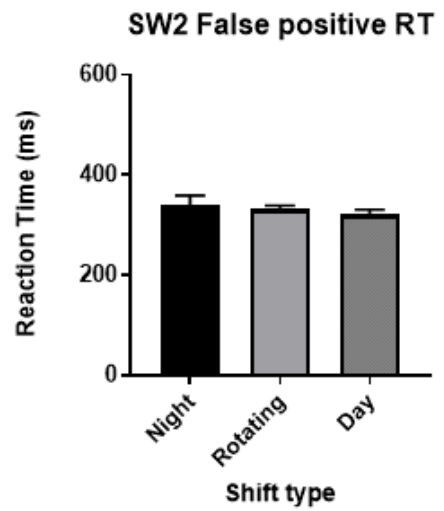
a



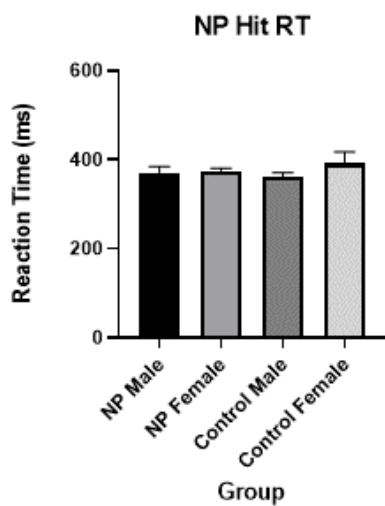
b



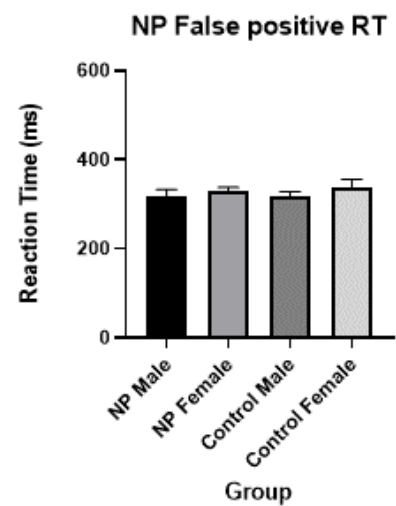
c



d



e



f

Figure 19 GNG Hit and false positive reaction times a) SW1 cohort b) SW2 cohort c) NP cohort. Error bars indicate SEM.

4.4.1.4 Within group RT comparisons suggest individuals respond faster to errors

Reaction times on hit and false positive trials were compared within group to determine if there was a response type dependant difference (Figures 20, 21 and 22). The sample size of each cohort and the number of participants removed following outlier analysis is detailed in Table 48. The outcomes of the statistical analysis are reported in Table 49. Whilst no significant differences were found within night shift workers in SW1, differences were seen in rotating and day workers in SW1 (Figure 20) and all groups in the SW2 cohort (Figure 21) and the NP cohort (Figure 22) with hit reaction times being consistently slower than false positive reaction times.

Table 48 Sample size of GNG within group RT comparisons

Cohort	Groups	n	Removed through outlier analysis
SW1	Night	11	1
	Rotating	28	3
	Day	15	1
SW2	Night	19	4
	Rotating	60	1
	Day	36	5
NP	NP male	30	1
	NP female	56	4
	C male	24	2
	C female	11	0

Table 49 Statistical analysis of within group hit/false positive reaction time comparison

Group	t/Wilcoxon statistic	p value	Effect size	Hit mean±SD	FP mean±SD
SW1 Night	t(10)=1.116	0.291	$\eta^2=0.11$	541.7 ± 28.15	465.9 ± 205.3
SW1 Rotating	t(27)=4.383	0.0002	$\eta^2=0.42$	539.7 ± 76.96	459.5 ± 94.29
SW1 Day/Evening	T=23	0.035	$r_{rb}=0.62$	508.5 ± 62.21	474.2 ± 98.23
SW2 Night	t(18)=5.269	<0.0001	$\eta^2=0.61$	360.8 ± 45.26	316.6 ± 54.04
SW2 Rotating	t(59)=8.602	<0.0001	$\eta^2=0.56$	384.4 ± 57.76	332.1 ± 53.06
SW2 Day	t(35)=8.762	<0.0001	$\eta^2=0.69$	361.2 ± 41.29	317.8 ± 46.88
NP Male (NP)	t(29)=5.754	<0.0001	$\eta^2=0.53$	371.3 ± 73.91	318.6 ± 79.74
NP Female (NP)	t(55)=10.74	<0.0001	$\eta^2=0.68$	375.9 ± 43.6	332.4 ± 45.39
NP Male (Control)	t(23)=8.161	<0.0001	$\eta^2=0.74$	365.4 ± 45.28	322.1 ± 48.62
NP Female (Control)	t(10)=4.181	0.0019	$\eta^2=0.64$	392.0 ± 86.10	337.3 ± 61.63

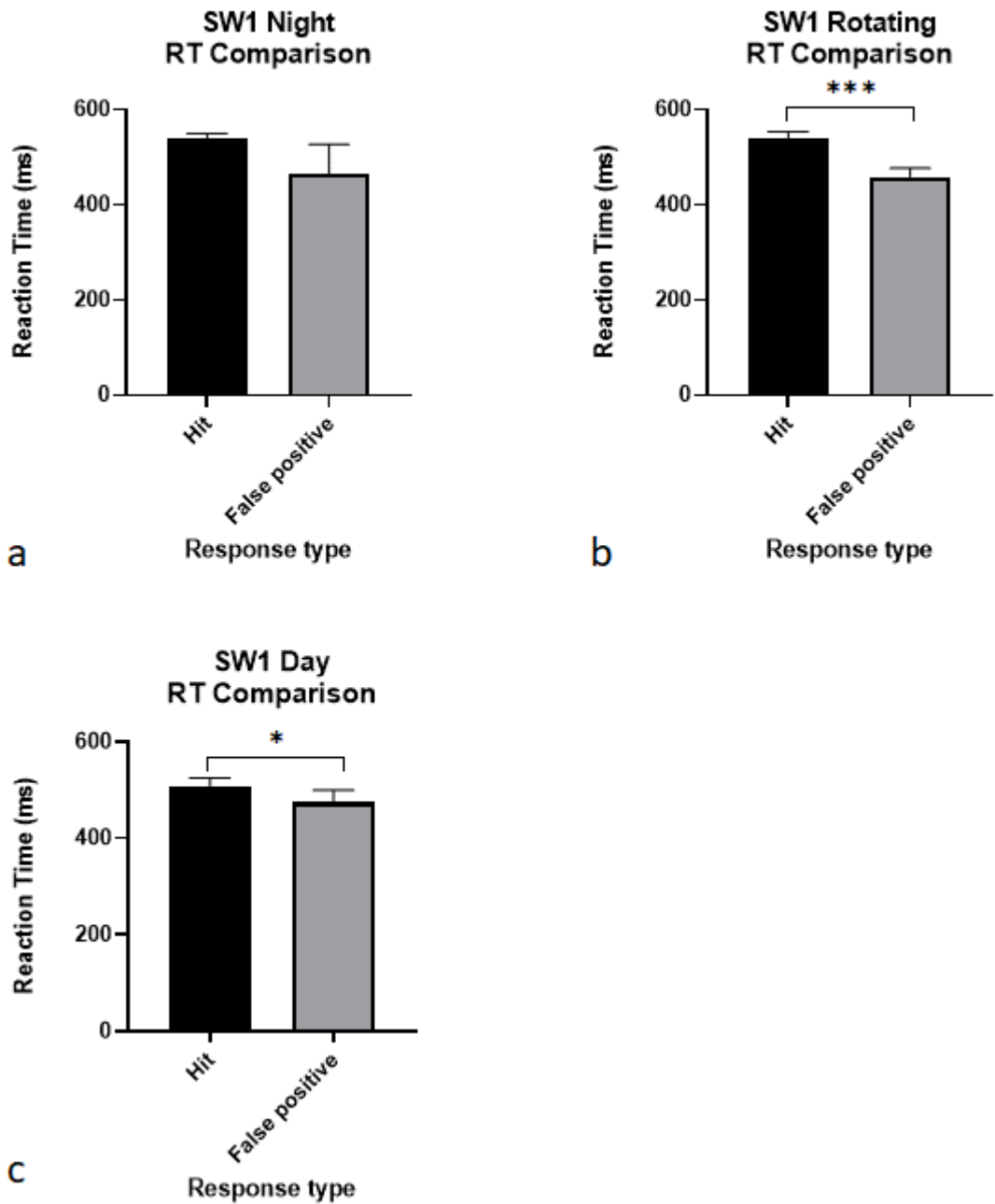


Figure 20 GNG Within group average reaction time (SW1) a) SW1 night shift workers b) SW1 rotating shift workers c) SW1 day shift workers. * refers to a p value <0.05, *** refers to a p value <0.001. Error bars indicate SEM.

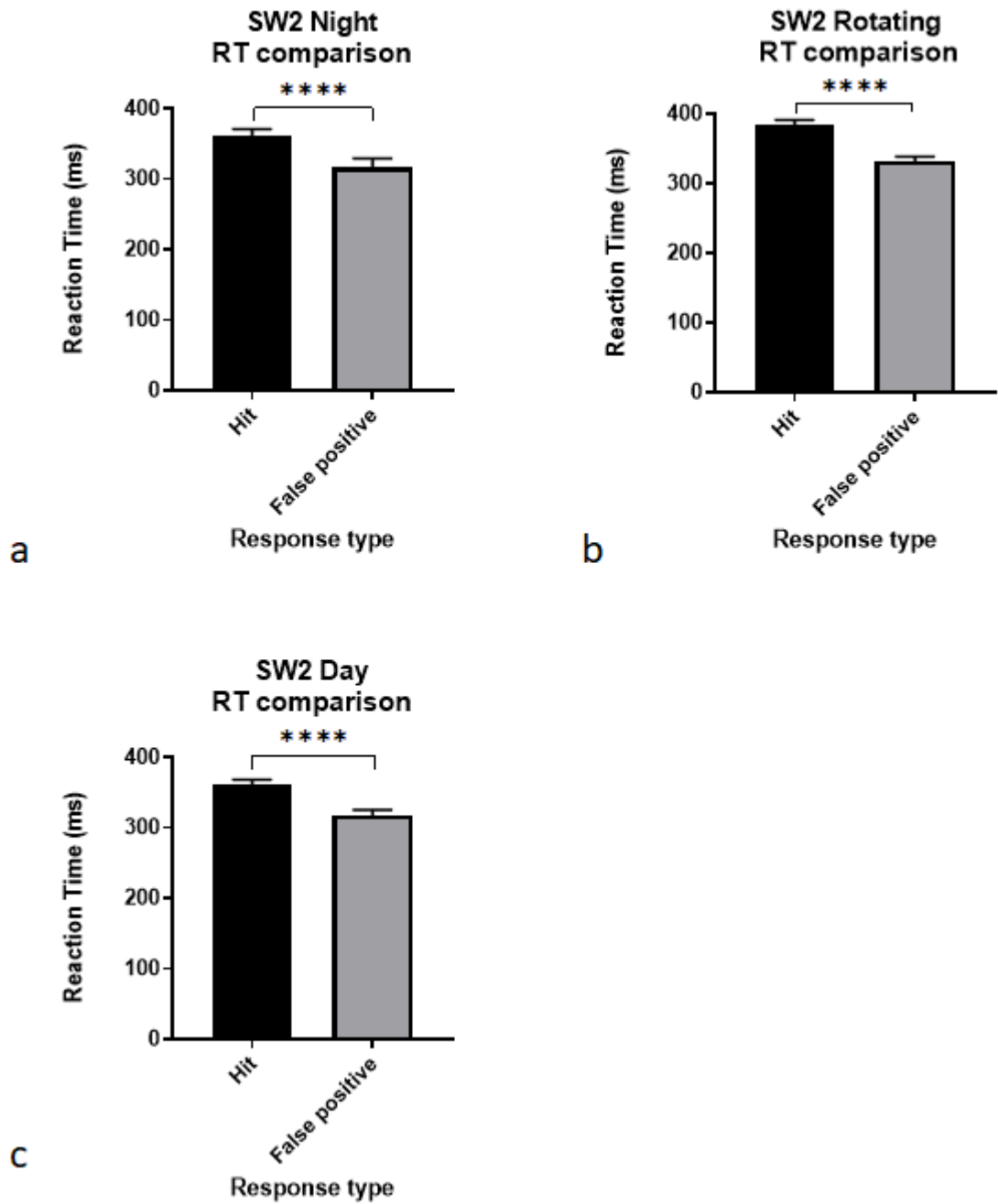


Figure 21 GNG within group average reaction time (SW2) a) SW2 night shift workers b) SW2 rotating shift workers c) SW2 day shift workers. **** refers to a p value <0.0001. Error bars indicate SEM.

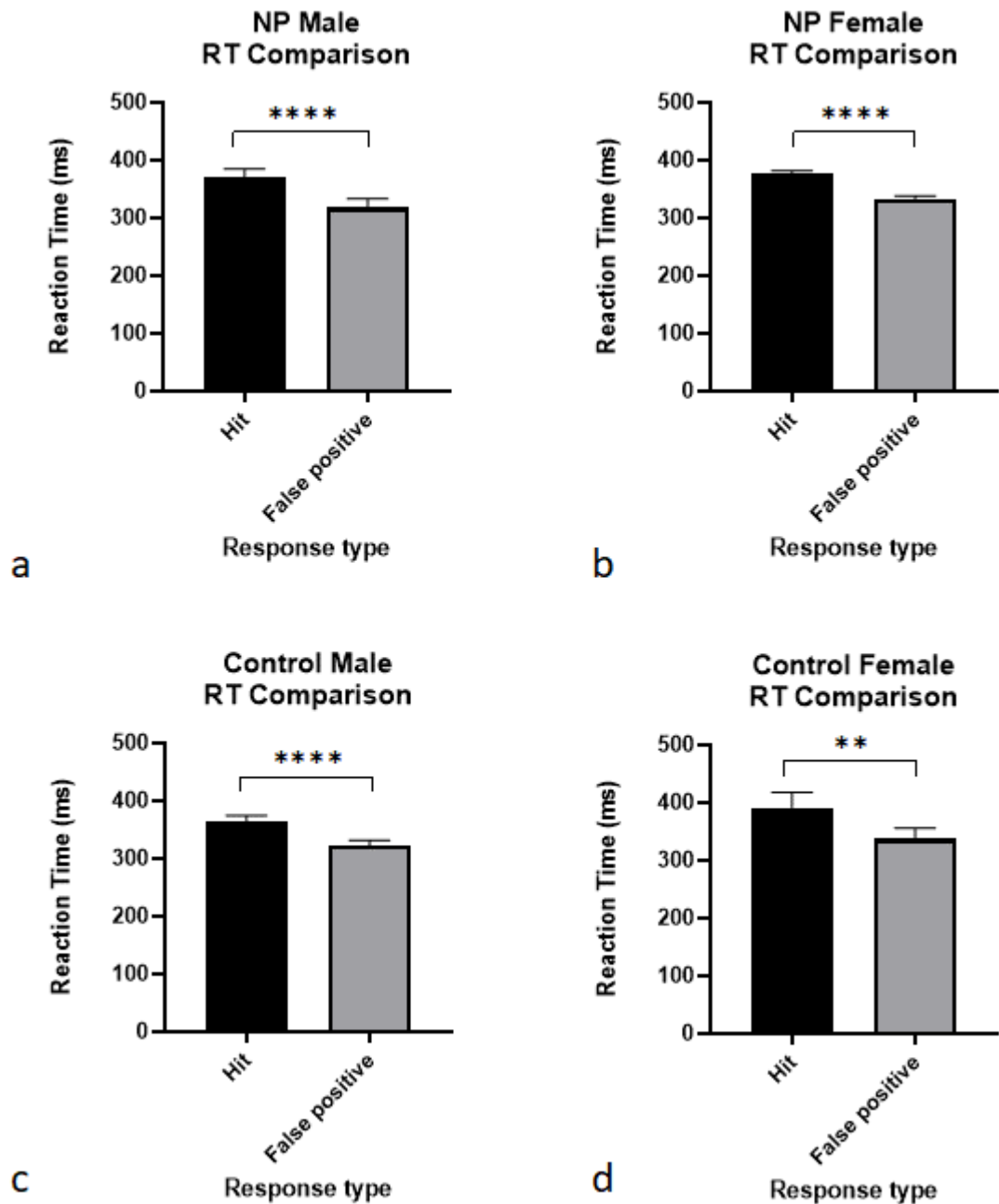


Figure 22 GNG within group average reaction time (NP) a) NP males b) NP females c) Control males d) Control females. ** refers to a p value <0.01, ** refers to a p value <0.0001. Error bars indicate SEM.**

4.4.1.5 Sensitivity measures

As explained in Chapter Three, due to the online nature of these studies, as well as the significant lack of impairment seen across multiple samples, it was necessary to further examine the sensitivity of the tasks used.

As with the PVT, increasing age has been linked to prolonged reaction time and performance impairment in a GNG task (Le, Chao, Levy, & Li, 2020). Correlation analysis was conducted on the SW2 sample, using mean reaction times of hits and false positives, to examine the impact of age.

Again as no significant differences were found on this variable, night, rotating and day participant groups were merged. A significant relationship was found between age and hit RT ($r_s(123)=0.32$, $p<0.001$, observed power=0.91) (Figure 23) and false positive RT ($r_s(123)=0.25$, $p=0.006$, observed power=0.63) (Figure 24). These outcomes suggest that the GNG used was sensitive to detect impairments in response inhibition. In particular the performance correlations suggest similar characteristics to other published tasks.

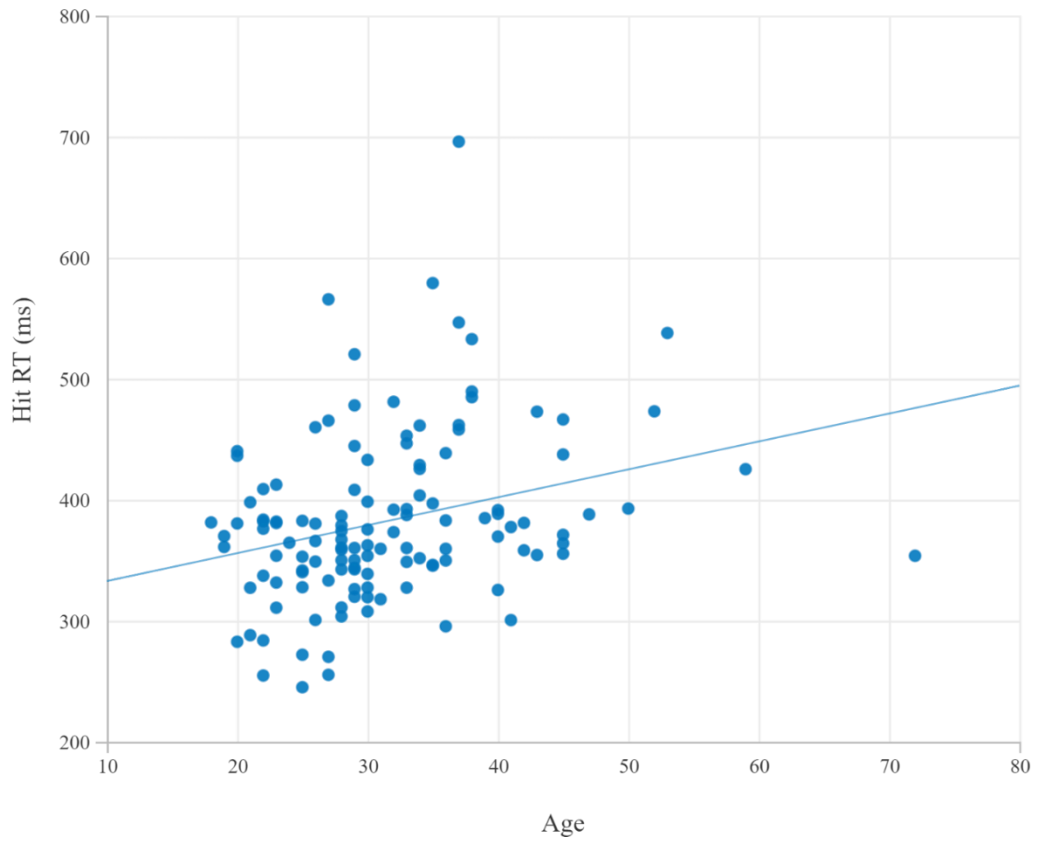


Figure 23 GNG Hit RT correlation

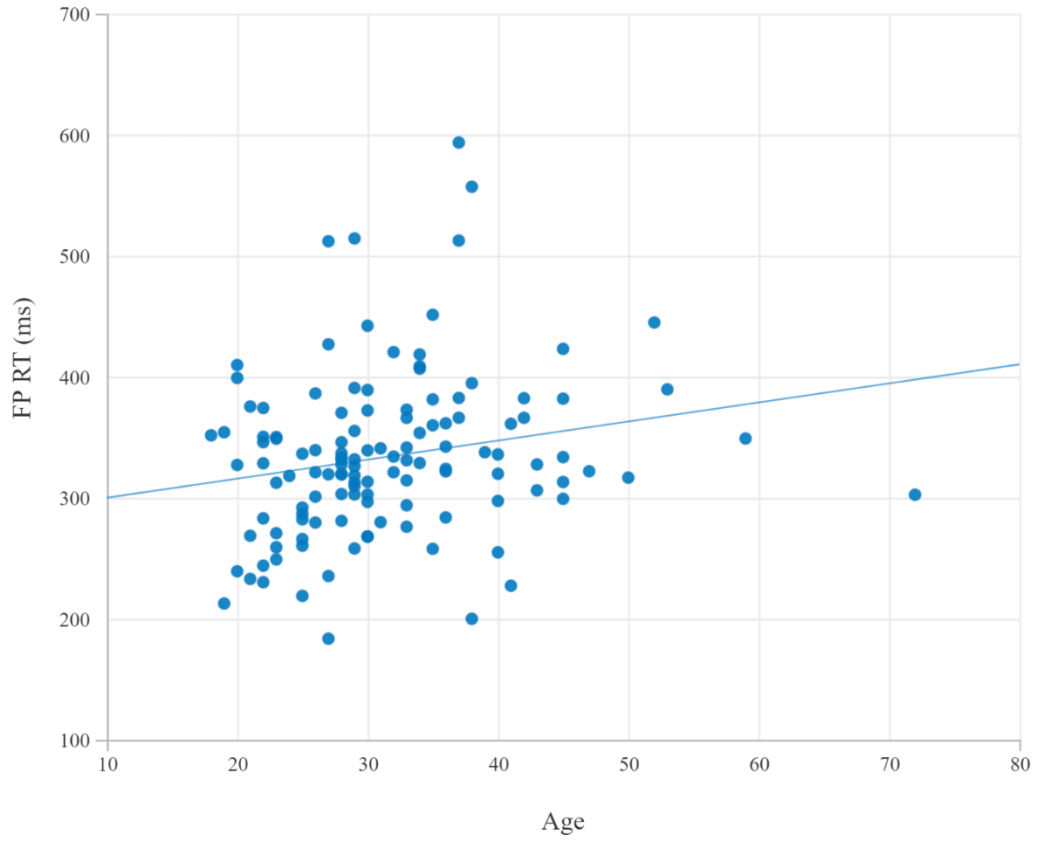


Figure 24 GNG False positive RT correlation

As with the PVT task, comparisons were made between the control participants in the SW2 and NP cohorts and controls found within the literature. The SW1 cohort was not included in this comparison due to the apparent ceiling effect present. Mander et al (2010) used a GNG however it did not use the same stimuli as the task used for the SW2 and NP cohorts. Reaction times were slower in the SW2 and NP cohort compared to the control used in Mander et al. As with the previous PVT task this may have been a result of the method of testing (Online VS In person). Though it is important to note that there is evidence to suggest that reaction times are not as easily translatable from in-person to online testing, due to the variations in computer hardware and response detection equipment (Backx, Skirrow, Dente, Barnett, & Cormack, 2020). More variation in the reaction times was seen in the Mander et al. task compared to those seen in the online version of the task. Given that the SEM describes how precise the mean is as an estimate of true mean of the population, this would indicate the online version was more accurate than Mander et al. Though the smaller SEM could be a result of a much larger sample size, compared to Mander et al., who only had nine participants. Outputs are described in Table 50.

Table 50 GNG comparisons

Cohort	Mean correct RT (SEM)
SW2	361.4 (7.76)
NP	370.50(10.56)
Mander et al	322.2 (22.22)

Further to the mean correct RT, Mander et al (2010) reported the correct inhibitions and correct responses as a % of each of those trial types. These were 92.6 (1.9) and 97.5 (1.6) respectively. As discussed previously the GNG task used in the SW1 cohort produced similarly high overall correct performance scores (all participants achieved at least 90% correct with a mean score of 96.01% for day workers). This outcome was attributed to a ceiling effect, with all participants getting between 90-100% correct. Therefore efforts were made to lower this however if the same principle were applied to Mander et al it would suggest that the task used there was also producing a ceiling effect.

Taken together with the other sensitivity measure it is possible that the testing environment led to higher reaction times across all samples, however there was still a range of reaction times that positively correlated with increasing age suggesting that the task was sensitive.

4.4.2 Eriksen flanker task

Due to the testing design, each shift classification had two participant groups, A and B. This was to control for any effects of assessment order. Two testing sequences were run and data from both assessment sequences was compared to determine if there was an order effect. Where no significant effect of order was detected, the two sub-groups were merged to increase group size

and statistical power. In this cohort no differences were found in any outcome measure so groups A and B were merged across all outcome variables.

4.4.2.1 Overall correct performance revealed no significant differences between shift types

Participants hits (correct responses) were calculated as a percentage of total trials presented (600 trials), and categorised into shift types (night, rotating, day). There was no significant difference between groups on overall correct performance ($H(2)=4.775$, $p=0.092$, $\eta_H=0.02$) (Figure 25).

Bayesian statistics showed there was moderate evidence for the alternative hypothesis ($BF_{10}=3.95$). The alternative hypothesis proposed there is an effect of group on overall correct performance.

The sample size of each cohort and the number of participants removed following outlier analysis is detailed in Table 51.

Table 51 Sample size of Eriksen flanker overall correct performance (%)

Cohort	Groups	n	Removed through outlier analysis
SW3	Night	8	0
	Rotating	43	1
	Day	65	9

Overall correct performance (% of 600)

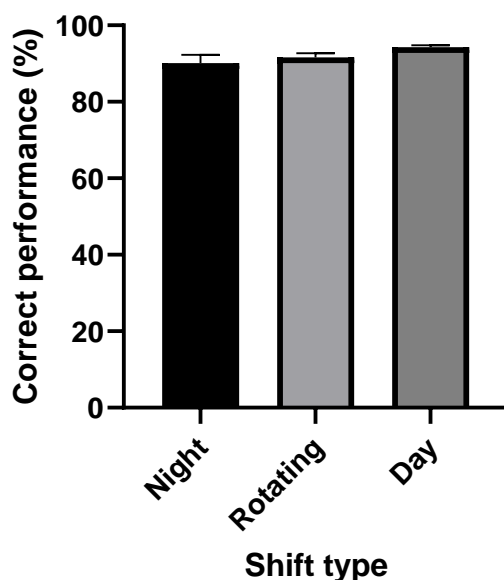


Figure 25 Eriksen flanker Overall correct performance Error bars indicate SEM.

As with the previous tasks, analysis was run again with shift groups split by BSWSQ score. Table 52 details the statistical analysis for each BSWSQ score and sample. Where data did not pass a

normality test it was transformed. The transformation applied is indicated in the table. Where data could not be made normal, nonparametric analysis was used.

Table 52 Eriksen flanker Overall correct performance BSWSQ score grouping

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW3	H(3)=4.81, p=0.19, $\eta_H=0.02$	H(3)=0.84, p=0.84, $\eta_H=0.04$	t(42)=1.63, p=0.11, $\eta^2=0.06$	H(3)=2.93, p=0.40, $\eta_H<0.01$

No significant differences were seen between High and Low Bergen shift and control groups when examining overall correct performance.

Further correlation analyses was run between BSWSQ score and overall correct performance.

Table 53 details the statistical analysis for each BSWSQ score and sample.

Table 53 Eriksen flanker Overall correct performance correlations

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW3	P(97)=-0.17, p=0.10, observed power=0.08	P(51)=-0.18, p=0.19, observed power=0.07	P(42)=-0.20, p=0.19, observed power=0.22	P(103)=-0.01, p=0.91, observed power=0.14

No significant correlations between BSWSQ score and overall correct performance were found.

ANCOVAs were run using the BSWSQ rest score groupings. In the SW3 cohort age and country of testing were not significantly related to overall correct performance. Further there was no effect of group on overall correct performance when these demographic variables were controlled for.

The covariate, activity level was significantly related to overall correct performance ($F(1,100)=4.30$, $p=0.04$, $\eta^2=0.04$). There was no effect of BSWSQ group on overall correct performance after controlling for activity level ($F(3,100)=1.52$, $p=0.21$, $\eta^2=0.04$). The covariate, years worked shifts was significantly related to overall correct performance ($F(1,100)=5.42$, $p=0.02$, $\eta^2=0.05$). There was no effect of BSWSQ group on overall correct performance after controlling for years worked shifts ($F(3,100)=1.00$, $p=0.40$, $\eta^2=0.03$). ANCOVA statistics can be found in Table 54.

Table 54 Eriksen flanker Overall correct performance x demographic variable ANCOVAs

Demographic variable	Main effect	Effect of group when demographic controlled for
Age	$F(1,100)=3.56$, $p=0.06$, $\eta^2=0.03$	$F(3,100)=0.81$, $p=0.49$, $\eta^2=0.02$
Country	$F(1,100)=1.89$, $p=0.17$, $\eta^2=0.02$	$F(3,100)=0.98$, $p=0.41$, $\eta^2=0.03$
Activity level	$F(1,100)=4.30$, $p=0.04^*$, $\eta^2=0.04$	$F(3,100)=1.52$, $p=0.21$, $\eta^2=0.04$
YWS	$F(1,100)=5.42$, $p=0.02^*$, $\eta^2=0.05$	$F(3,100)=1.00$, $p=0.40$, $\eta^2=0.03$

4.4.2.2 Congruent and incongruent trial data showed no evidence of shift type dependant changes (percentage of incorrect responses)

The percentage of incorrect responses (incorrect press) was calculated for both congruent and incongruent trials, based on the total number of trials responded to by each individual. Analysis showed no significant main effect of group in either congruent ($H(2)=2.334$, $p=0.311$, $\eta_H<0.01$) or incongruent trials ($H(2)=1.783$, $p=0.41$, $\eta_H<0.01$) (Figure 26). The sample size of each cohort and the number of participants removed following outlier analysis is detailed in Table 55.

Table 55 Sample size of Eriksen flanker percentage of incorrect responses (congruent and incongruent)

Cohort	Groups	Congruent n	Removed through outlier analysis	Incongruent n	Removed through outlier analysis
SW3	Night	8	0	8	0
	Rotating	42	2	43	1
	Day	65	9	68	6

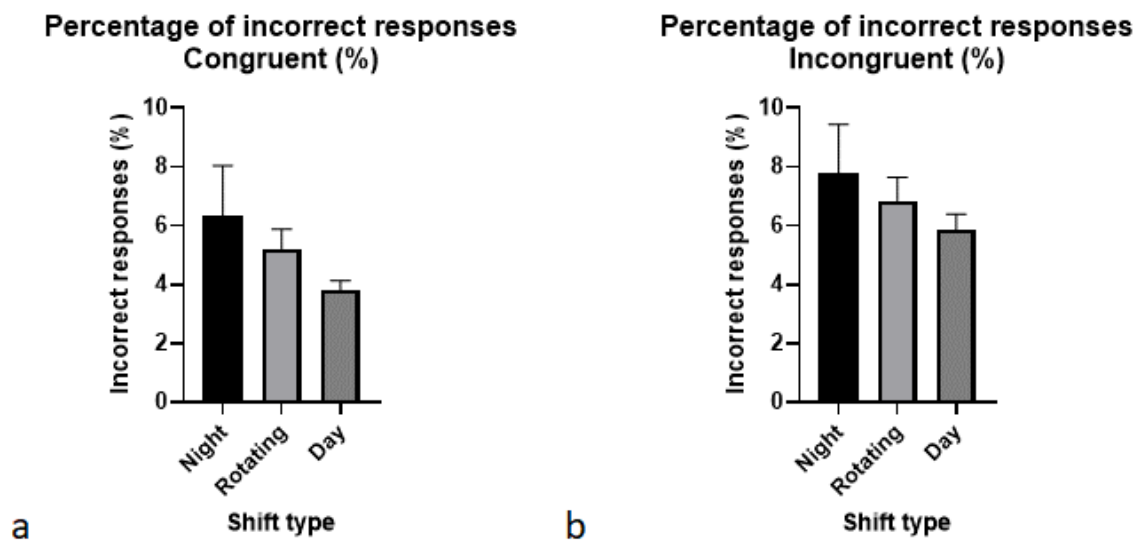


Figure 26 Eriksen flanker percentage of incorrect responses (as a percentage of total trials responded to) (a) Congruent trials (b) Incongruent trials. Error bars indicate SEM.

4.4.2.3 Missed trials showed no shift type dependant differences

The total number of trials in which a participant did not respond at all (missing trials) showed no main effect of group ($H(2)=3.892$, $p=0.143$, $\eta_H=0.02$)(Figure 27). The sample size of each cohort and the number of participants removed following outlier analysis is detailed in Table 56.

Table 56 Sample size of Eriksen flanker number of missed trials

Cohort	Groups	n	Removed through outlier analysis
SW3	Night	8	0
	Rotating	40	4
	Day	64	10

Number of missed trials

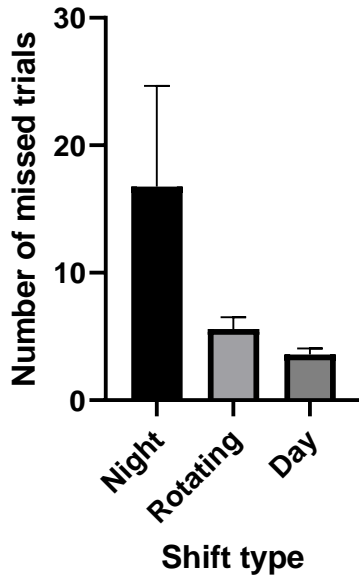


Figure 27 Number of missed trials, of a potential 600 trials. Error bars indicate SEM.

4.4.2.4 Mean reaction times showed no shift dependant significant differences

For each participant the mean reaction time was calculated for each response/trial type (congruent hit, congruent incorrect press (IP), incongruent hit, incongruent IP). The sample size of each cohort and the number of participants removed following outlier analysis is detailed in Table 57. The outcomes of statistical analysis of these data are reported in Table 58. No main effects of group on average reaction time were observed, regardless of trial or response type (Figure 28).

Bayesian statistics showed there was moderate evidence for the null hypothesis in Congruent Hit RT (BF10=0.12), Congruent IP RT (BF10=0.17) and Incongruent Hit RT (BF10=0.12). There was anecdotal evidence for the null hypothesis in Incongruent IP RT (BF10=0.53). The null hypothesis proposed there is an absence of an effect of shift group on reaction time.

Table 57 Sample size of Eriksen flanker mean reaction times

Cohort	Groups	Congruent Hit n	Congruent IP n	Incongruent Hit n	Incongruent IP n
SW3	Night	8	8	8	8
	Rotating	44	39	44	40
	Day	73	69	73	72
Removed through outlier analysis	Night	0	0	0	0
	Rotating	0	3	0	4
	Day	1	2	1	2

Table 58 Average reaction time between groups

Trial type	Response type	ANOVA/Kruskal-Wallis statistic	p value	Effect size
Congruent	Hit	F(2,122)=0.151	0.8597	$\eta^2=0.002$
Congruent	Incorrect press	H(2)=0.430	0.807	$\eta_H=0.01$
Incongruent	Hit	H(2)=0.264	0.876	$\eta_H=0.01$
Incongruent	Incorrect press	H(2)=1.831	0.400	$\eta_H=<0.01$

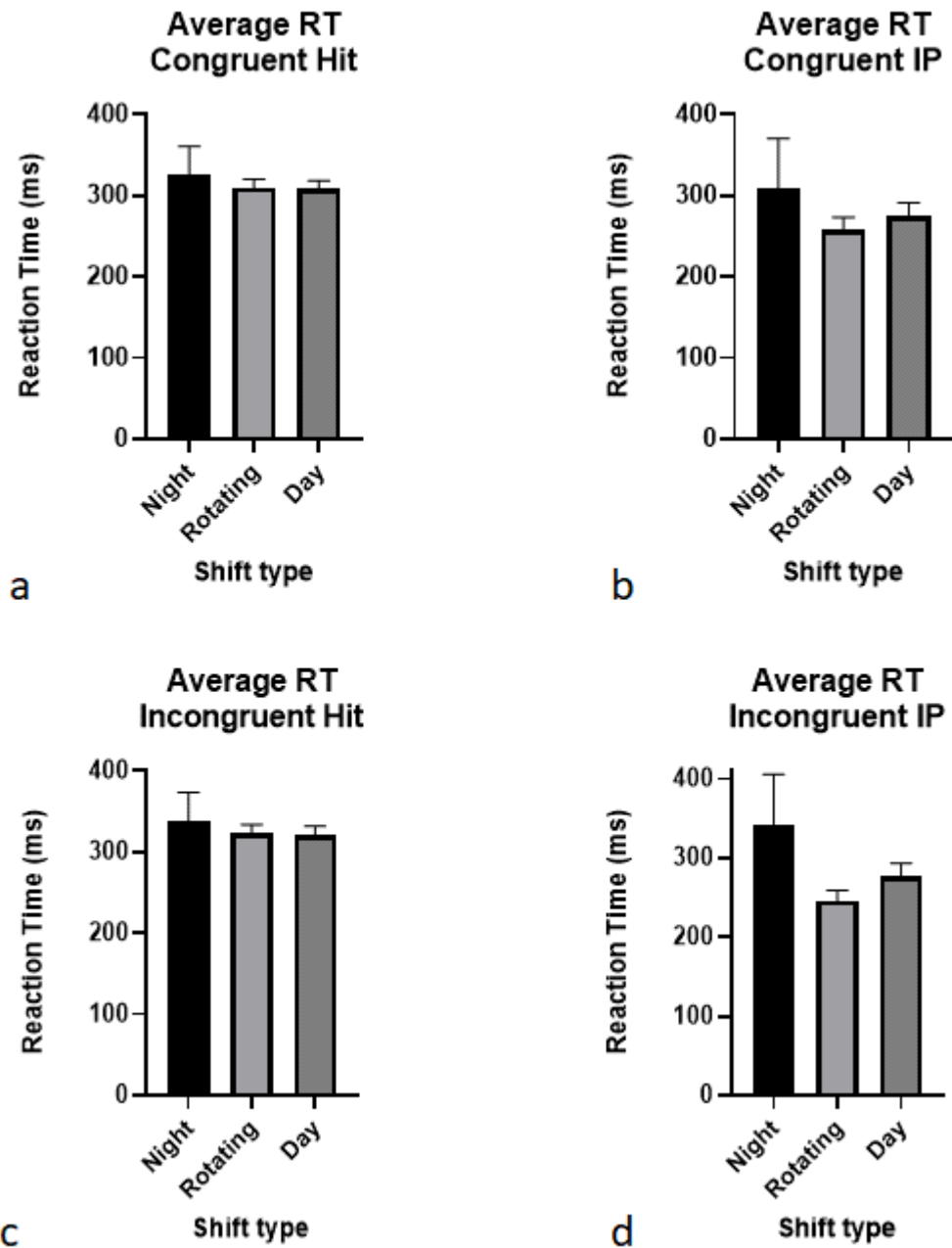


Figure 28 Average reaction time (a) Congruent hit (b) Congruent incorrect press (c) Incongruent hit (d) Incongruent incorrect press. Error bars indicate SEM.

As with the previous variables, analysis was run again with shift groups split by BSWSQ score. Table 59 details the statistical analysis for each BSWSQ score and sample. Where data did not pass a normality test it was transformed. The transformation applied is indicated in the table. Where data could not be made normal, nonparametric analysis was used.

Table 59 Eriksen flanker Average reaction time BSWSQ score grouping

Variable	Day (A)	Evening (B)	Night (C)	Rest (D)
Congruent Hit	F(3,95)=0.62, p=0.60, $\eta^2=0.02$	F(3,49)=1.83, p=0.15, $\eta^2=0.10$	t(42)=0.53, p=0.598, $\eta^2=0.01$	F(3,101)=1.75, p=0.16, $\eta^2=0.05$
Congruent IP	F(3,92)=1.09, p=0.36, $\eta^2=0.03$ (Log Transformed)	F(3,48)=1.55, p=0.21, $\eta^2=0.09$ (Log Transformed)	t(41)=1.05, p=0.299, $\eta^2=0.03$ (1/ Transformed)	F(3,98)=1.06, p=0.37, $\eta^2=0.03$ (Log Transformed)
Incongruent Hit	F(3,95)=0.51, p=0.68, $\eta^2=0.02$	F(3,49)=1.06, p=0.37, $\eta^2=0.06$	t(42)=0.20, p=0.84, $\eta^2=0.001$	F(3,101)=2.16, p=0.097, $\eta^2=0.06$
Incongruent IP	F(3,95)=1.42, p=0.24, $\eta^2=0.04$ (Log Transformed)	F(3,49)=2.05, p=0.12, $\eta^2=0.11$ (Log Transformed)	t(42)=0.19, p=0.85, $\eta^2=0.001$ (Log Transformed)	F(3,101)=0.47, p=0.70, $\eta^2=0.01$ (Log Transformed)

No significant differences were seen between High and Low Bergen shift and control groups when examining average reaction time.

Further correlation analyses was run between BSWSQ score and mean reaction time. Table 60 details the statistical analysis for each BSWSQ score and sample.

Table 60 Eriksen flanker Average reaction time correlations

Variable	Day (A)	Evening (B)	Night (C)	Rest (D)
Congruent Hit	$r(97)=-0.07$, p=0.52, observed power=0.095	$r(51) < 0.01$, p=0.98, observed power=0.03	$r(42)=-0.01$, p=0.93, observed power=0.03	$r_s(103)=0.15$, p=0.12, observed power=0.13
Congruent IP	$r_s(94)=-0.10$, p=0.34, observed power=0.25	$r_s(50)=0.13$, p=0.37, observed power=0.13	$r_s(41)=0.16$, p=0.31, observed power=0.03	$r_s(100)=0.06$, p=0.56, observed power=0.10
Incongruent Hit	$r_s(97)=-0.08$, p=0.44, observed power=0.097	$r(51)=-0.05$, p=0.71, observed power=0.06	$r(42)=-0.06$, p=0.71, observed power=0.06	$r_s(103)=0.19$, p=0.058, observed power=0.19
Incongruent IP	$r_s(97)=-0.10$, p=0.34, observed power=0.399	$r_s(51) < 0.01$, p=0.997, observed power=0.05	$r_s(42)=-0.02$, p=0.91, observed power=0.03	$r_s(103)=0.04$, p=0.69, observed power=0.06

No significant correlations between BSWSQ score and average reaction time were found.

ANCOVAs were run using the BSWSQ rest score groupings. In the SW3 cohort the covariate age was significantly related to congruent hit RT (F(1,100)=4.65, p=0.03, $\eta^2=0.04$) however there was no effect of BSWSQ group on congruent hit RT after controlling for age (F(3,100)=1.18, p=0.32, $\eta^2=0.03$).

The covariate age was significantly related to incongruent hit RT ($F(1,100)=4.98$, $p=0.03$, $\eta^2=0.05$) however there was no effect of BSWSQ group on incongruent hit RT after controlling for age ($F(3,100)=1.51$, $p=0.22$, $\eta^2=0.04$).

All other demographic covariates were not significantly related to each of the outcome measures (congruent hit, congruent IP, incongruent hit and incongruent IP). Further there was no effect of group on these outcome measures when these demographic variables were controlled for.

ANCOVA statistics can be found in Table 61.

Table 61 Eriksen flanker Average reaction time x demographic variable ANCOVAs

Response type	Demographic variable	Main effect	Effect of group when demographic controlled for
Congruent Hit RT	Age	$F(1,100)=4.65$, $p=0.03^*$, $\eta^2=0.04$	$F(3,100)=1.18$, $p=0.32$, $\eta^2=0.03$
	Country	$F(1,100)=0.02$, $p=0.89$, $\eta^2<0.01$	$F(3,100)=1.60$, $p=0.20$, $\eta^2=0.05$
	Activity level	$F(1,100)=1.48$, $p=0.23$, $\eta^2=0.01$	$F(3,100)=1.96$, $p=0.12$, $\eta^2=0.06$
	YWS	$F(1,100)=2.86$, $p=0.90$, $\eta^2=0.03$	$F(3,100)=1.42$, $p=0.24$, $\eta^2=0.04$
Congruent IP RT	Age	$F(1,97)=3.11$, $p=0.08$, $\eta^2=0.03$	$F(3,97)=1.79$, $p=0.15$, $\eta^2=0.05$
	Country	$F(1,97)=1.78$, $p=0.19$, $\eta^2=0.02$	$F(3,97)=1.96$, $p=0.13$, $\eta^2=0.06$
	Activity level	$F(1,97)=0.69$, $p=0.41$, $\eta^2=0.01$	$F(3,97)=1.27$, $p=0.29$, $\eta^2=0.04$
	YWS	$F(1,97)=1.39$, $p=0.24$, $\eta^2=0.01$	$F(3,97)=1.63$, $p=0.19$, $\eta^2=0.05$
Incongruent Hit RT	Age	$F(1,100)=4.98$, $p=0.03^*$, $\eta^2=0.05$	$F(3,100)=1.51$, $p=0.22$, $\eta^2=0.04$
	Country	$F(1,100)=0.24$, $p=0.62$, $\eta^2=0.002$	$F(3,100)=1.89$, $p=0.14$, $\eta^2=0.05$
	Activity level	$F(1,100)=1.11$, $p=0.29$, $\eta^2=0.01$	$F(3,100)=2.33$, $p=0.08$, $\eta^2=0.07$
	YWS	$F(1,100)=3.72$, $p=0.06$, $\eta^2=0.03$	$F(3,100)=1.78$, $p=0.16$, $\eta^2=0.05$
Incongruent FP RT	Age	$F(1,100)=1.92$, $p=0.17$, $\eta^2=0.02$	$F(3,100)=0.55$, $p=0.65$, $\eta^2=0.02$
	Country	$F(1,100)=0.0004$, $p=0.99$, $\eta^2<0.001$	$F(3,100)=0.67$, $p=0.57$, $\eta^2=0.02$
	Activity level	$F(1,100)=3.39$, $p=0.07$, $\eta^2=0.03$	$F(3,100)=1.12$, $p=0.35$, $\eta^2=0.03$
	YWS	$F(1,100)=0.84$, $p=0.36$, $\eta^2=0.01$	$F(3,100)=0.51$, $p=0.68$, $\eta^2=0.02$

4.4.2.5 Reaction time comparisons within group

Correct vs. incorrect response reaction times for both congruent and incongruent trials were analysed within each shift group. The sample size of each cohort and the number of participants

removed following outlier analysis is detailed in Table 62. Statistical analysis outcomes are reported in Table 63. Whilst no significant differences were observed within the night shift group, there were significant differences between hit and false positive reaction times within both trial types in rotating and day shift groups, with hit reaction times being significantly slower than false positives (Figure 29).

Table 62 Sample size of Eriksen flanker reaction time comparisons within group

Cohort	Groups	n (congruent and incongruent)	Removed through outlier analysis
SW3	Night	8	0
	Rotating	37	5
	Day	67	4

Table 63 Statistical outputs for within group reaction time comparisons *t*= student *t*-test, *T*= Wilcoxon

Shift group	Trial type	Statistical analysis outcome	Effect size	Hit mean±SD	FP mean±SD
Night	Congruent	$t(7)=0.508$, $p=0.627$	$\eta^2=0.04$	325.4 ± 99.46	308.8 ± 175.0
	Incongruent	$t(7)=0.059$, $p=0.955$	$\eta^2=0.0005$	338.9 ± 96.82	341.1 ± 181.8
Rotating	Congruent	$T=130$, $p=0.0005$	$r_{rb}=0.63$	297.0 ± 72.76	253.6 ± 95.45
	Incongruent	$T=57$, $p<0.0001$	$r_{rb}=0.84$	309.3 ± 69.32	244.0 ± 95.58
Day	Congruent	$T=589$, $p=0.0005$	$r_{rb}=0.48$	297.8 ± 82.95	265.4 ± 128.5
	Incongruent	$T=484$, $p<0.0001$	$r_{rb}=0.58$	310.0 ± 85.07	268.5 ± 125.0

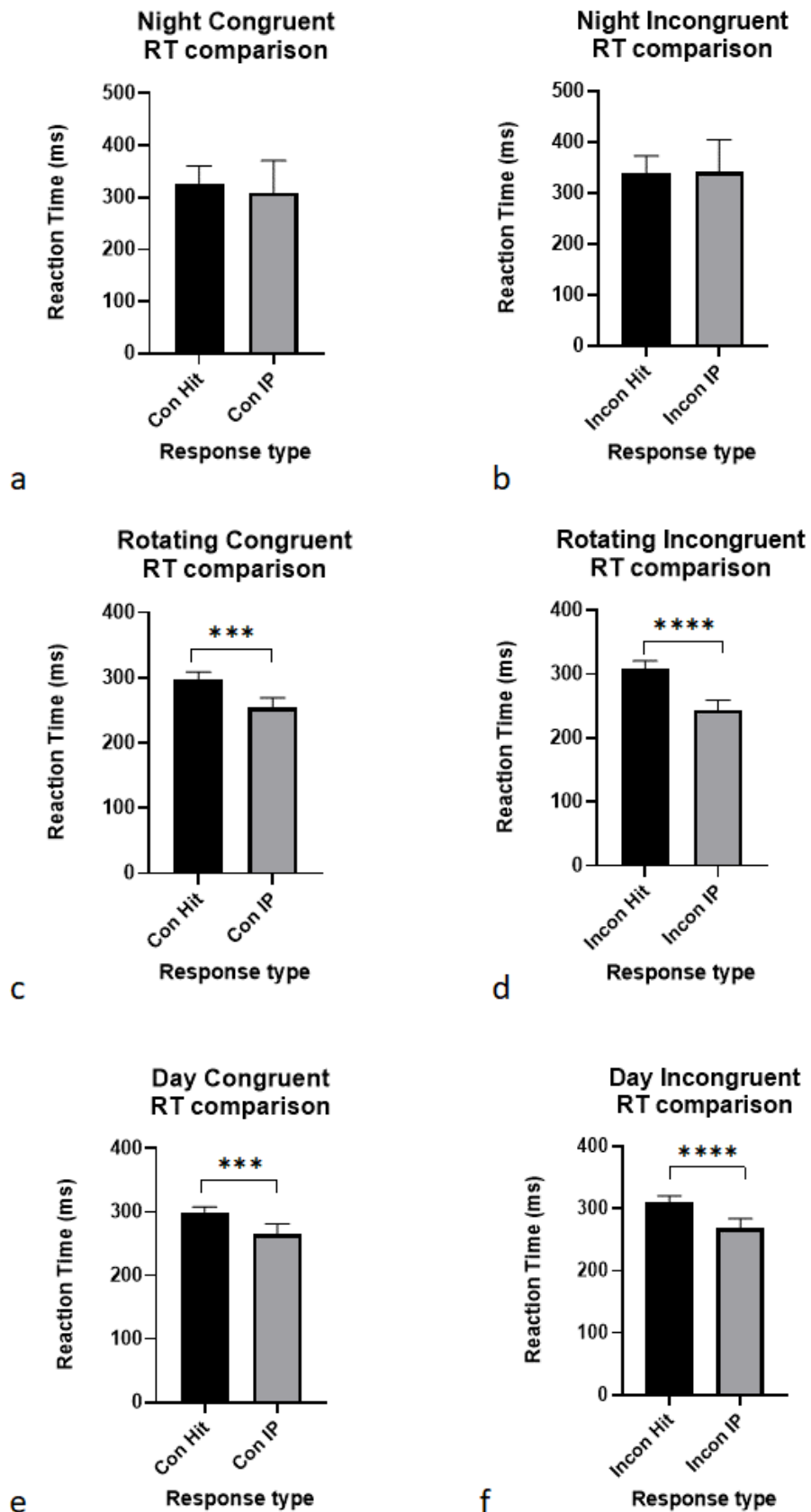


Figure 29 Eriksen flanker within shift type average RT comparisons (a) Night Congruent trials (b) Night Incongruent trials (c) Rotating Congruent trials (d) Rotating Incongruent trials (e) Day

*Congruent trials (f) Day Incongruent trials. *** refers to a p value <0.0005, **** refers to a p value <0.0001. Error bars indicate SEM.*

4.4.2.6 Sensitivity measures

Task sensitivity was examined with the use of a variable previously shown to be correlated with increasing reaction times, age. Salthouse (2010) found that increasing age was associated with slower performance in both congruent and incongruent trials (Salthouse, 2010). Therefore the relationship between age and the reaction times for each of the trial and response types was examined. As no significant differences were found in the analysis of these variables all three shift groups were collapsed to increase power.

A significant correlation was observed between age and Congruent Hit RT ($r_s(104)=0.28$, $p=0.003$, observed power=0.73, Figure 30), Incongruent Hit RT ($r_s(104)=0.29$, $p=0.002$, observed power=0.76, Figure 32) and Incongruent IP RT ($r_s(104)=0.20$, $p=0.04$, observed power=0.34, Figure 33).

There was no significant correlation between age and Congruent IP RT ($r_s(101)=0.19$, $p=0.051$, observed power=0.32). However if outliers were removed this relationship proved significant ($r_s(95)=0.22$, $p=0.03$, observed power=0.62, Figure 31).

Taken together these correlations suggest that the Eriksen flanker task used in this population was sensitive enough to detect impairments, therefore adding support to the results reported here. In particular the performance correlations suggest similar characteristics to other published tasks.

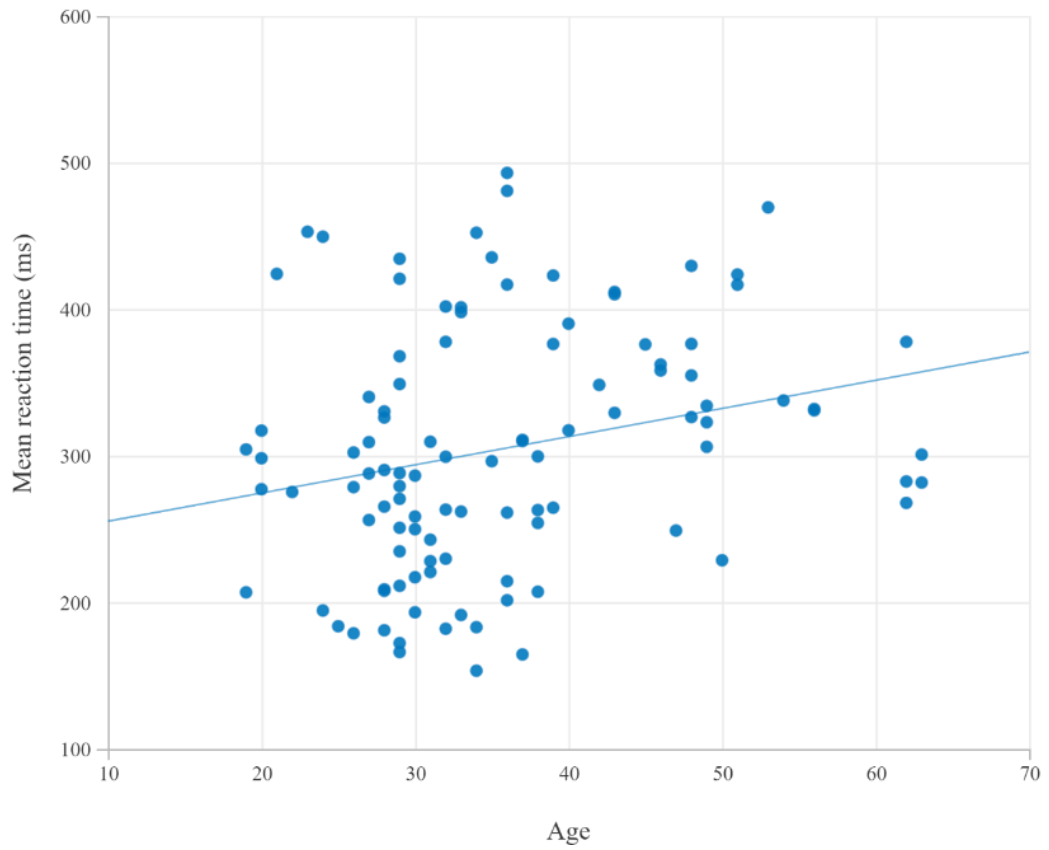


Figure 30 Congruent Hit RT correlation

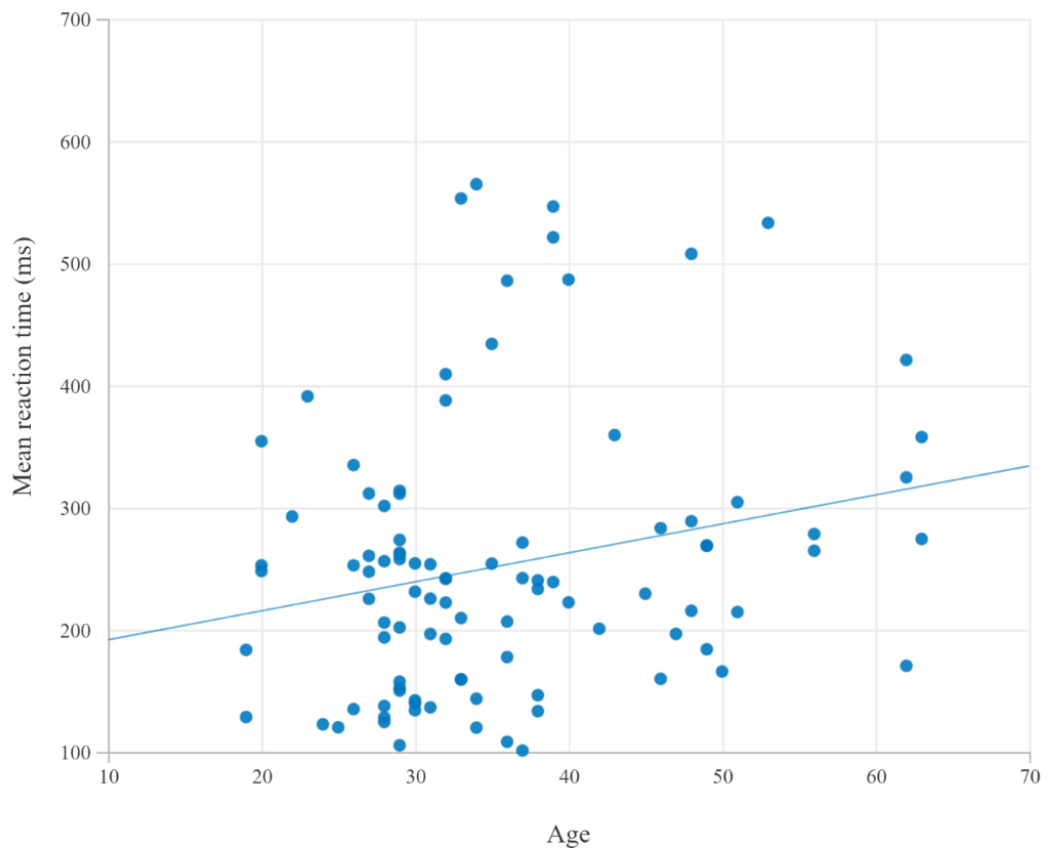


Figure 31 Congruent IP RT correlation

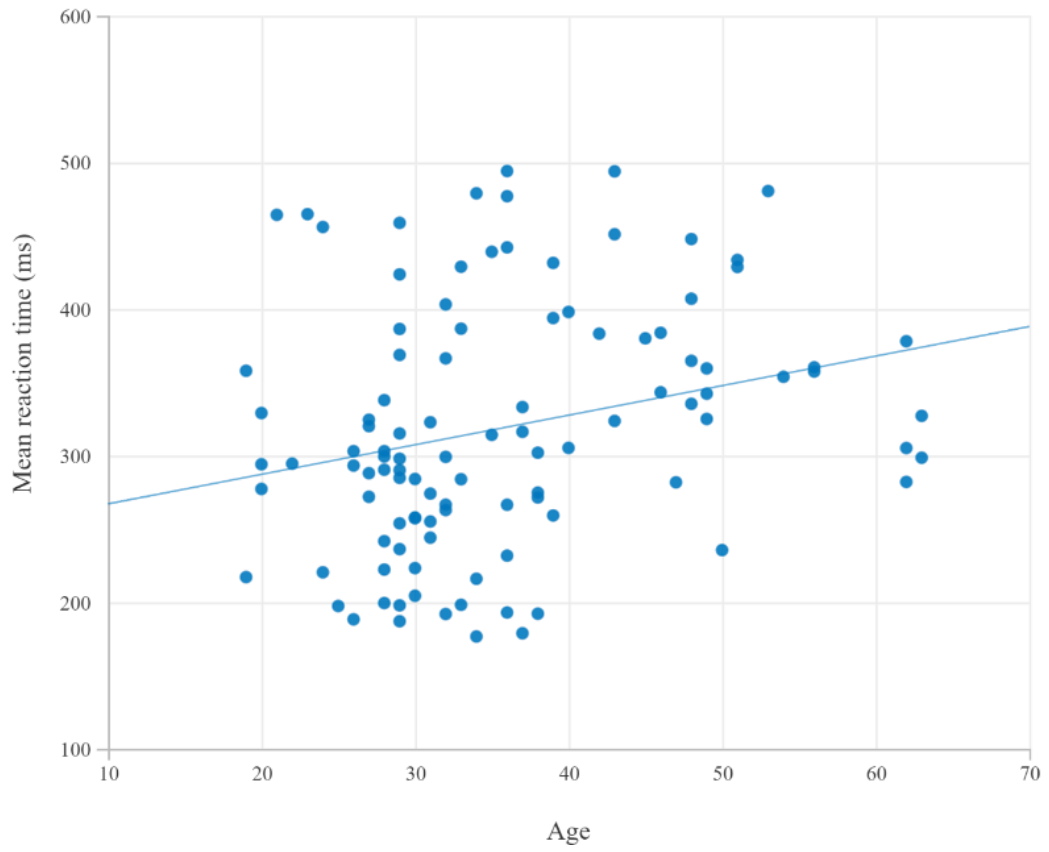


Figure 32 Incongruent Hit RT Correlation

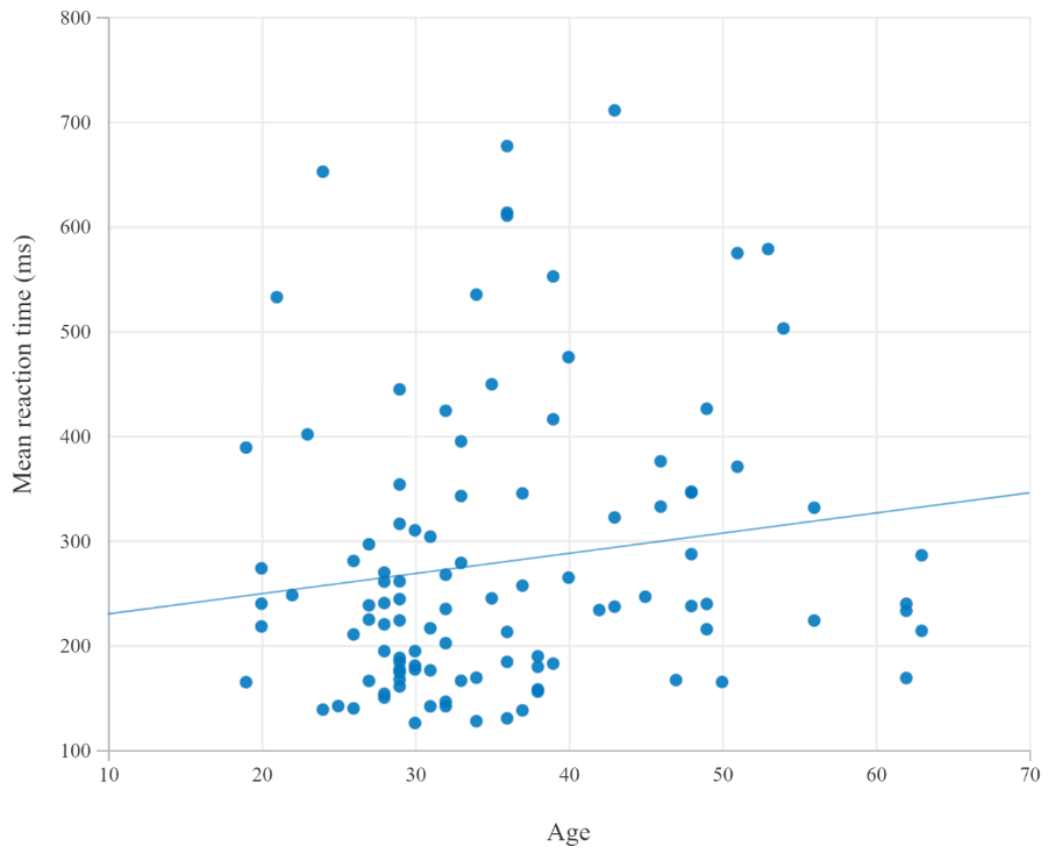


Figure 33 Incongruent IP RT Correlation

To explore the sensitivity of the Eriksen Flanker task used here further, average scores from control samples in the literature were extracted and compared with the day workers, who acted as a control in the present study. In Renn and Cote (2013), the paper on which the current task design was based, the mean reaction time for controls was 309.75 with a standard deviation of 35.43. Whilst an overall mean reaction time was not collected in the present study individual mean reaction times for each of the response types (congruent hit and IP and incongruent hit and IP) were calculated. For the day workers these were as follows; mean congruent hit RT=308.1 SD=87.65, mean congruent IP RT=274.7 SD=137.7, mean incongruent hit RT=320.8 SD=90.26 and mean incongruent IP RT=277.4 SD=134.9. The mean of all these reaction times combined was 295.59 SD=115.77. This is a difference of 14.16 ms, however the present study has a larger standard deviation. Given the relatively small difference in mean reaction times it suggests that the present Eriksen Flanker task is in line with that used in Renn and Cote (2013). The increased SD could suggest enhanced variability although this may be a cohort effect.

Further, number of missed trials was also extracted in both the present study and Renn and Cote (2013). The mean missed trials in the controls of Renn and Cote was 0.67, SD=1.01, and in the day workers 3.58, SD=3.89. This suggests that the participants in the SW3 cohort were more error prone than the control sample in Renn and Cote. This could be due to the online nature of the present study, meaning a lack of control of the testing environment. However it is important to note that both these numbers are out of a total of 600 trials. Therefore both are very low percentages of total trials (0.11% vs 0.60%).

4.5 Discussion

The studies reported here aimed to measure the effect of shift work and postnatal sleep loss on response inhibition via two tasks designed to examine different cognitive components associated with response inhibition, in conditions of minimal fatigue. To do this, working participants were tested on a day off from work, and new parents were asked to complete the study just after waking up in order to test when they are most rested. A lack of significant differences were seen across multiple outcome metrics in both the GNG and the Eriksen flanker, suggesting response inhibition may be resistant to the effects of sleep disruption experienced by shift workers and new parents. These frequentist findings were mostly supported by Bayesian analysis with there being anecdotal to moderate support for the null hypothesis in many of the outcome metrics. Though it is important to note here that not all Bayesian analysis showed support for the null hypothesis, as discussed further below.

As discussed, response inhibition is a multi-faceted cognitive process, for which a large battery of tests (each assessing a different profile of response inhibition-related cognitive sub-components) has been developed. SD literature suggests a negative relationship with response inhibition, with

increased SD leading to impairment. However, these laboratory based studies have low ecological validity in that they require participants to experience sustained periods of extended wakefulness. Therefore, extrapolating findings from such studies to populations of shift workers and new parents, who both experience sleep disruptions with markedly different characteristics, is potentially challenging. Despite the great importance of normally functioning response inhibition in the workplace, the relationship between shift work and response inhibition is still unclear. It is important to evaluate shift workers (not participants imitating a shift working lifestyle for a short period of time) in conditions where acute fatigue can be discounted, to explore if any effect on response inhibition is persistent. This has both occupational and personal safety relevance. One group of individuals who experience a more ecologically relevant form of SD is new parents. This also has great occupational and personal safety relevance given that one, if not both, parent(s) may have to return to work whilst still caring for a newborn child. Yet the current literature is sparse and focuses predominantly on the mothers, who will also be experiencing hormonal and biological changes which may confound results. It is vital to know the impact of shift work and new parenthood on response inhibition beyond the impact seen immediately after work or following a bad night's sleep due to a newborn child.

Both of the tasks used in this study have shown a good test – retest reliabilities and internal consistencies within one test session (Wöstmann et al., 2013). The GNG and Eriksen flanker tasks were used due to the different components of response inhibition they primarily assess. The GNG task assesses task relevant response inhibition, processing speed and sustained attention (Donders, 1969) whereas the Eriksen flanker task examines information processing, interference suppression and selective attention (Eriksen & Eriksen, 1974). As response inhibition is multi-faceted, in order to get a full representation of any potential impairments/improvements it was important to use more than one task.

4.5.1 The impact of circadian disruption on response inhibition – behavioural suppression
GNG assessments are typically reported using two outcome parameters to assess response inhibition performance: reaction time and trial responses (Donders, 1969; Drummond et al., 2006). In the present study, this information was used to calculate overall correct performance, total false positives, overall reaction times as a function of response type, and within group reaction time comparisons. Performance related variables (overall correct performance and total false positives) measure response inhibition, the lower the performance score the greater the response inhibition impairment. Reaction time data assesses attention as well as response inhibition, with a longer reaction time indicative of a failure in attention.

Following the data collection of the SW1 cohort, a significant proportion of participants scored between 90-100% correct, indicative of a ceiling effect. The changes made following this to

increase difficulty in order to combat the ceiling effect appear to have worked, with overall correct performance falling and an increase in false positives in SW2 and NP cohorts. These adaptations included the addition of new Go stimuli, reduction in stimulus presentation time and an increased ratio of S+ to S- trials. The changes in outcome scores provide support for the task adaptations used to reduce ceiling performance. These revisions receive further support from Rezvanfard et al (2016) who found that decreasing stimulus presentation time whilst also using more complex stimuli led to a significant decrease in hits on Go trials (Rezvanfard et al., 2016).

4.5.1.1 Shift workers

Overall correct performance showed no significant differences in either shift working cohort (SW1 and SW2). This suggests that there was no overall change in response inhibition regardless of shift type. However whilst there was moderate support for a lack of difference (null hypothesis) in the SW1 cohort, there was anecdotal evidence for the alternative hypothesis in the SW2 cohort. These conflicting findings makes conclusions more difficult to draw. Given the p value in the frequentist statistic was close to significance (0.06) and the Bayesian statistic shows anecdotal evidence in support of the alternative hypothesis it is plausible that in a larger sample a significant difference would be seen. The precise relationship between the groups however remains unclear. This finding highlights the need for power analysis to be conducted prior to data collection to ensure the study has enough power to detect differences.

There were no significant differences found in false positives, a direct measure of inhibition failure in the SW1 or SW2 cohorts. This was supported by Bayesian analysis which found anecdotal and strong evidence for the null hypothesis in the SW1 and SW2 cohorts respectively.

The findings in these shift working cohorts are counter to those reported in the existing sleep deprivation literature (Anderson & Platten, 2011; Drummond, Paulus, & Tapert, 2006; Mander et al., 2010) as well as the existing shift worker studies assessed using a Stroop task (Kaliyaperumal et al., 2017; Shwetha & Sudhakar, 2012b).

There was further support for a lack of significant differences between shift workers and non-shift workers when the groups were categorised on the basis of the BSWSQ. There were no significant differences in overall correct performance and total false positives, nor a correlation between BSWSQ scores and these variables. This suggests that even in participants who were experiencing more severe sleep issues there was no discernible impact on response inhibition following a period of rest. There were some interactions between demographic variables and cognitive variables, with sex and time awake significantly related to overall correct performance and sleep time significantly related to total false positives, both in the SW2 cohort. However there was no main effect of BSWSQ group, when analysis was run controlling for these demographic confounds. This suggests that while the expected relationships between broad demographics (e.g.

age) and task performance were present in the data, the BSWSQ score itself did not have any significant effect on performance. These findings highlight the need to collect and examine potential demographic confounds to ensure they do not significantly influence outcomes. Further, this may provide an explanation for the results seen in the literature when samples are extremely occupationally homogeneous. If samples contain a wider variety of job types and shift lengths, as with the presented cohorts, it is possible that the impact of shift work is dampened.

Average reaction time also showed no significant differences in the shift working cohorts (SW1 and SW2), suggesting a lack of impairment in processing speed. However, the reaction time analysis within group did show some effects. All cohorts, with the exception of SW1 night shift workers, showed a significant difference between hit and false positive reaction times. Hits were significantly slower than false positives, suggesting participants took less time to respond when response inhibition failed (resulting in a false positive). The lack of difference in the SW1 night shift workers seems to be driven by an approximate doubling in the variability of the incorrect press reaction times (notably this increase in variability was not detected in the hit reaction time for the night group, suggesting it is not simply an artefact of a smaller group size). Increased variability in performance could be indicative of variation in the cognitive strategy used to complete the task by some participants, perhaps suggesting differences in stimulus discrimination or perception developing within the night shift group. Why this distinction only manifests in the night shift group is unclear, but it could indicate a participant interaction between response inhibition and circadian misalignment, which would be maximised in this group relative to the rotating and day shift workers.

4.5.1.2 New parents

No significant differences in overall correct performance were observed in the new parent cohort, including no apparent sex differences. This was supported with anecdotal Bayesian evidence for the null hypothesis. There were also no significant differences in false positives between new parents and controls, this was supported with strong Bayesian evidence for the null hypothesis.

The lack of effect in the new parent cohort mirrors the findings of Bannbers et al. (2013) who reported similar results when assessing post-partum women, 48 hours after delivery, 4-6 weeks after delivery as well as non-postpartum controls. No significant differences were observed between any groups in this study (Bannbers et al., 2013). Similarly, Crawley et al. (2003) assessed divided and focused attention (using a Stroop and a Trail Making subtest, both of which depend heavily on response inhibition) in pregnant woman on four occasions (twice during pregnancy and twice post-partum) and compared them to non-pregnant women at equivalent intervals (Crawley, Dennison, & Carter, 2003). They found no performance differences between the groups. This further supports our findings of no differences between new mothers and control females.

One of the key differences between the new parent study presented here and the existing studies (Bannbers et al., 2013; Crawley et al., 2003) is that both male and female new parents were included in this data set. This was deemed an important expansion given that the effects of pregnancy related hormones, the physical strain of motherhood and different feeding practicalities for mothers and fathers could all contribute to a differential impact on cognition. It also mirrors wider work in new parenthood where both parents are evaluated (Gay et al., 2004).

However, there is debate around whether sex has an impact on differences in executive functioning – in particular response inhibition. There are clear differences in neurobiological correlates yet no sex differences were observed in the GNG new parent cohort. Evolutionarily, it has been suggested that men and women may have developed different levels of inhibition and self-regulation due to differences in selective pressures on early humans (Bjorklund & Kipp, 1996; Hosseini-kamkar & Morton, 2014; Mansouri et al., 2016).

Several studies have suggested that males are more vulnerable to impairment in inhibitory control and have higher levels of impulsivity compared to females (Petry, Kirby, & Kranzler, 2002). Upadhayay and Guragain (2014) found whilst there were no cognitive differences between men and women on an Eriksen flanker task, males showed poorer performance than post-ovulatory phase women in correct responses of a Stroop task (Upadhayay & Guragain, 2014). The authors linked these differences to hormonal changes, given that they were not present in pre-ovulatory women.

Contrasting this, Li et al. (2006) assessed 20 men and 20 women, of varying ages using a Stop Signal Task (Li et al., 2006). Whilst there were differences in brain activations, with men activating the motor circuitry whilst women appeared to use visual association or habit learning, their performances on the task did not differ. This would suggest that whilst there are sex differences in terms of regional brain activations to response inhibition, they do not extend to performance differences.

Given the evidence, it appears that sex-related impairment of response inhibition may be dependent on the task used to assess it. Whilst this might suggest that the present findings are not robust, it could also indicate that different response inhibition tasks are differentially dependant on various cognitive subcomponents. For example, those primarily assessed by Stroop are impacted while the combination of subcomponents in GNG, Eriksen flanker task and a Stop Signal Task are not (Littman & Takács, 2017). The Stroop task assesses the ability to inhibit cognitive interference that occurs when the processing of a specific stimulus feature impedes the simultaneous processing of another attribute of the same stimulus (Stroop, 1935). This is distinct from other response inhibition tasks and suggests this component is vulnerable to sex-related impairment.

Average reaction time also showed no significant differences in the new parent cohort, with no significant main effect of group found. Significant differences were observed when examining reaction time within group. All groups showed a significant difference between hit and false positive reaction times. Hits were significantly slower than false positives, suggesting participants took less time to respond when response inhibition failed (resulting in a false positive).

4.5.2 The impact of circadian disruption on response inhibition – interference suppression

The Eriksen flanker task, similar to the GNG, produces two types of outcome measures.

Performance based measures (such as overall correct performance, missed trials and incorrect responses) and reaction based measures (reaction time within and between groups) are assessed on the basis of trial type, congruent or incongruent.

No significant differences were observed between any shift types in overall performance, incorrect responses, missed trials or average reaction time (as a function of response type).

Bayesian analysis also indicated moderate evidence for the null hypothesis (an absence of an effect) in mean Congruent Hit RT, Congruent IP RT and Incongruent Hit RT. Incongruent IP RT also showed anecdotal evidence for the null. However Bayesian analysis revealed moderate support for the alternative hypothesis in overall correct performance. Frequentist analysis showed a p value of 0.092, suggesting an effect may have been present and could be detected with a larger sample.

When grouped based on BSWSQ score there were no significant differences in either overall correct performance, nor each of the mean RT calculations. Further no correlations were observed between BSWSQ score and these cognitive variables.

Similarly to the GNG task there were some interactions between demographic variables and cognitive variables. Activity level and years worked shift were significantly related to overall correct performance and age was significantly related to Incongruent Hit RT. However again there were no main effect of BSWSQ group when analysis was run controlling for these demographic variables.

These findings mirror Murphy et al. (2006) who found no significant differences in participants following extended wakefulness (Murphy, Richard, Masaki, & Segalowitz, 2006). Participants were tested using the Eriksen flanker task, after 4 and 20 hours of wakefulness. After each testing session they were asked to estimate the number of errors they made, as well as how they thought they performed. These were then compared to the objective measures collected with the Eriksen flanker task. They found no differences in the subjective estimate of number of errors across the two testing conditions. Further, these closely matched the objective number of errors made. They did however report a subjective decline in performance. This would suggest that whilst

participants felt they were negatively impacted by extended wakefulness overall, this was not reflected in their objective measurement of error nor their perception of these errors. The absence of an effect in both the present study and that of Murphy et al. suggests that response inhibition is relatively resistant to both mild (4 hours) and moderate (20 hours) sleep deprivation and also to shift work exposure (after recovery sleep) when measured using the Eriksen flanker task. However, as impairments have been seen in SD studies, when the GNG and Stroop tasks have been used to assess response inhibition, this is highly suggestive that findings are dependent upon which cognitive task is used.

The data presented here does show significant differences when reaction time was assessed within group. Hits were significantly slower than incorrect presses in rotating shift workers and day controls, however this relationship was not found in night shift workers. This difference in responding speed replicates the reaction time findings observed in the GNG trials, with all but SW1 night shift workers showing difference in responses. Whilst rotating and day shift workers' reaction time for incorrect presses appears to get faster, thus resulting in a significant difference between hit RT and incorrect press RT, night shift workers stays the same. There was also more variation within this shift group which is likely to be due, in part, to its smaller group size. Nevertheless, this lack of difference may be suggestive of a slower processing speed in night shift workers, leading to a longer time being taken to discriminate between stimuli. Further, these individuals may also be more conscious of the risk of errors and consequently take more time to respond, in order to reduce errors. Overall, the findings from the SW1 cohort GNG data and the SW3 Eriksen flanker data may indicate that there is something distinctive about night shift workers and the impact of their work pattern on response inhibition.

This relationship between hit and IP RT notwithstanding, the findings from both the GNG task and the Eriksen flanker task here, are in direct contrast with those of the existing shift working response inhibition literature, where significant differences have been found both within shift workers (tested at the end of an 8 hour night shift and at the end of an 8 hour day shift) (Kaliyaperumal et al., 2017), and when comparing shift workers to non-shift working controls tested at the end of a shift (Shwetha & Sudhakar, 2012) using a Stroop task.

It is important to note that the shift worker data reported here was collected on a day off from work. This feature of the study design was included in an effort to disentangle the potential contributions of acute work-related fatigue and the longer term effects of a shift working lifestyle on any cognitive impairment observed. As described above, fatigue has been shown to be a key contributor to failure of this cognitive process (Guo et al., 2018; Guo et al., 2015; Kato et al., 2009) but as participants had slept prior to assessment this will have likely alleviated any accumulated fatigue. In addition, short recovery sleep (in relation to length of sleep deprivation preceding it)

has been shown to partially restore normal response inhibition (Drummond et al., 2006; Jin et al., 2015; Mander et al., 2010). Therefore, the lack of any response inhibition impairment seen here could suggest that (in the absence of work-related fatigue) shift workers do not experience any significant, persistent adverse impacts on response inhibition as a consequence of their lifestyle.

Similarly, the lack of impairment present in new parents may suggest that whilst they may experience highly disrupted sleep, it is not to a level detrimental to their response inhibition, replicating the findings of Bannbers et al. (2013) and extending them into a larger more diverse sample.

It is also important to highlight that the data presented here were gathered from shift workers using different tasks (a GNG task and Eriksen flanker task). As mentioned previously, individual response inhibition tasks may rely differentially on distinct underlying processes and so may assess different aspects of response inhibition (Khng & Lee, 2014; Littman & Takács, 2017). Two tasks were therefore used here in an effort to determine if shift work differentially impacted these different underlying processes. It is possible that the elements evaluated using the GNG task and the Eriksen flanker task are relatively resistant compared to those assessed using the Stop-Signal Task, for example (Littman & Takács, 2017). This may also contribute to the divergence between the findings here and those generated from shift workers assessed with the Stroop task.

The lack of effect observed here may also be partially due to the sensitivity of the GNG to accurately assess response inhibition. Following their observation of no significant difference in false alarms (false positives) in total sleep deprivation conditions, Jin et al. (2015) suggested that due to response inhibition being such a complex cognitive process it is possible the task itself may not be sensitive to accurately measure it (Jin et al., 2015). Further, the GNG employed in all cohorts here contains significantly fewer trials than other GNG tasks, with many containing thousands of trials and very few Nogo trials (Garavan et al., 2002; Kaufman, Ross, Stein, & Garavan, 2003; Meule, Lukito, Vögele, & Kübler, 2011). It may therefore be that the shorter GNG assessments used here were insufficient to unmask any impairment in response inhibition. However, GNG tasks of similar length to those employed here have shown significant differences in sleep deprivation cohorts (Drummond et al., 2006). Further there is a significant body of literature suggesting the GNG task to be a sensitive measure of response inhibition in various populations (Paula Alhola & Polo-Kantola, 2007; Anderson & Platten, 2011; Mander et al., 2010; Schapkin et al., 2007). It is therefore unlikely that a lack of task sensitivity is the sole reason for the lack of effect observed. Indeed, that two independent response inhibition tasks reported similar results from independent samples of shift workers seems to robustly indicate an absence of a lasting response inhibition impairment in this population.

Finally, evidence within the substance abuse literature suggests that response inhibition itself may not be a stable construct, instead fluctuations may occur within a lifetime, influenced by environmental, physiological or emotional events (Wit, 2009). There is also evidence for individual differences within this cognitive domain (Jones, Christiansen, Nederkoorn, Houben, & Field, 2013). This suggests that it may be challenging to use a community sample to evaluate the effect of any condition including shift work, new parenthood and sleep deprivation, on response inhibition.

4.5.3 Limitations and future directions

All data presented here was collected online, using an online recruitment platform. One limitation of online testing is the lack of control regarding the assessment environment of the participants. In a laboratory setting, noise levels, distractions, distance from equipment and indeed the equipment used are all strictly controlled, in order to reduce variation between participants and confounding variables. Using online recruitment and testing methods means these factors cannot be controlled for. In particular, the outcomes from tasks that require focus and sustained attention, such as the reaction time and responses from the GNG and Eriksen flanker task, may be impacted, potentially masking relationships between groups. Indeed, Mansouri et al. (2016) found, when listening to music, females performed faster, whereas men performed slower on go trials, on the Stop-Signal Task (Mansouri et al., 2016). Equally, this lack of control extends to the accuracy of the reported time of assessment. Whilst we asked that participants complete the task as soon after waking as possible, in order to mitigate the effects of fatigue that naturally accumulate with wakefulness, with online testing it is not possible to ensure the length of wakefulness is the same in each participant.

This lack of control may have led to slower RTs in the GNG task, as well as more misses in the Eriksen Flanker task, when compared to those found in the literature. As mentioned previously this lack of control regarding the testing environment is an inherent factor related to online cognitive testing. Whilst attention checks and thresholds can be employed to remove any participants who are extreme outliers, it appears that as a whole cognitive data collected from an online sample can be slower and more error prone. It is important to note that all participant data was collected using the same method, therefore, in theory, if there were a significant difference between groups this would have been maintained even when additional attentional distractions were possible. Sensitivity analysis regarding correlation between reaction times and age did show positive correlations in both tests, suggesting enough sensitivity of the task to detect impairments. Therefore either there is no difference between groups due to shift work, or the difference is markedly smaller than those seen due to age.

Future studies assessing these populations should include a fatigue questionnaire to establish whether testing on a day off from work/immediately after waking does in fact reduce the impact of fatigue on cognition. Further, by testing after a shift (for shift working cohorts) and during the evening (for new parents) as well as on a day off, a better profile of any response inhibition fluctuations could be obtained. By increasing the number of time points assessed it would be possible to get a better perspective on the fluctuations in response inhibition as a function of daily accumulated fatigue and synchrony with key circadian zeitgebers such as daylight and food intake.

Finally, the small sample size of night shift workers in the Eriksen flanker task may have resulted in a lack of power in this task. As with all cognitive testing, large sample sizes are preferable in order to ensure true interpretations of the data can be made.

4.5.4 Conclusions

Based on the current literature, two tasks were employed to assess response inhibition in shift workers and new parents, in an ecologically relevant testing scenario, without the confounding effect of fatigue.

Data presented here suggests that response inhibition is fairly resistant to the persistent effects of both shift work and the varied sleep schedule associated with new parenthood. This is based on the lack of significant differences found across multiple outcome metrics in both the GNG and the Eriksen flanker task. This may be a result of the minimisation of work-related fatigue and highlight the speed at which recovery sleep can ameliorate any response inhibition impairment.

5.1 Introduction

As outlined in Chapter One, current models of working memory specify four components; the central executive, the visuospatial sketchpad, the episodic buffer and the phonological loop (Baddeley and Hitch, 1974). Each of these provide a key contribution to normal working memory function. Occupationally, normal working memory is vital in order to perform effectively and efficiently both in the workplace and in everyday activities, such as driving. For example, Johannsdottir and Herdman (2010) found a visuospatial task interfered with driver ability to recall positions of traffic ahead of the vehicle, whereas a phonological task interfered with recall of traffic behind the vehicle (Johannsdottir & Herdman, 2010).

Due to this multi-module structure several cognitive tests have been developed to assess working memory. As outlined in Chapter One, some of the most commonly used tests include: the N-back task (in spatial, digit and verbal variations)(Kirchner, 1958), the Sternberg Working memory task (Sternberg, 1969), and the Delayed Match to Sample task (Parr & White, 1992). However, not all working memory assessment examines the same component or combination of components. For each of the four components described above, three main elements can be assessed separately or in conjunction. These are capacity, filtering and retention duration. For example, it is possible, using an N-back task, to assess capacity and, using different variants such as the spatial N-back (Meule, 2017), visuospatial sketchpad and central executive capacity can also be specifically assessed.

In the present study an N-back task (Kirchner, 1958) was used, which examines working memory capacity. The N-back task involves participants holding a piece of information in mind and then using that information in subsequent trials to direct appropriate responding, based on rules set out at the beginning of the task. These tests can be either a spatial, digit or verbal variant and can be manipulated in order to increase difficulty, for example by adjusting the duration for which the information must be retained (using a 3-back design, where participants are required to respond when the stimulus shown matches the stimulus '3' places prior instead of a 1-back, where the participants are required to respond when the stimulus shown matches the stimulus '1' place prior, for example).

In common with many other cognitive domains, working memory has shown some impairment following extended periods of wakefulness. Chee et al. (2006) assessed 26 healthy students following 24 and 35 hours of total sleep deprivation. The LTR, PLUS and the PLUS-L tasks were used to assess maintenance of WM, manipulation of verbal WM and executive processing. In the

LTR task participants are presented four letters (memory stimulus set), followed by a single letter (probe). Individuals are asked if the probe stimulus was a match to any in the memory stimulus set. The PLUS task is similar in that participants have to indicate if a probe letter is a match or non-match however they are shown only two letters e.g. B + J and required to remember for the match/non-match the consecutive letter e.g. C + K. The PLUS-L task is identical to the PLUS task except that in the non-match trials the probe is the same as one of the memory stimulus set e.g. B. It was found that whilst performance accuracy declined in all three tasks, and an increase in variability within the 35 hour testing group was present, there was not a significant difference between the 24 hour sleep deprivation testing session and the 35 hour one (Chee et al., 2006). This suggests that a maximal working memory impairment is achieved after 24 hours deprivation, beyond which no further deterioration occurs, although clearly the impact of sleep deprivation longer than 35 hours is unknown. Similarly, using a verbal variant of a continuous recognition test, Turner and colleagues assessed 40 participants before and after 42 hours of sleep deprivation (Turner, Drummond, Salamat, & Brown, 2007). They found a large decline in the working memory span parameters, however also noted individual differences, suggesting the level of impairment might be different from participant to participant. These individual differences were present even within the task, with individuals showing different sleep deprivation induced effects on different components of the task.

Task difficulty may also impact the profile of WM impairment observed following sleep deprivation. Terán-Pérez et al. (2012) used a 1-back and 3-back variant of the N-back task to assess the impact of task difficulty on WM performance in the context of sleep deprivation. Over the course of a 36 hour sleep deprivation protocol, both N-back tasks were applied every 6 hours to healthy young males. 9 participants were allocated to a control non-deprived group and 9 were allocated to the sleep deprivation group. Efficiency to discriminate between target and non-target stimuli was assessed using an adjusted hit rate (hit rate minus error rate). Compared to controls, sleep deprivation participants showed a decrease in efficiency to solve the 1-back task after 24 hours, however no further decreases were seen at 30 and 36 hours. This again supports the findings of Chee et al. (2006), suggesting that 24 hours of sleep deprivation is sufficient to cause a maximal working memory impairment, and further sleep deprivation does not necessarily lead to further impairment. In the 3-back variant, no decreases in task completion efficiency were observed at any time point. The sleep deprived group also showed slower reaction times in both tasks (Terán-pérez et al., 2012). The authors suggested that the results from the 3-back indicate the prefrontal function required to solve this complex task was not affected by 36 hours of sleep deprivation. The deterioration seen in the 1-back were due to this simpler variant being influenced by attention. This is supported by Lo et al (2012), who observed that whilst there was a negative impact of total and partial sleep deprivation on an 1-back, 2-back and 3-back, the n-back

tasks with higher executive load did not appear to be any more affected than the lower executive load task (Lo et al., 2012). Further, there is some evidence to suggest that increasing task difficulty can paradoxically enhance performance (Drummond, Brown, Salamat, & Gillin, 2004; Washburn & Thompson Putney, 2001). As such, the 3-back used in Terán-Pérez et al. (2012) could have masked the sleep deprivation impairment due to over-compensation that was driven by the increased task difficulty.

There is evidence to suggest that the elements of working memory (capacity, duration, filtering) can be impacted differently. Drummond et al. (2012) assessed visual working memory in 44 healthy young participants using two visual working memory tasks designed to assess capacity and filtering separately (Drummond et al., 2012). This task was a variant of the sequential comparison paradigm developed by Phillips (1974) and adapted by Vogel et al. (2001) (Phillips, 1974; Vogel, Woodman, & Luck, 2001). The task measuring capacity involved participants remembering an image and then identifying if an image was the same or different from the target, with a focus on accuracy over speed. The task assessing filtering involved participants remembering a target image and then being shown just one part of that image and having to state if it was in the correct location/colour, filtering out irrelevant information. Drummond et al. found that neither total (one night of sleep deprivation) nor partial (4 hours in bed a night) deprivation affected visual working memory capacity. Filtering ability was also not affected in the partial sleep deprivation category. However total sleep deprivation did impair filtering task performance. These findings suggest that not only can the type of sleep deprivation experienced determine if impairment occurs, the distinct elements of each working memory component can potentially be impacted differentially.

The issue with many sleep deprivation studies is the low ecological validity of sleep deprivation conducted in a laboratory setting. One group of individuals who experience similar sleep restriction to the partial sleep restriction described above but in a more naturalistic environment are new parents. These are a unique group of individuals given they experience a naturalistic sleep deprivation of a random schedule i.e. not receiving the same amount of sleep each night (Palagini et al., 2014) and cannot predict when their sleep will be disturbed (Gay et al., 2004). Sleep disturbance begins within the new parent population before the birth occurs, pregnant women have been shown to have short sleep duration, insomnia and poor sleep quality throughout all three trimesters of pregnancy (Palagini et al., 2014) and this continues following the birth of the child (Gay et al., 2004). Given that laboratory studies indicate working memory impairments can occur following sleep deprivation, and new parents appear to experience a form of sleep deprivation, it is plausible that new parents would also experience alterations in working memory performance.

In a study of primigravid (first time being pregnant), primiparous (first time having been pregnant) and nulligravida (never been pregnant) women, the primigravid and primiparous groups subjectively reported poorer memory performance since pregnancy (Janes et al., 1999). Further, the primigravid group reported more sleep disruption. This was supported by an objective measure of working memory (the backward digit span test from WAIS) with primigravid and primiparous groups scoring significantly lower than nulligravida women. However, it is important to note that no differences were seen in a reading span test, also used to assess working memory. This suggests that the components assessed in the digit span test (numbers) were impacted differently to those involved in the reading span test (language). Further, reported sleep change did not predict performance on any objective test. This may suggest that whilst impairments are seen in this sample group, they were not related to changes in sleep deprivation.

There is evidence to suggest that affective state may also play a role in the working memory performance of pregnant women and post-partum parents. Hampson et al. (2015) assessed the impact of depression on working memory in pregnant women. Assessed using a battery of tests including the spatial working memory task (Duff & Hampson, 2000), the self-ordered pointing task (Petrides & Milner, 1982) and the Corsi blocks test (a nonverbal variant of the digit span task) (Milner, 1971), they found that pregnant women who were showing depressive symptoms (as measured by the Edinburgh Ante/Postnatal Depression Scale (Cox, Holden, & Sagovsky, 1987) and the Montgomery-Asberg Depression Rating Scale (Montgomery & Asberg, 1979)) had impaired working memory, however those who were pregnant but not showing these symptoms performed equally or better than non-pregnant controls (Hampson et al., 2015). This would imply that whilst there are individuals who experience memory problems during pregnancy these are not as widespread as believed (memory issues linked with 'baby brain' are often quoted in the media (Leake, 2019; Young, 2018)) and are potentially linked to the mental (specifically affective) state of the individual. These findings are further supported by Kataja et al. (2017) who found depressive symptoms and pregnancy related anxiety symptoms were significant predictors of poor visuospatial working memory performance in pregnant women (Kataja et al., 2017). The impact of depression on working memory has also been seen post birth in both mothers and fathers, with depressed participants performing worse on a word span test (Sigaran et al., 2012). This study is unique in that it assesses postpartum depression in both the mothers and the fathers and finds both perform worse with respect to working memory. While compelling, the lack of assessment of sleep deprivation in these studies makes interpretation challenging, given that both depression and anxiety are associated with substantial sleep disruption (Cox & Olatunji, 2020; Slaughter, 2006). As such, the arc of causality between affective state, sleep deprivation and working memory is not necessarily linear or unidirectional.

As with much of the literature assessing cognition in new parents/parents-to-be, the focus of working memory studies is predominantly on females. Further, many focus on pregnancy and do not assess individuals in the post-partum period, where arguably they will be experiencing more sleep disturbance. The lack of assessment in fathers is an issue, as an opportunity to directly evaluate the effects of new parenthood on cognition (and working memory specifically) in the absence of the profound endocrinological and physiological changes associated with pregnancy and childbirth is lost in many studies. For example, oestrogen is suggested to improve performance in working memory tasks (Gasbarri et al., 2008; Hampson, 1990) and while oestrogen levels fluctuate across the lifespan, there is a significant rise during pregnancy. A rise in oestrogen during pregnancy could therefore effectively 'mask' or 'protect' the female from any impact caused by the pregnancy-associated sleep disruption on the working memory domain. This is further complicated by the fact that, while the male partner may be 'unprotected' from the adverse effects of pregnancy-associated sleep disruption, due to the absence of oestrogen, the cognitive impact they experience may be lesser in magnitude, due to the relatively less disrupted sleep they experience. This is evidenced by Gay et al. (2004) which reported that from late pregnancy to one month postpartum mothers lost an average of 41.2 minutes of night time sleep while fathers lost an average of 15.8 minutes. Better understanding of the balance between the protective effects of oestrogen and the differential sleep disruption experienced between the sexes in the parenthood context is therefore required, and systematic studies of males would provide valuable insight.

Another group who experience a form of sleep disturbance is shift workers. Unlike new parents, shift workers experience much more predictable sleep periods, and while often experiencing circadian mismatching, are not typically disturbed during sleep as often as new parents. Further, unlike laboratory based sleep deprivation studies, shift workers do not tend to routinely experience prolonged periods of forced wakefulness. Therefore, extrapolating the findings of the studies based on new parents or laboratory sleep deprivation protocols into shift working samples may not be appropriate.

Within the context of shift work, research suggests that working memory is relatively resilient to impairment. Testing 60 control room operators across two shift patterns (4 and 7 consecutive night shifts), Kazemi et al. (2018) found no impact on reaction time on an N-back task (1-back design) though there were differences in the number of correct responses. Those working 7 consecutive night shifts performed better (had more correct responses) than those working the 4 night pattern. They also found that whilst there were no differences in sleep quantity, those working more night shifts consecutively had better quality sleep (assessed using the PSQI (Buysse et al., 1988)). This suggest that those working more consistent work patterns (7 night shifts) were less impacted than those working shorter rotations. Consistency in circadian mismatching may be

an important factor in stabilising any working memory deficit. As there was no non-shift working control it is not possible to establish how the groups in the study performed relative to non-shift working baseline.

Shwetha and Sudhakar (2012) addressed the issue of the non-shift working baseline condition when they found no significant differences in working memory between 50 male business process outsourcing (BPO) shift workers and 50 non-BPO non-shift working controls (Shwetha & Sudhakar, 2012b). Using both a verbal and visual N-back (1 and 2-back design) they tested individuals at the end of a shift. This lack of differences suggests that there were no impairments in working memory that could be attributed to shift work. However no questionnaires were given to determine if any sleep quality differences existed between the two groups.

Kazemi et al. (2016) assessed 60 male control room operators before and after a night and day shift. These individuals worked seven night shifts, seven day shifts and then seven days off. They found no significant difference in N-back score or reaction time between the two shift types. There were, however, significant differences between the start and end of a shift. Both shift types showed a decrease in the number of correct responses and an increase in reaction time following a shift. Further, sleepiness steadily increased during the night shift whereas during the day shift a stable or decreasing trend was seen (Kazemi et al, 2016). This would suggest that fatigue (accumulated as a function of being awake and occupationally engaged) appears to impair working memory and that the magnitude of this impairment is independent of shift type and perceived sleepiness.

There is debate over the precise impact of fatigue on working memory. Jain and Nataraja (2019) assessed working memory and fatigue in musicians, who were suggested to have better working memory abilities than non-musicians (Jain & Nataraja, 2019). 26 musicians and 25 non musicians were assessed pre- and post-fatigue conditions, using operation span, reading span and digit span (forward and backward) tests. Fatigue was assessed using a 100-point visual analog scale. They found working memory and speech perception to be affected in both groups, due to fatigue. Even the perception of fatigue can lead to an impairment of working memory. Clarkson et al. (2011) found individuals provided with feedback after a task that led to perceptions of low depletion showed greater working memory capacity, assessed using an automated version of the operation span task (Clarkson et al., 2011). Crucially this was independent of the participant's actual state of depletion.

In contrast, Gergelyfi et al. (2015) found that despite a significant increase in subjective fatigue, deterioration in a working memory task (a variant of the missing scan task (Buschke, 1963)) was small (Gergelyfi, Jacob, Olivier, & Zénon, 2015). They state that this is due to individuals maintaining performance by means of a compensatory increase in mental effort, which is

supported by Esposito et al. (2014), Hockey (1997) and Nakagawa et al. (2013). Overall, it seems that working memory is sensitive to sleep deprivation (as seen in laboratory based SD studies). Though task selection and task difficulty appear to be important with respect to the pattern of results observed, likely due to the complexity of the construct. Understanding the impact on working memory of more naturalistic samples appears to be more complicated. For example, there appears to be a complex relationship in new parents between working memory, sleep, hormones, general affective state and whether the male or female is assessed. Similarly, in shift workers while there seems to be evidence of a degree of resilience to working memory disruption relative to non-shift workers, this is limited to one study of a single occupation. Equally, there appears to be an association between fatigue and WM irrespective of shift type but whether this association persists beyond the period immediately after shift is unclear.

The neurobiology of working memory involves predominantly bilateral frontal and parietal cortical areas (Rottschy et al., 2012). However, given the range of tasks used to assess different components and elements of working memory, it has been suggested that the type of task used has a considerable impact on the specific profile of brain regions involved (Wager & Smith, 2003). N-back tasks that assess executive functioning (which involves working memory, cognitive flexibility and inhibitory control) have shown activation of Brodmann Area 7 in the posterior parietal cortex, whereas verbally driven tasks were associated with left frontal activation, however only in low executive demand conditions (Wager & Smith, 2003). Dorsolateral prefrontal cortex activity has been linked with successful maintenance of information by directing attention to internal representations of sensory stimuli and motor plans (Curtis & Esposito, 2003), as well as being vital for executive attentional functioning (Kane & Engle, 2002). Further a meta-analysis of 24 N-back studies showed activations in the lateral and medial premotor cortex, the dorsolateral and ventrolateral prefrontal cortex, medial and lateral posterior parietal cortex and the dorsal cingulate. After exploring the studies two clear divisions were found: the manner in which stimuli were presented (verbal or nonverbal) and the type of monitoring that was required (identity of the stimulus or location of the stimulus). Broadly similar activation patterns were observed for identity monitoring of verbal stimuli and both location and identity monitoring of nonverbal stimuli. Some evidence of distinct frontoparietal activation patterns in response to different tasks has also been reported (Owen, McMillan, Laird, & Bullmore, 2005).

Despite the importance of working memory to global cognition and the substantial occupational relevance of this construct, relatively few studies have evaluated it within the context of occupationally varied shift work. Gaps in the literature can also be seen regarding new fathers. Further, none attempt to isolate the impact of work-related/general fatigue. This chapter presents an opportunity to address these issues by testing working memory in a range of shift

workers and both new parent females and new parent males in conditions of minimised accumulated daily fatigue.

5.2 Specific aims

1. To determine if working memory is impacted in shift workers
2. To determine if working memory is impacted in new parents
3. To evaluate the use of the N-back task for online testing

5.3 Method

All research presented in this chapter has received ethical approval following review by The Open University's Human Research Ethics Committee (HREC/2016/2444/Breese/2 and HREC/2017/2549/Breese/1). This study also adheres to all BPS ethics standards (The British Psychological Society, 2018).

A full information sheet and debrief form were provided and each participant was required to provide informed consent before being enrolled. Participants were informed of their right to withdraw at any point and contact details of the research team were provided at the beginning and end of testing, should participants wish to ask any questions.

5.3.1 Recruitment approach

Data presented in this chapter is an amalgamation of several recruitment drives. All data were collected using the online participant platform Prolific (www.prolific.co) and the Gorilla Experiment Builder (www.gorilla.sc) to create and host all experiments (Anwyl-Irvine et al., 2018). All received financial payment for taking part in the study.

5.3.2 Participants

Four different groups were recruited. An in-depth explanation of the differences between the sample groups as well as the rationale for each can be found in Chapter Two.

1. Shift worker one (SW1): the first instance of using the N-back task online assessing shift and non-shift workers in this project.
2. Shift worker two (SW2): following data analysis of SW1, in contrast to the other cognitive tasks given (reported elsewhere in this thesis), no changes to the N-back were necessary. This presented an opportunity for a direct replication of the task used in the SW1 cohort. Again, data were collected from both shift workers and non-shift working controls.
3. New parents (NP): Parents of a child under one year old were asked to complete the N-back. This task had the same parameters as SW1 and SW2, and therefore a control

group (individuals who were not currently new parents or shift workers) was extracted from the SW2 non-shift working participant sample.

4. Shift worker three (SW3): A revised N-back (see description below) was used to collect data from shift workers and non-shift working controls. However due to a technical issue, no data was usable from this group.

No participants were permitted to take part in more than one of these recruitment drives, however some data from SW2 was used as a control in NP.

Prior to outlier analysis the sample sizes (including controls) were as follows:

- SW1: 62 participants (15 removed following exclusion screening)
- SW2: 125 participants (9 removed following exclusion screening)
- NP: 128 participants (13 removed following exclusion screening)
- SW3: No data were usable

5.3.3 Exclusion criteria

For all sample groups participants were excluded from analysis if they stated they had had a recent head injury that required hospitalisation, were under the age of 18, if it was not possible to put them in a shift group due to conflicting/absent/uninterpretable description of their work pattern, they were not on a day off from work or did not fully complete the task.

For the N-back task, a threshold based on signal detection theory was developed in order to remove individuals who were not meaningfully engaging with the task. This was based on participant responses, and aimed to exclude those who were continuously pressing and those who left the task to run without any engagement. Similar to the GNG exclusion criteria (outlined in Chapter Four), there are two target types in the N-back task: S+ (participant is required to press) and S- (participant is required to withhold). Each of these have two possible outcomes (outlined in Table 64). If an individual achieved more than 80% press responses or <80% do not press responses they were excluded from further analysis. This was also modelled at 90% to check for participant dropout however the change in sample size was not deemed large enough to impact results. Similar response pattern-based exclusion criteria have been used previously in human and animal cognitive studies (Hedge et al., 2018; Young et al., 2009).

Table 64 Signal detection theory grid All possible outcomes from both target types

Target / Response	Press	Do not press
S+	Hit	Miss
S- (small triangle)	False positive	Correct reject

5.3.4 Design

As explained above, participants were recruited through Prolific and tested using Gorilla Experiment Builder. Participants were all tested once, for the SW1, SW2 and SW3 cohorts' participants were asked to complete on a day off from work, for the NP cohort participants were asked to complete the assessment after they had woken up in the morning. This was to reduce any direct impacts of work-related fatigue or acute tiredness on cognition. As mentioned above, due to a technical error in the revised N-back used for SW3 no usable data were collected.

5.3.5 Testing procedure

Once participants had read the information sheet and given informed consent, each individual received the full questionnaire battery to complete, as outlined in Chapter Two. Following this SW1, SW2 and NP participants completed an N-back and a GNG (Chapter Four). The SW1 cohort received the N-back task first. For the SW2 and NP participants this was given in a randomised order. The randomisation of task order was introduced following SW1 in order to counter any effect of order.

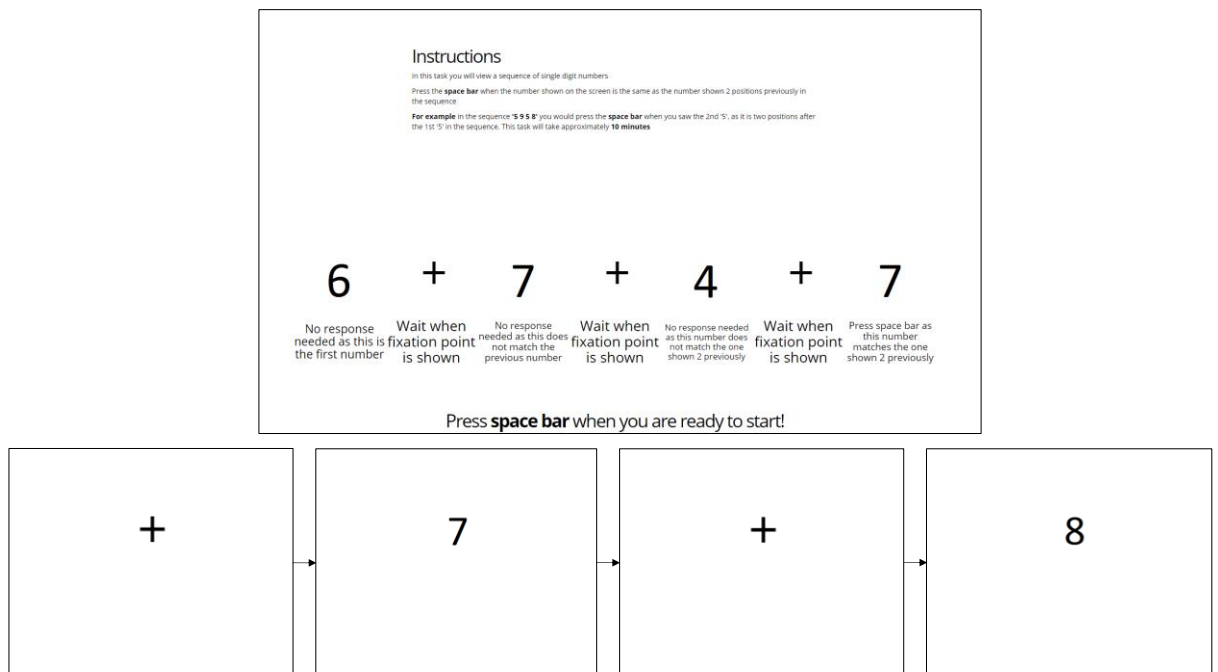


Figure 34 Screen presentation sequence for N-back task used for SW1, SW2 and NP

First participants were presented with an instructional page on how to complete the N-back task. This stated 'In this task you will view a sequence of single digit numbers. Press the space bar when the number shown on the screen is the same as the number shown 2 positions previously in the sequence. For example in the sequence '5 9 5 8' you would press the space bar when you saw the 2nd '5', as it is two positions after the 1st '5' in the sequence. This task will take approximately 10 minutes.'

As explained, the N-back task (Figure 34) required participants to view a single visual stimulus presented on the screen for 1000ms. These stimuli would either be S+ (and require a response) or S- (and require withholding of a response). This was dependant on the stimuli that had passed previously. In this study, a 2-back design was used. 200 trials were completed, 50 of which were S+, over a period of approximately 10 minutes. The fixation cross was shown for 750ms. The stimuli used (numbers) and the N-back condition (2-back) are based on those used by Kretschmer, Schmidt, & Griefahn (2012).

As with many cognitive tasks there is a lack of consistency within the literature regarding trial length. For example, Kretschmer et al (2012) presented the stimuli for 1500ms with no apparent inter trial stimulus. In comparison Choo et al (2005), on which the second N-back was based, presented stimuli for 500ms and an inter trial fixation point for 2400ms. In the original N-back, designed using a series of lights, the 'stimuli' were shown for 1500 ms (Kirchner, 1958). The times used in a task may impact the outcome seen. For example, a longer stimulus presentation time allows participants more time to consider their response, potentially reducing impulsivity. A shorter presentation time would likely increase the pressure and stress on the participant and potentially lead to an increase in errors. Similarly the use of an inter-trial stimulus allows participants to consider their response before pressing (or not pressing) before the next trial.

Following the data collection from the SW1, SW2 and NP cohorts, there was concern that the lack of working memory differences were due to the N-back only having one level. Whilst Kretschmer et al (2012) only included one level, many other instances of the N-back task involve at least two levels. Therefore, changes to task design and parameters were made for the SW3 cohort, to create a more complex N-back. This aimed to further challenge working memory capacity in a shift working sample above that experienced by the SW1 and SW2 cohorts.

SW3 participants received an information sheet and, once informed consent was obtained, were given a questionnaire battery to complete (outlined in Chapter Two). Following this, participants completed one of two possible N-back tasks and the Eriksen flanker task (Chapter Four). This was given in a randomised order, to counter any effect of testing sequence.

The two possible N-back tasks were of the same design however in order to ensure all possible trial combinations were given, two variants of the task were used. First participants were presented with an instructional page on how to complete the N-back task. This stated *'In this task you will view a sequence of single letters. These can be either upper or lower case. You are required to memorise these letters and indicate if the letter you are looking at either matches or does not match the letter you saw at an earlier point in the sequence.'*

Press F if the letter you see on-screen matches the one you saw a specific number of letters ago and press J when it does not.

For example 'M n t N P Q p' for this sequences of letter, we will apply a '2-Back' rule so you will need to decide if the letter displayed on the screen matches the letter displayed two places earlier in the sequences. So here you would press F when the fourth letter (the N) is displayed, as the same letter (the n) was displayed 2 places before it in the sequence. You would also press F when the seventh letter (the p) was displayed because the same letter (the P) was displayed 2 places before it in the sequence. For all the other letters in this sequence, you would press J. Matching in this task is not case sensitive. For example, valid matches for the letter P would include: P and P, p and p, P and p, p and P'

The parameters and task design used was based on that of Choo et al. (2005). Different from the N-back task used in previous cohorts, this variant used letters as stimuli (instead of numbers), involved a practise session and varied the difficulty of the task (by changing the N-back rule). All trials required a response (compared to the previous task where only correct stimulus trials required a response). Finally, the stimulus was presented on screen for 500 ms (rather than 1000ms in the previous version) and the fixation cross was shown for 2400 ms (as opposed to 750ms in the previous version). In total there were 190 trials, made up of 10- trial blocks using different N-back rules. Three 1-back, 2-back and 3-back blocks were separated by 0-back blocks, resulting in a total of 19 blocks.

Unfortunately, due to a technical issue none of the data collected from the SW3 cohort were usable. A coding error in the task production led to participants not having time to respond to the stimuli during presentation (500ms) and the response during the fixation not being recorded.

5.3.6 Output variables

The variables extracted for analysis are summarised below.

1. Overall correct performance (%) – total number of correct responses (both hit and correct reject) as a percentage of 200 trials
2. Missed trials – number of trials where a miss was recorded
3. Reaction time of correct responses (ms) – the average reaction time of correct responses (hits)
4. Reaction time comparisons within group (ms) – comparisons of average correct reaction times (hits) and average incorrect reaction times (false positives) within participant sub-groups
 - i. Night
 - ii. Rotating

- iii. Day
- iv. New parent Male
- v. New parent Female
- vi. Control Male
- vii. Control Female

5.3.7 Statistical analysis

Data was downloaded from Gorilla and prepared for statistical analysis using Microsoft Excel 2013 (Microsoft, 2013). Descriptive statistics (mean, standard deviation and range) were generated for demographic data, including age, sex, years working shifts and sleep disorder frequency using GraphPad Prism (version 8.2.1) (GraphPad Software, La Jolla California USA, n.d.) and StatsCloud (www.statscloud.app) and are outlined in Chapter Two.

Cognitive assessment data were analysed using frequentist statistics with JASP (www.jasp-stats.org, version 0.11.1) and GraphPad Prism (version 8.2.1). Data was first screened for normality using the D'Agostino and Pearson test. Outliers were identified with box plots and points identified as being outside the whiskers (set to 1.5*interquartile range above/below the 75th/25th percentile) were subsequently removed. If data were normally distributed parametric tests were used (ANOVA and t-test), if normality was not achieved non-parametric tests were employed (Kruskal-Wallis, Mann-Whitney, Wilcoxon). To address multiple comparisons, Tukey post hoc analyses were performed as appropriate. Significance was given by a p-value of less than 0.05. Bayesian analysis was conducted using JASP and conclusions based on the thresholds found in Van Doorn et al (2019). These can be found in Table 22.

5.4 Results

For the SW2 and NP cohorts, in order to control for any potential order effect the design contains group A and B (see Figures 2 and 5 in Chapter Two). Data from groups A and B was assessed statistically to determine if the groups could be merged to increase statistical power. Where possible, the two testing order conditions were merged, in order to maximise power. All testing groups in all cohorts were able to be merged.

5.4.1 Overall correct performance (%) showed no evidence of group dependant differences

Overall correct performance was calculated on the basis of total correct responses (hits and correct rejects) as a percentage of total trial presented (200). The SW1 cohort ($H(2)=3.902$, $p=0.142$, $\eta_H=0.03$) showed no main effect of group on correct performance, suggesting no difference in working memory between groups (Figure 35a). Conversely, the SW2 cohort did show

a significant main effect of group ($H(2)=6.792$, $p=0.034$, $\eta_H=0.04$), however post hoc analysis revealed no significant pairwise differences between the groups (Figure 35b). Finally, the NP cohort ($H(3)=7.666$, $p=0.053$, $\eta_H=0.04$) showed no main effect of group, again suggesting no difference in working memory between groups (Figure 35c).

Bayesian statistics showed there was anecdotal evidence for the null hypothesis in the SW1 cohort ($BF_{10}=0.37$). The null hypothesis proposed there is an absence of an effect of shift group in overall correct performance. There was moderate evidence for the alternative hypothesis in the SW2 cohort ($BF_{10}=5.78$) and the NP cohort ($BF_{10}=3.62$). The alternative hypothesis for the SW2 cohort proposed there is an effect of shift group in overall correct performance. The alternative hypothesis for the NP cohort proposed there is an effect of group in overall correct performance.

The sample size of each cohort and number of participants removed following outlier analysis is detailed in Table 65.

Table 65 Sample sizes of N-back Overall correct performance (%)

Cohort	Groups	n	Removed through outlier analysis
SW1	Night	9	1
	Rotating	33	2
	Day	16	1
SW2	Night	22	0
	Rotating	56	2
	Day	39	6
NP	NP male	29	0
	NP female	56	2
	C male	25	2
	C female	14	0

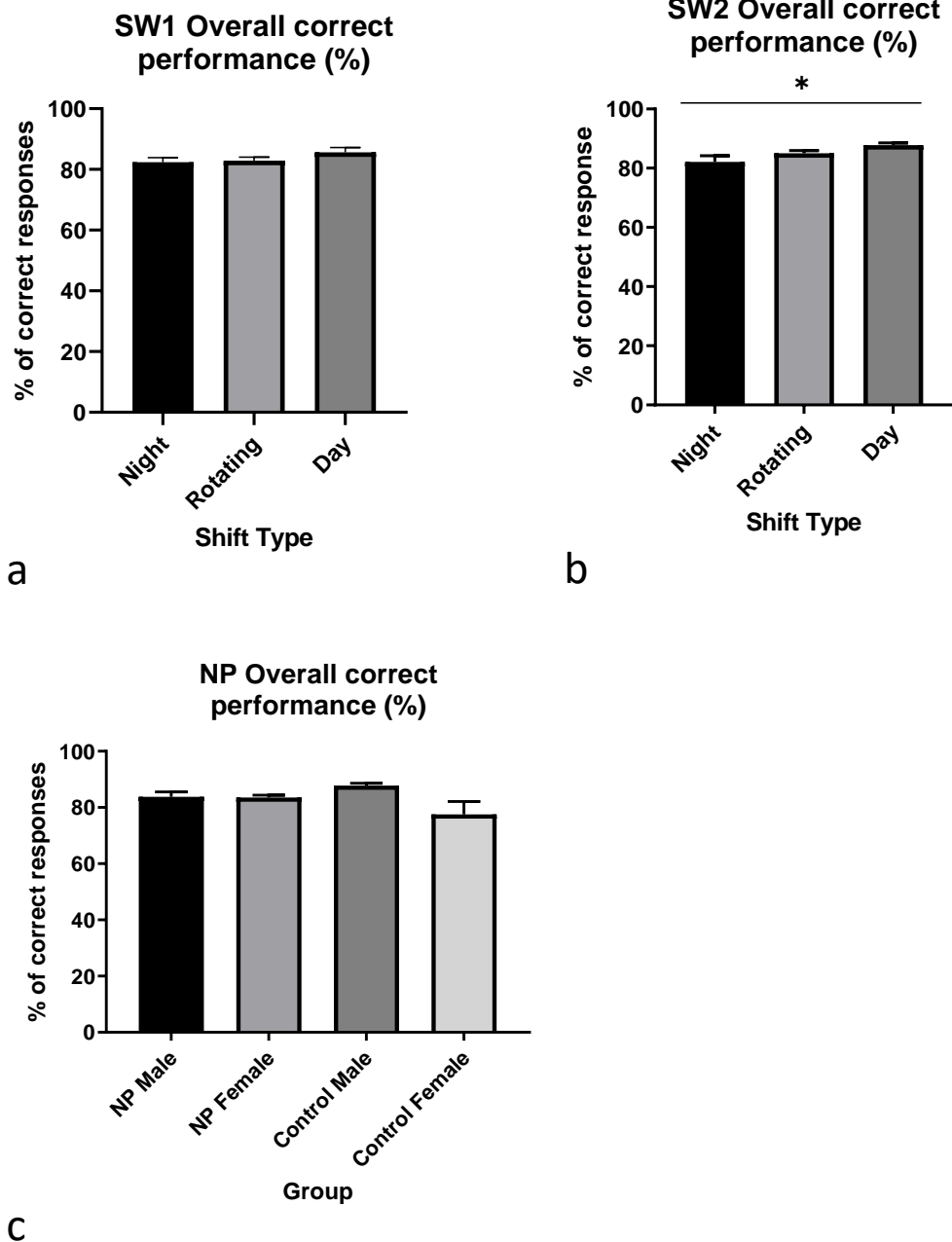


Figure 35 N-back Overall correct performance a) SW1 cohort b) SW2 cohort c) NP cohort. Error bars indicate SEM.

As with previous tasks, analysis was run again with shift groups split by BSWSQ score. Table 66 details the statistical analysis for each BSWSQ score and sample. Where data did not pass a normality test it was transformed. The transformation applied is indicated in the table. Where data could not be made normal, nonparametric analysis was used.

Table 66 N-back Overall correct performance BSWSQ score grouping

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	H(3)=4.05, p=0.26, $\eta_H=0.02$	H(3)=4.64, p=0.20, $\eta_H=0.04$	U=139.5, p=0.23, r=0.19	H(3)=7.49, p=0.06, $\eta_H=0.09$
SW2	H(3)=0.80, p=0.85, $\eta_H=0.03$	H(3)=1.18, p=0.76, $\eta_H=0.02$	U=552, p=0.48, r=0.09	H(3)=4.63, p=0.20, $\eta_H=0.02$

No significant differences were seen between High and Low Bergen shift and control groups when examining overall correct performance.

Further correlation analyses was run between BSWSQ score and overall correct performance.

Table 67 details the statistical analysis for each BSWSQ score and sample

Table 67 N-back Overall correct performance correlations

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	$r_s(44)=-0.15$, p=0.33, observed power=0.05	$r_s(44)=0.04$, p=0.81, observed power=0.08	$r_s(38)=-0.10$, p=0.52, observed power=0.12	$r_s(54)=0.04$, p=0.798, observed power=0.07
SW2	$r_s(86)=-0.01$, p=0.899, observed power=0.05	$r_s(76)=0.07$, p=0.56, observed power=0.08	$r_s(68)=-0.09$, p=0.48, observed power=0.21	$r_s(106)=-0.20$, p=0.04*, observed power=0.55

A significant negative correlation between BSWSQ score and overall correct performance was found in the SW2 cohort in the Rest BSWSQ work category. No other significant correlations were observed.

ANCOVAs were run using the BSWSQ rest score groupings. In SW1 the covariate, age, was not significantly related to overall correct performance ($F(1,51)=0.37$, $p=0.55$, $\eta^2=0.01$). There was also no effect of BSWSQ group on overall correct performance after controlling for age ($F(3,51)=1.56$, $p=0.21$, $\eta^2=0.08$). The covariate 'years worked shifts' was not significantly related to overall correct performance ($F(1,51)=0.15$, $p=0.70$, $\eta^2=0.003$). There was also no effect of BSWSQ group on overall correct performance after controlling for years worked shifts ($F(3,51)=1.53$, $p=0.22$, $\eta^2=0.08$).

In the SW2 cohort none of the demographics tested significantly related to overall correct performance. Further, there was no effect of group on overall correct performance when demographic variables were controlled for. ANCOVA statistics can be found in Table 68.

Table 68 N-back Overall correct performance x demographic variable ANCOVAs

Demographic variable	Main effect	Effect of group when demographic controlled for
Sex	F(1,103)=0.29, p=0.59, $\eta^2=0.003$	F(3,103)=1.17, p=0.33, $\eta^2=0.03$
Country	F(1,103)=0.31, p=0.58, $\eta^2=0.003$	F(3,103)=1.36, p=0.26, $\eta^2=0.04$
Activity level	F(1,103)=0.53, p=0.47, $\eta^2=0.01$	F(3,103)=1.49, p=0.22, $\eta^2=0.04$
Sleep time	F(1,101)=0.85, p=0.36, $\eta^2=0.01$	F(3,101)=1.34, p=0.27, $\eta^2=0.04$
Time awake	F(1,101)=0.98, p=0.33, $\eta^2=0.01$	F(3,101)=1.63, p=0.19, $\eta^2=0.05$

5.4.2 Number of missed trials showed no differences in working memory failure

Missed trials refers to the number of trials during the task that were S+ (therefore required a response) but in which the participant made no response. None of the cohorts showed a main effect of group on number of missed trials (SW1: F(2,56)=0.231, p=0.795, $\eta^2=0.008$, SW2: H(2)=3.428, p=0.180, $\eta_H=0.01$, NP: H(3)=1.401, p=0.705, $\eta_H=0.01$) (Figure 36a, 36b, 36c).

Bayesian statistics showed there was moderate evidence for the null hypothesis in the SW1 cohort (BF10=0.18). There was anecdotal evidence for the null hypothesis in the SW2 cohort (BF10=0.41). There was strong evidence for the null hypothesis in the NP cohort (BF10=0.09). The null hypothesis proposed there is an absence of an effect of group on number of missed trials.

The sample size of each cohort and number of participants removed following outlier analysis is detailed in Table 69.

Table 69 Sample sizes of N-back Missed trials

Cohort	Groups	n	Removed through outlier analysis
SW1	Night	10	0
	Rotating	32	3
	Day	17	0
SW2	Night	22	0
	Rotating	57	1
	Day	45	0
NP	NP male	28	1
	NP female	57	1
	C male	27	0
	C female	14	0

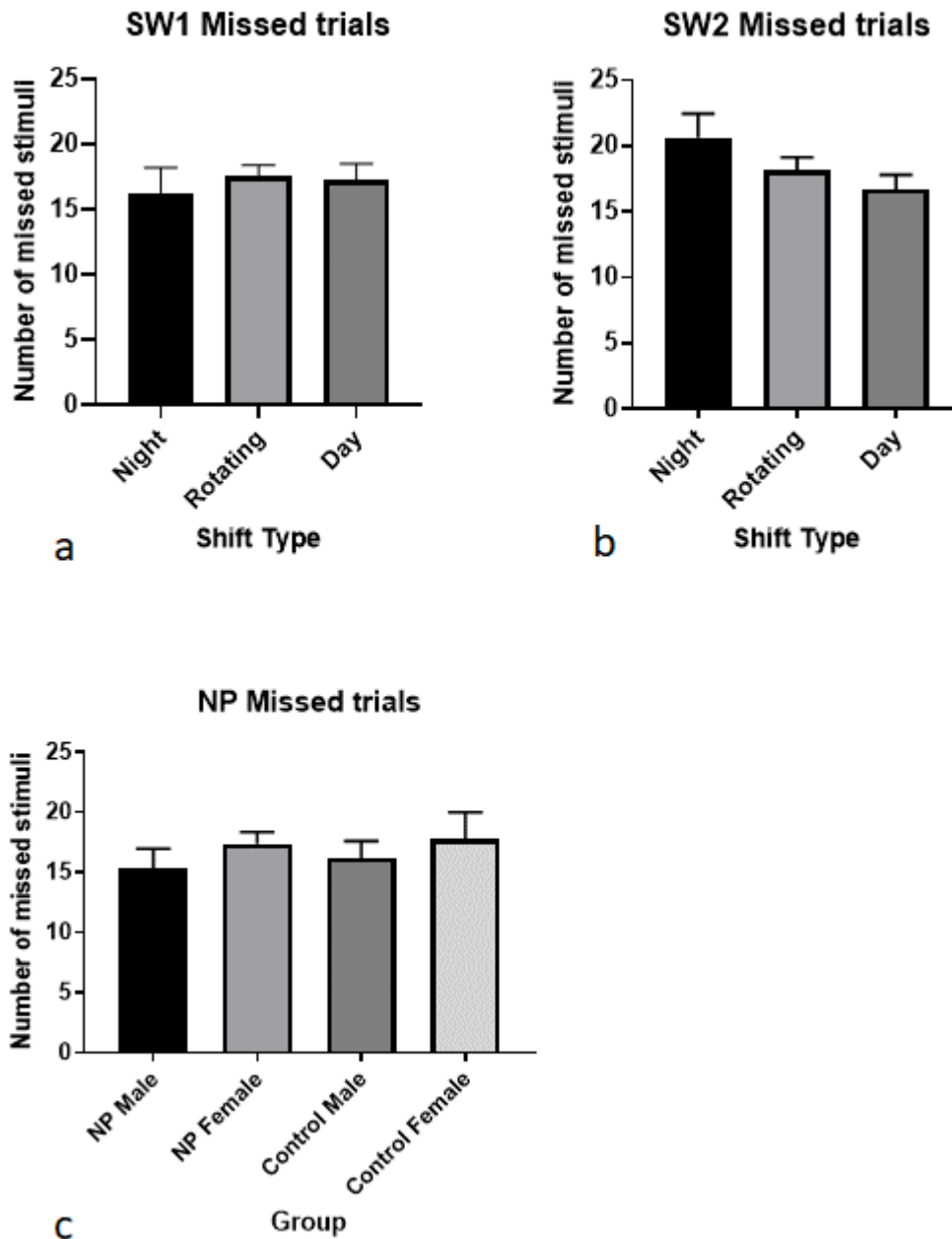


Figure 36 N-back Number of missed trials a) SW1 cohort b) SW2 cohort c) NP cohort. Error bars indicate SEM.

As with previous variables, analysis was run again with shift groups split by BSWSQ score. Table 70 details the statistical analysis for each BSWSQ score and sample. Where data did not pass a normality test it was transformed. The transformation applied is indicated in the table. Where data could not be made normal, nonparametric analysis was used.

Table 70 N-back Number of missed trials BSWSQ score grouping

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	F(3,42)=0.53, p=0.67, $\eta^2=0.04$ (SQRT Transformed)	H(3)=1.92, p=0.59, $\eta_H=0.03$	U=179, p=0.67, $\eta^2=0.07$	H(3)=1.743, p=0.63, $\eta_H=0.02$
SW2	F(3,84)=3.25, p=0.03*, $\eta^2=0.10$ Low Bergen shift group (19.84±7.69) VS High Bergen shift group (15.19 ±4.82) p=0.04* Low Bergen shift group (19.84±7.69) VS High Bergen control group (14.65±5.99) p=0.05*	F(3,74)=1.10, p=0.35, $\eta^2=0.04$	t(68)=1.31, p=0.19, $\eta^2=0.02$ (Log Transformed)	H(3)=2.50, p=0.47, $\eta_H<0.01$

A main effect of group was seen in the SW2 cohort in the Day BSWSQ work category, with Low Bergen shift group having significantly more missed trials than both the High Bergen shift group and High Bergen control group. No other significant differences were seen.

Further correlation analyses was run between BSWSQ score and number of missed trials. Table 71 details the statistical analysis for each BSWSQ score and sample.

Table 71 N-back Number of missed trials correlations

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	$r_s(44)=0.03$, p=0.87, observed power=0.12	$r_s(44)=0.06$, p=0.68, observed power=0.03	$r_s(38)=-0.22$, p=0.16, observed power=0.16	$r_s(54)=0.07$, p=0.62, observed power=0.11
SW2	$r(86)=-0.18$, p=0.95, observed power=0.39	$r_s(76)=-0.11$, p=0.36, observed power=0.26	$r_s(68)=-0.04$, p=0.76, observed power=0.08	$r_s(106)=0.09$, p=0.34, observed power=0.13

No significant correlations between BSWSQ score and number of missed trials were found in either cohort.

ANCOVAs were run using the BSWSQ rest score groupings. In SW1 the covariate, age, was not significantly related to missed trials (F(1,51)=30, p=0.58, $\eta^2=0.01$). There was also no effect of BSWSQ group on missed trials after controlling for age (F(3,51)=1.19, p=0.32, $\eta^2=0.07$). The covariate ‘years worked shifts’ was not significantly related to missed trials (F(1,51)=1.76, p=0.19,

$\eta^2=0.03$). There was also no effect of BSWSQ group on missed trials after controlling for years worked shifts ($F(3,51)=1.46, p=0.24, \eta^2=0.08$).

In the SW2 cohort none of the demographics tested significantly related to missed trials. Further there was no effect of group on missed trials when demographic variables were controlled for. ANCOVA statistics can be found in Table 72.

Table 72 N-back Number of missed trials x demographic variable ANCOVAs

Demographic variable	Main effect	Effect of group when demographic controlled for
Sex	$F(1,103)=0.71, p=0.40, \eta^2=0.01$	$F(3,103)=1.29, p=0.28, \eta^2=0.04$
Country	$F(1,103)=0.29, p=0.59, \eta^2=0.003$	$F(3,103)=1.38, p=0.25, \eta^2=0.04$
Activity level	$F(1,103)=0.10, p=0.75, \eta^2=0.001$	$F(3,103)=1.21, p=0.31, \eta^2=0.03$
Sleep time	$F(1,101)=0.17, p=0.68, \eta^2=0.002$	$F(3,101)=0.98, p=0.40, \eta^2=0.03$
Time awake	$F(1,101)=0.03, p=0.87, \eta^2<0.001$	$F(3,101)=1.04, p=0.38, \eta^2=0.03$

5.4.3 Mean correct reaction times indicated differing response speeds within cohorts

No significant main effect of group on average hit reaction time was observed in the SW1 cohort ($F(2,57)=2.088, p=0.133, \eta^2=0.07$) (Figure 37a). The SW2 cohort did show a significant main effect of group on average correct reaction time ($F(2,102)=4.839, p=0.0098, \eta^2=0.09$). Post hoc analysis showed night shift workers ($529.6 \pm 71.70, p=0.022$) and day workers ($540.0 \pm 55.33, p=0.047$) performed faster than rotating shift workers (568.1 ± 42.17) (Figure 37b). No significant main effect of group was seen in the NP cohort ($H(3)=7.628, p=0.054, \eta_H=0.04$) (Figure 37c).

Bayesian statistics showed there was anecdotal evidence for the null hypothesis in the SW1 cohort ($BF_{10}=0.74$). There was moderate evidence for the alternative hypothesis in the SW2 cohort ($BF_{10}=4.61$). There was anecdotal evidence for the null hypothesis in the NP cohort ($BF_{10}=0.63$). The null hypothesis proposed there is an absence of an effect of group in mean correct reaction time. The anecdotal hypothesis proposed there is an effect of group in mean correct reaction time.

The sample size of each cohort and number of participants removed following outlier analysis is detailed in Table 73.

Table 73 Sample sizes of N-back average correct reaction times

Cohort	Groups	n	Removed through outlier analysis
SW1	Night	10	0
	Rotating	34	1
	Day	16	1
SW2	Night	20	2
	Rotating	48	10
	Day	37	8
NP	NP male	29	0
	NP female	58	0
	C male	27	0
	C female	14	0

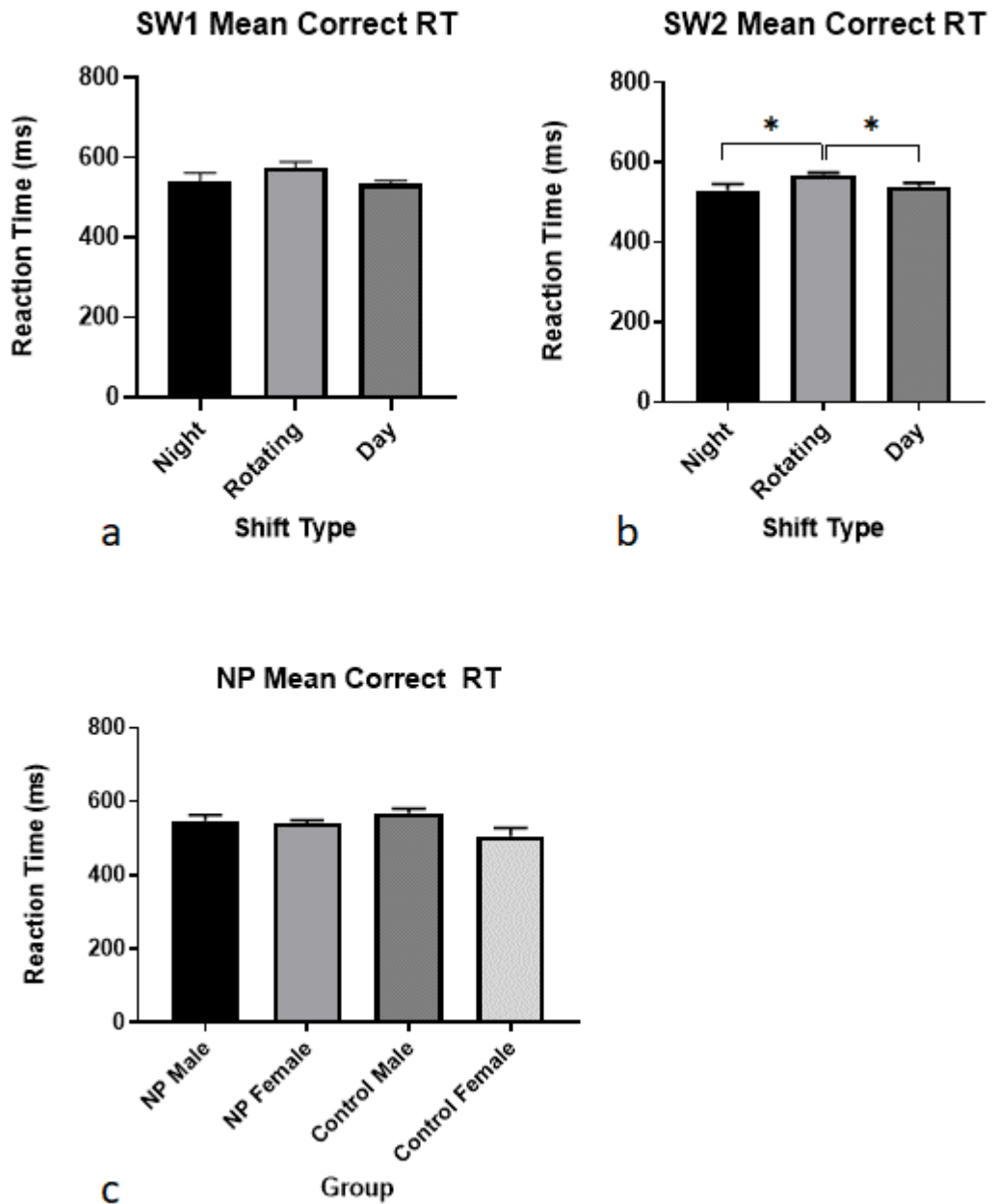


Figure 37 N-back mean correct reaction time a) SW1 cohort b) SW2 cohort c) NP cohort * refers to a p value <0.05. Error bars indicate SEM.

As with previous variables, analysis was run again with shift groups split by BSWSQ score. Table 74 details the statistical analysis for each BSWSQ score and sample. Where data did not pass a normality test it was transformed. The transformation applied is indicated in the table. Where data could not be made normal, nonparametric analysis was used.

Table 74 N-back mean correct reaction time BSWSQ score grouping

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	H(3)=1.996, p=0.57, $\eta^2=0.02$	H(3)=3.41, p=0.33, $\eta^2=0.01$	U=163, p=0.398, r=0.14	F(3,52)=1.397, p=0.25, $\eta^2=0.07$
SW2	F(3,84)=2.17, p=0.098, $\eta^2=0.07$	F(3,74)=1.76, p=0.16, $\eta^2=0.07$	t(68)=3.16, p=0.002**, $\eta^2=0.13$ High Bergen shift group (532±73) Vs Low Bergen shift group (583±63)	F(3,104)=1.31, p=0.27, $\eta^2=0.04$

A significant difference was seen in the SW2 cohort in the Night BSWSQ work category with High Bergen shift group significantly faster than Low Bergen shift group. No other significant differences were found.

Further correlation analyses was run between BSWSQ score and mean correct RTs. Table 75 details the statistical analysis for each BSWSQ score and sample.

Table 75 N-back mean correct reaction time correlations

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	r(44)=0.05, p=0.74, observed power=0.05	r(44)=0.12, p=0.42, observed power=0.13	r(38)=-0.03, p=0.83, observed power=0.04	r _s (54)=0.10, p=0.45, observed power=0.18
SW2	r(86)=-0.06, p=0.57, observed power=0.08	r _s (76)=0.10, p=0.38, observed power=0.08	r(68)=-0.32, p=0.007**, observed power=0.79	r(106)=-0.13, p=0.19, observed power=0.27

A significant negative correlation was found between BSWSQ score and mean correct reaction time in the Night BSWSQ work category in the SW2 cohort. No other significant correlations were observed.

ANCOVAs were run using the BSWSQ rest score groupings. In SW1 the covariate, age, was not significantly related to mean correct RT (F(1,51)=1.01, p=0.32, $\eta^2=0.02$). There was also no effect of BSWSQ group on mean correct RT after controlling for age (F(3,51)=0.88, p=0.46, $\eta^2=0.05$). The covariate 'years worked shifts' was not significantly related to mean correct RT (F(1,51)=0.68, p=0.41, $\eta^2=0.01$). There was also no effect of BSWSQ group on mean correct RT after controlling for years worked shifts (F(3,51)=1.07, p=0.37, $\eta^2=0.06$).

In the SW2 cohort none of the demographics tested significantly related to mean correct RT. Further there was no effect of group on mean correct RT when demographic variables were controlled for. ANCOVA statistics can be found in Table 76.

Table 76 N-back mean correct reaction time x demographic variable ANCOVAs

Demographic variable	Main effect	Effect of group when demographic controlled for
Sex	F(1,103)=0.98, p=0.32, $\eta^2=0.01$	F(3,103)=1.25, p=0.30, $\eta^2=0.04$
Country	F(1,103)=1.30, p=0.26, $\eta^2=0.01$	F(3,103)=1.19, p=0.32, $\eta^2=0.03$
Activity level	F(1,103)=0.21, p=0.65, $\eta^2=0.002$	F(3,103)=1.37, p=0.26, $\eta^2=0.04$
Sleep time	F(1,101)=0.38, p=0.54, $\eta^2=0.004$	F(3,101)=1.29, p=0.28, $\eta^2=0.04$
Time awake	F(1,101)=0.13, p=0.72, $\eta^2=0.001$	F(3,101)=1.27, p=0.29, $\eta^2=0.04$

5.4.4 Within group RT comparisons suggest differences in response profiles between cohorts

The average reaction times of both hits and false positives were compared within group to determine if there were any differences in responding technique. The sample size of each cohort and number of participants removed following outlier analysis is detailed in Table 77.

As reported in Table 78, the SW1 cohort showed no significant differences within shift groups (Figure 38a, 38b, 38c). The SW2 cohort showed significant differences between average reaction times for hits and false positives in all three shift groups, with correct reaction times being consistently faster (Figure 38d, 38e, 38f; Table 78). The NP cohort also showed significant differences in NP males, NP females and control males, again with correct reaction times being faster than incorrect. However, there was no significant difference seen in control females (Figure 39a, 39b, 39c, 39d; Table 79).

Table 77 Sample sizes of N-back within group reaction time comparisons

Cohort	Groups	n	Removed through outlier analysis
SW1	Night	10	0
	Rotating	33	1
	Day	15	2
SW2	Night	22	0
	Rotating	54	4
	Day	45	0
NP	NP male	29	0
	NP female	58	0
	C male	27	0
	C female	14	0

Table 78 Statistical output for within group average reaction time comparisons: Shift working cohorts

	Night	Rotating	Day
SW1	t(9)=1.492, p=0.1698, $\eta^2=0.198$	t(32)=1.853, p=0.073, $\eta^2=0.097$	t(14)=1.870, p=0.083, $\eta^2=0.200$
SW2	t(21)=2.596, p=0.017, $\eta^2=0.24$	t(53)=4.128, p=0.0001, $\eta^2=0.24$	t(44)=3.631, p=0.0007, $\eta^2=0.23$

Table 79 Statistical output for within group average reaction time comparisons: New parent cohort

	NP Male	NP Female	Control Male	Control Female
NP	T=348, p=0.0038, $r_{rb}=-0.60$	t(57)=2.395, p=0.0199, $\eta^2=0.09$	t(26)=2.908, p=0.007, $\eta^2=0.25$	t(13)=1.258, p=0.2304, $\eta^2=0.11$

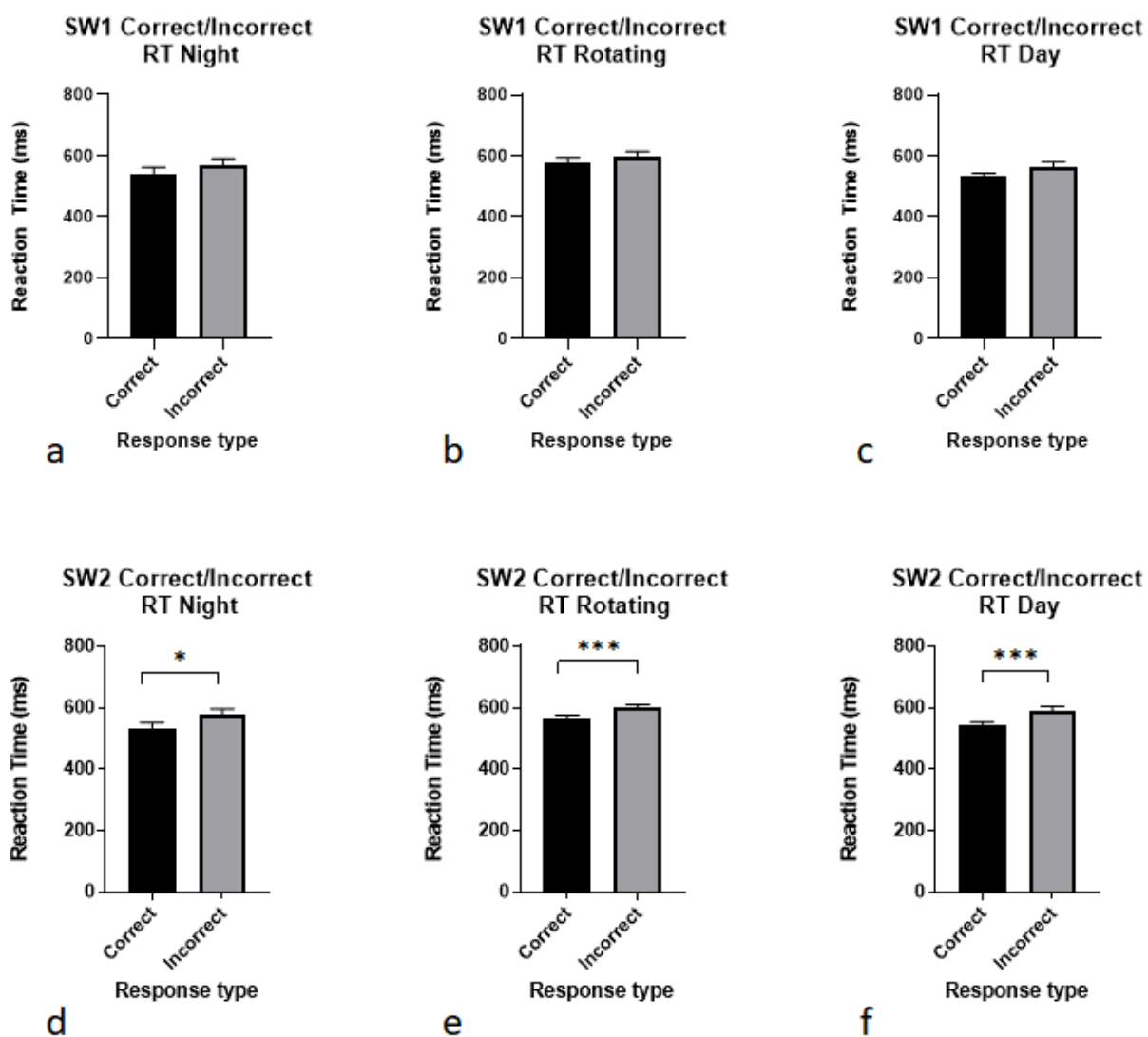


Figure 38 SW1 and SW2 cohort reaction time comparisons a) SW1 night b) SW1 rotating c) SW1 day d) SW2 night e) SW2 rotating f) SW2 day. * refers to a p value < 0.05, * refers to a p value < 0.001. Error bars indicate SEM.**

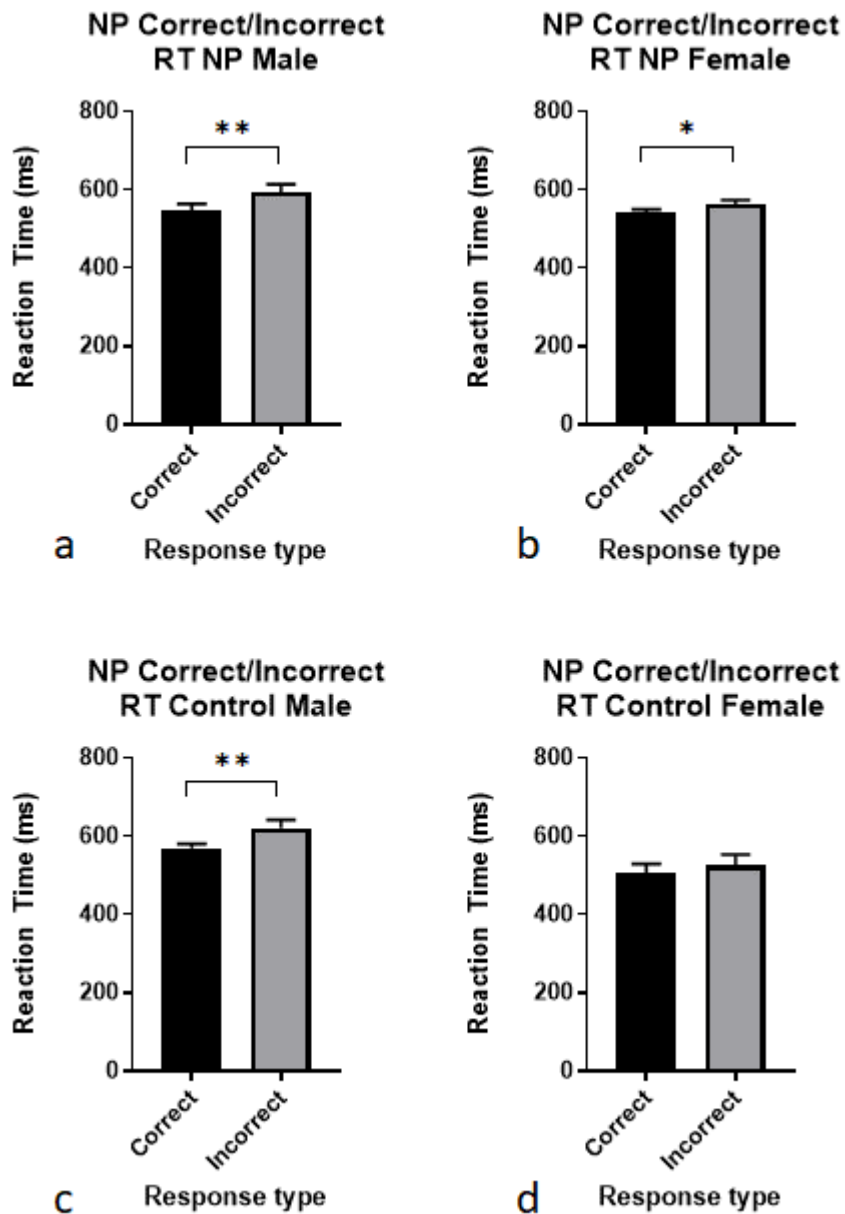


Figure 39 NP cohort reaction time comparisons a) NP male b) NP female c) Control male d) Control female. * refers to a p value <0.05, ** refers to a p value <0.01. Error bars indicate SEM.

5.4.5 Sensitivity measures

Task sensitivity was examined with the use of correlation analysis between age and two variables that have previously shown an age dependant impairment. Gajewski et al (2018) found an increase in reaction times and in missed targets in older participants compared to middle-aged and younger participants in a 2-back design (Gajewski, Hanisch, Falkenstein, Thönes, & Wascher, 2018). Whilst no significant differences were seen in the SW2 missed variable, and therefore groups were merged, differences were seen in the mean correct reaction time, therefore the three groups were analysed separately.

No significant correlation was found between age and number of missed trials ($r_s(123)=0.07$, $p=0.41$, observed power 0.07). No outliers were found within the cognitive data and therefore no outlier removal was conducted.

Age correlation analysis was also run on mean correct reaction time, however the three groups were not collapsed due to previous analysis revealing significant differences between the shift groups. No correlation was found between age and mean RT in night ($r_s(20)=-0.04$, $p=0.87$, observed power=0.15), rotating ($r_s(56)=-0.20$, $p=0.13$, observed power=0.14) or day groups ($r_s(43)=-0.04$, $p=0.80$, observed power=0.03).

Taken together this suggests that this task is not sensitive enough to detect working memory impairments. This might explain the lack of significant difference seen in a number of the samples and variables, and it is important to take this into account when discussing the overall findings. However significant differences were seen in the SW2 in two outcome measures. The NP cohort also showed a significant difference in overall correct performance. This indicates that the tasks were sensitive to detect a working memory impairment. Whilst task sensitivity is important to highlight, it cannot be the sole reason for the outcomes seen.

As with the previous cognitive tasks, cognitive data collected here was compared to that in the literature. However, again, given the differences in methodologies used in the present study and the literature it is difficult to make direct comparisons. It was not possible to find a paper within the sleep deprivation/shift working literature that used an N-back task similar to the one used in the SW1, SW2 and NP cohorts. Therefore two control samples from the depression literature were used. In these papers (Bartova et al., 2015; Korsnes et al., 2013) accuracy was reported as a percentage, comparable to the overall correct performance (%) reported here. Both used a 2-back design with digits as the target stimuli. These outputs are detailed in Table 80.

Table 80 N-back comparisons

Cohort/sample	Mean accuracy as % (SD)
SW1	85.59 (6.43)
SW2	87.82 (4.33)
NP	84.10 (11.73)
Korsnes et al (2013)	81.00 (16.00)
Bartova et al (2015)	81.00 (15.00)

Overall, the accuracy scores taken for the SW1, SW2 and NP cohorts are higher than those found in the literature. This may be indicative of a ceiling effect, providing an explanation for the seeming lack of significant difference between shift workers and non-shift workers and new parents and controls. However the accuracy difference is relatively small (between 3 and 7% difference), therefore the real world significance of this finding is unclear. As discussed previously

there are differences in the task procedure which could lead to this slight variation in mean accuracy scores found here. Further the variability in accuracy was much greater in the reported papers compared to the shift working cohorts reported. The NP cohort showed variation more in line with that found in the depression literature.

5.5 Discussion

This chapter aimed to assess the impact of shift work and sleep disruption associated with new parenthood on working memory, through the use of an N-back task. Data taken from three cohorts suggests little to no impairment to working memory indicating a possible rapid recovery effect following sleep, in both shift workers and new parents. Whilst some variables in the SW2 cohort did indicate potential working memory difference, they were not replicated in the SW1, casting doubt upon the robustness of these findings. However Bayesian analysis showed moderate support for differences in overall correct performance in the SW2 and NP cohorts therefore strengthening the possibility of differences being present in these samples.

Sleep deprivation studies suggest that impaired sleep can negatively impact working memory (Chee et al., 2006; Turner et al., 2007). However, due to working memory being a complex cognitive domain, consisting of multiple components, and the use of a variety of working memory assessments which challenge these components differentially, these studies collectively have drawn an inconsistent conclusion as to the precise impact of sleep deprivation on this cognitive domain (Drummond et al., 2012; Terán-pérez et al., 2012).

Laboratory based sleep deprivation studies often have low ecological validity due to the long periods of wakefulness usually enforced during these protocols (often over 24 hours). Therefore, while these studies have established a relationship exists between sleep and working memory performance, they do not necessarily provide direct insight into the impact of naturalistic/less extreme sleep or circadian disruption on this cognitive domain.

Two groups of individuals that experience more naturalistic forms of sleep disturbance are new parents and shift workers. One key difference between these groups is that shift workers experience a more structured circadian misalignment and are therefore able to compensate time awake at night (due to a shift) with sleep during the day. New parents on the other hand, cannot predict the time a newborn will wake during the night and therefore cannot develop a consistent routine to compensate.

As outlined above, existing new parent studies suggest that these individuals do experience impaired working memory, though the precise cause of this is unclear, with factors including general affective state, endocrinological changes and whether the female or male parent is assessed potentially contributing (Hampson et al., 2015; Janes et al., 1999; Kataja et al., 2017). In

contrast, shift worker studies suggest that working memory is relatively resistant to the circadian disruption associated with a shift working lifestyle (Kazemi et al., 2016, 2018; Shwetha & Sudhakar, 2012). As discussed, the main issue with both the current new parent and shift working literature is they do not account for fatigue. Shift workers are often tested before and after a shift, and time of testing is not often controlled for in new parents. This is an issue as there is evidence to suggest that fatigue impacts working memory (Jain & Nataraja, 2019; Kaur, Malik, Sharma, & Jangra, 2018). Therefore, without isolating this confounding variable it is impossible to determine the cause of any impairment seen.

The data presented here aims to start to address some of these issues, specifically by testing individuals on a day off from work (shift workers) and as close to waking as possible (new parents). Here, one of the most popular working memory tasks, an N-back, was used (2-back variant) (Owen, Mcmillan, Laird, & Bullmore, 2005) which assesses working memory capacity. Four output measures were assessed: Overall correct performance, number of missed trials, correct reaction times and within group reaction time comparisons. Overall correct performance, and reaction time measures assess attention as well as working memory. The number of missed trials was extracted here as most participants did not respond to all trials within the allotted time period. This assesses lapses in attention and working memory performance.

5.5.1 The impact of shift work on working memory

Two cohorts were used to examine the effect of shift work on working memory capacity. Overall correct performance showed no significant differences between shift groups in the SW1 cohort, with anecdotal evidence in support of an absence of an effect of shift group (null hypothesis). Significant differences were seen in the SW2 cohort, however post hoc analysis revealed no further interactions. Bayesian statistics showed moderate evidence in support of the alternative hypothesis. This would suggest there was no working memory capacity impairment in shift workers compared to controls in the SW1 cohort, but that the relationship is more complex in the SW2 cohort. Whilst there were some working memory capacity differences in the SW2 cohort, post hoc analysis was not able to extract the precise relationship, likely due to the magnitude of the effect. As the findings did not replicate across cohorts, the robustness of the SW2 differences must be considered. Given the Bayesian outcomes it is likely that in a large sample, with more power, this relationship may have been distinguishable in post hoc analysis.

When grouped based on sleep quality (BSWSQ) there remained no significant differences between any of the groups. This lends support for the finding seen in the original SW1 cohort of no impact on working memory as a result of shift work. Further, there were no correlations seen between BSWSQ score and overall correct performance in the majority of groups. The SW2 rest group did show a negative correlation between these factors though with an observed power of

only 0.55. Whilst this result cannot be dismissed, the lack of correlation in all other work categories and cohorts suggests little to no correlation between BSWSQ score and overall correct performance. Finally, there were no interactions between demographic variables and cognitive variables.

These findings are broadly consistent with the SW literature, which showed that working memory is relatively resilient to impairment through shift working (Kazemi et al., 2016, 2018; Shwetha & Sudhakar, 2012). Of note is the occupational homogeneity of the existing studies compared to the occupational heterogeneity of the present study. This may indicate that, in the case of working memory, occupation may not be an influencing factor and therefore findings from small groups of shift workers working the same job may in fact be applicable to the global shift working population. However, given the discrepancy between the smaller SW1 cohort and the larger SW2 cohort, it is possible that differences could be seen in larger populations, further highlighting the need for large scale replicability studies to be conducted.

The number of missed trials assesses failure in working memory and sustained attention. There were no significant differences in either the SW1 or SW2 cohort, with moderate and anecdotal evidence in support of the null respectively. This would suggest that there was no impairment in working memory assessed using the N-back task, nor a failure in attention. This is consistent with the SW1 cohorts overall correct performance which also found no working memory capacity impairment. The apparent lack of attentional impairment is consistent with the findings presented in Chapter Three, where no impairment in attention was seen in the SW1 and SW2 cohorts when assessed using the PVT or in a more occupationally homogenous group of UK police force staff.

However, when grouped based on BSWSQ score the SW2 day group showed a significant difference in number of missed trials. This significance was driven by the Low Bergen shift group having significantly more misses than both the High Bergen shift group and the High Bergen control group. This is unexpected given the suggestion that those scoring highly on the BSWSQ would have more severe sleep issues and therefore, according to the literature, have more attentional impairment. However when correlation analysis was run between BSWSQ score and number of missed trials no significant relationship was seen in either cohort. Further, no significant demographic interactions were seen. Again, this provides support to the complexity of the impact of shift working on working memory and highlights the need for larger, more powered studies in a range of shift workers to be conducted.

Another variable used to assess working memory performance, as well as attention, is the average reaction time of correct responses. No significant differences were seen in the SW1 cohort (Bayesian analysis showing anecdotal support for the null hypothesis) however there were

significant differences in SW2, and post hoc analysis revealed that rotating shift workers were reacting significantly slower than night and day shift workers (Bayesian analysis showing moderate support for the alternative hypothesis). This finding is consistent with Kazemi et al. (2018) who assessed shift workers working 4 and 7 consecutive night shifts. They found that those working the short shift rotations were experiencing more working memory impairments (had more incorrect responses) than those working long shift patterns, suggesting that consistency in circadian mismatching is important in stabilising any working memory deficit. In the present study, individuals classed as rotating experience both night and day shifts. Therefore, they may also not have a sufficiently consistent routine to be able to effectively adapt to new sleeping/working times (similar to those working 4 night shifts in Kazemi et al.), thus having more profound working memory impairment than those not working shift or those only working nights. Taken together these findings may indicate that longer shift cycles and/or consistent shift types (i.e. working permanent nights) may be better for preserving working memory.

However when regrouped based on BSWSQ score, only SW2 night showed a significant difference and negative correlation between BSWSQ score and mean reaction time. Given the lack of significant differences in the majority of BSWSQ work categories and correlations it is difficult to say how meaningful the result is. This may indicate a difference in groups based on BSWSQ score however given no day shift workers were in these sample it does not indicate any differences between shift and non-shift workers. No demographic interactions were found. Overall this suggests that the significant differences found in the SW2 cohort in average correct reaction time were not due to differences in sleep problems (as indicated by BSWSQ score). Indeed given the lack of demographic interactions this significant differences were likely due to the differences in shift work type.

Finally, the average reaction times of correct and incorrect presses were compared within group to see if there was any pattern of responding. The SW1 cohort showed no significant differences in any of the three testing groups (night, rotating and day/evening shift workers). The SW2 cohort did show significant differences in all three shift groups, with false positive reaction times being consistently slower than hit reaction times. This would suggest that the majority of people hesitated before incorrectly pressing. Responding during an incorrect trial is suggestive of both a working memory and response inhibition failure. However, as described in Chapter Four, two cohorts of occupationally heterogeneous shift workers showed the reverse pattern of responding during a response inhibition task, with hit reaction times being significantly slower than false positive reaction times. This may indicate that a working memory failure was responsible for the response patterns observed in the N-back task. It is likely that the lack of any significant differences in the SW1 cohort are due to the small sample size leading to a lack of power.

Of note is the key methodological difference between data presented here and that of much of the existing shift working literature, the SW1 and SW2 cohorts received the N-back task in the context of minimal fatigue (on a day off from work). As fatigue, and even perceived fatigue, has been shown to impair working memory (Clarkson et al., 2011; Jain & Nataraja, 2019), the presence of work-related fatigue in previous studies (as participants are often tested before and after a shift) needs to be taken into account. The findings presented here suggest working memory impairments are not seen in such magnitude on a day off from work and highlight the apparent restorative effect of sleep.

5.5.2 The impact of new parenthood on working memory

One cohort of new parents was used to explore the impact of new parenthood and the associated sleep disruption on working memory capacity. Overall correct performance showed no significant differences in the NP cohort, suggesting that there was no working memory capacity impairment in new parents compared to controls. However there was moderate support for the alternative hypothesis in overall correct performance, suggesting there may be a difference present. The lack of working memory impairment was further supported by the findings from the number of missed trials and the correct reaction time variable, which both showed no significant differences in the NP cohort relative to the control groups and had strong and anecdotal evidence in support of the null respectively. As with the shift working cohort, this discrepancy between Bayesian and frequentist statistics suggest that the relationship may be more complex and warrant further investigation in a larger sample.

This finding is partially supported by Janes et al. (1999) who found contrasting results. Janes observed that whilst both primigravid and primiparous groups reported a poorer working memory following pregnancy (which was objectively confirmed by a backward digit span test from WAIS), there were no differences in a reading span test which is also used to assess working memory. The lack of working memory difference reported in the reading span test supports the findings of the present study. The difference in working memory findings within the sample may be explained by the tasks used. The reading span test assesses working memory capacity (Daneman & Carpenter, 1980), similar to the N-back. On the other hand, the backward digit span test examines working memory manipulation (Fortier-Brochu et al., 2012). This again provides evidence that working memory elements can be assessed in isolation, and that the pattern of impairment observed are dependent on the task used for assessment.

The number of missed trials showed no differences across all three cohorts, suggesting that there was no failure in either working memory capacity or attention. This variable is reliant upon both these domains of cognition, and therefore any differences could have been attributed to either one. Lapses in attention have previously been used as an explanation of poor performance on an

N-back task during a sleep deprivation protocol (Terán-pérez et al., 2012). Further, attention has also been shown to be vulnerable in new parenthood (Wilson et al., 2019). However, the findings presented in Chapter Three report no attentional impairment in a group of new parents, consisting of both mothers and fathers, collected at the same time as the NP cohort reported here.

Finally, the average reaction times of correct and incorrect presses were compared within group to see if there was any pattern of responding. The NP cohort did show significant differences between hit and false positive reaction times in all groups (NP male, NP female, control male) except control female. In all significant groups, false positive reaction times were significantly slower than hit reaction times. This suggests that the majority of individuals hesitated longer before incorrectly pressing than when correctly pressing. The lack of this relationship in the control female group is possibly linked to the small sample size, which was likely lacking in power. This finding is the opposite of that observed in assessment of response inhibition in a similar sample of new parents (Chapter Four), suggesting this relationship may have been driven by working memory capacity failure, as opposed to response inhibition failure.

One key methodological strength of the presented data is the inclusion of both males and females. As described previously, much of the current literature regarding new parents focuses primarily on the mother, despite the physical and hormonal differences between new mothers and new fathers. No significant differences were observed in any variable, in either the new mothers or the new fathers. Further, no differences were seen in either sex in the control groups. This would suggest that sex is not a factor that influences working memory in these populations. The lack of significant differences between males and females is counter to much of the existing sex related literature (Hill, Laird, & Robinson, 2014; Speck et al., 2000). Specifically Speck et al. (2000) used four different verbal working memory tasks (modelled on tasks from the California Computerised Assessment package – a 1-back, a 2-back and two sequential number tasks) and found higher accuracy and marginally slower reaction times in females, compared to males. However, the contrast in the findings reported here with that of the existing literature may be due to technical differences (in the task design, participants used, and testing method).

Finally, as with the shift working cohort, this cohort received the N-back task in the context of minimal fatigue. The lack of any working memory differences may be a result of the removal of fatigue and represent the positive impact of recovery sleep on this domain.

5.5.3 The impact of individual differences

The findings presented here are broadly consistent with that of existing shift worker and new parent studies. It is important to consider individual differences in all cognitive assessment, however the field of working memory appears to have placed particular emphasis on this.

Individual differences are where performance differs from participant to participant due to differences in psychological characteristics (Williamson, 2018), rather than a result of external factors (such as shift work). Individual differences within this cognitive domain have shown to be significantly influenced by genes. Ando, Ono and Wright (2001) assessed working memory in 143 monozygotic and 93 dizygotic twins and found heritability estimates to be high (between 43%-49%) (Ando, Ono, & Wright, 2001).

Another variable that has shown individual differences is resilience to sleep disruption. Chee et al. (2006) grouped individuals into sleep deprivation vulnerable (SDV) or sleep deprivation resilient (SDR) based upon the greatest and smallest accuracy difference in working memory performance following sleep deprivation. Eight individuals were stratified into each group. They found that the vulnerable group had a larger decline in reaction time following sleep deprivation than the resilient group, suggesting a larger magnitude of impairment. Mu et al. (2005) examined the individual differences further with the use of neuroimaging. In a sample of 10 SDV and 10 SDR, they found increases in reaction time and decreases in correct responses in both groups as well as a significant reduction in global brain activity. For the SDV group this was associated with reductions in activity in parietal and bilateral prefrontal circuits. However, in the SDR group this was attributed to diminished activation of bilateral parietal circuits, without prefrontal cortex involvement (Mu et al., 2005). It is possible that the variation within group, due to individual differences, was larger than the variation between them, and as a result no significant differences were found. Further these individual differences may explain why some individuals appear to better adapt to shift work/new parenthood than others.

5.5.4 Evaluation of the use of the N-back task for online testing

The N-back task used here requires individuals to pay attention to the task for approximately 10 minutes. Therefore, sustained attention is needed to complete the task and assess working memory capacity. Online N-backs have been used previously in the general public to explore the use of a gamified battery of cognitive tests (Thirkettle et al., 2018). However, to the best of our knowledge, this is one of the first uses of a computerised N-back given using an online testing platform (therefore lacking any control of surrounding environment) in the study of shift workers and new parents. Consequently, it is difficult to ensure that no distractions were present throughout the testing session. Further, as there is variability within the literature regarding the predicted outcomes in these cohorts, it is not possible to use this to examine the success in implementing this task online (i.e. if the resounding opinion in the field was that shift work led to no impairment in working memory, a lack of findings in the SW1 and SW2 cohorts would suggest this task has appropriately measured working memory capacity). However, in all three cohorts, there was a high completion rate and a relatively small number of exclusions on the basis of non-engagement with the task. Participants were able to understand what was required of them and

completed the task, as evidenced by sample sizes. Therefore, it appears that this online implementation of the N-back task was successful. However, given the disparity in the literature (regarding both shift workers and new parents), as well as the methodological changes implemented here to alleviate the impact of fatigue, in order to fully evaluate the use of an online N-back, testing needs to be conducted in a group where a clear impairment is expected, for example in people with schizophrenia (Erickson et al., 2015). To further assess the effectiveness of the task, normative data should be collected from healthy participants, using an ascending difficulty ramp for the N-back (increasing difficulty of an N-back has been shown to lead to increased reaction times and a decrease in accuracy (Choo, Lee, Venkatraman, Sheu, & Chee, 2005)).

5.5.5 Limitations and future directions

Lack of control is one area of limitation in the presented findings. As online testing was used it is impossible to control all elements of the testing environment. Further, a key novel component of these studies is that they were designed to be conducted under conditions of minimal fatigue. Whilst all participants were asked to complete the task on a day off from work (shift workers), and as close to waking as possible (new parents), it is impossible to be certain all participants did. In order to control for this in future studies, fatigue questionnaires should be included to establish exact levels of fatigue within each cohort.

Another limitation of the presented data is that only one cognitive task was used. As outlined previously, working memory is a complex construct, and there is a large battery of tests designed to test different components and elements of this cognitive domain. By only utilising one of these tasks (the N-back used to assess working memory capacity) it is impossible to apply the conclusions to all components of working memory. As described above, different working memory tasks have shown contrasting findings within the same sample group of mothers (Janes et al., 1999). Future studies should aim to use multiple working memory tasks in the same population to provide a clearer overview of the impact of shift working and new parenthood on this cognitive domain.

One factor that was not controlled for in the NP cohort, which has been shown to impact working memory independent of sleep is mental state. As described previously, several studies assessing both pregnant women and postpartum parents have shown that those displaying depressive symptoms have a more impaired working memory than those who are not displaying such symptoms (Hampson et al., 2015; Kataja et al., 2017). Future work should aim to assess mental state alongside working memory capacity and sleep disruption in order to establish a better understanding of this relationship in new parents.

Finally, it is important to evaluate the sensitivity of this task. There was no correlation between age and mean correct reaction time or number of missed trials. When scores from these cohorts were compared with those in the literature, it appeared a ceiling effect may have been present. However, as mentioned previously, there is huge variation with regards to the methodology used here and the technical specifications of the N-back tasks used in much of the scientific literature. As a post hoc power analysis is not considered statistically appropriate (Zhang et al., 2019) it is not possible to know whether these cohorts had a large enough sample size to detect any differences. Future studies should ensure power analysis is conducted a priori and a range of cognitive tasks are used to fully examine working memory in both new parents and shift workers.

5.5.6 Conclusions

Current literature suggests that working memory is impaired following long periods of forced wakefulness (as seen in laboratory based sleep deprivation studies). However the relationship with more naturalistic forms of sleep disruption is more complex. Here an N-back task was used to assess working memory in two shift working groups and a cohort of new parents, without the confounding impact of fatigue. The presented data suggests minimal to no working memory impairment in shift workers and new parents in the context of low fatigue. Further, no apparent sex differences were seen in the new parent cohort. Differences between the two cohorts of shift workers indicates that if a working memory impairment does exist, it is likely to be extremely small.

6.1 Introduction

The maintenance of visuomotor coordination under conditions of fatigue or in the context of shift worker-related circadian mismatching is critical for the health and welfare of both individuals and those around them. Further, it is important to ascertain whether impairments persist even once an opportunity to sleep has occurred.

Visuomotor coordination is the ability to synchronise visual information with physical movement. It can be measured with a variety of tasks (outlined in Chapter One), with one of the most commonly used being the Trail Making Task. The Trail Making Task was originally a component of the Army Individual Test Battery and a paper based task that required feedback to be given by a researcher during the task (Corrigan & Hinkeldey, 1987). Consisting of two parts: TMTA and TMTB, it requires participants to connect either numbers (TMTA) or numbers and letters (TMTB) in ascending order i.e. 1-A-2-B-3-C. In common with many cognitive tasks, the TMT is not 'construct pure' and has been shown to assess attention, visual search and scanning, sequencing and shifting, flexibility, and the ability to maintain two trains of thought simultaneously (Salthouse, 2011). However, it also has a visuomotor coordination element which distinguishes it somewhat from the other tasks included in this thesis. Specifically, TMTA has been used to determine visual search and motor speed skills, whereas TMTB measures higher level executive functions, such as mental flexibility (Bowie & Harvey, 2006). TMTB has additional cognitive demands due to switching mental sets, as well as an increase in visual search demands due to there being more interfering stimuli (Gaudino, Geisler, & Squires, 1995). Whilst susceptible to practise effects, the TMT does have good interrater reliability (Spren & Strauss, 1998). This test is also influenced by age (Davies, 1968), with performance decreasing with increasing age. Further, the level of participant education shows a similar impact, with lower levels of education associated with poorer TMT performance (Tombaugh, 2004).

As outlined in Chapter One, visuomotor coordination has been assessed in sleep deprived populations, showing a negative impact of extended periods of wakefulness (De Gennaro, Ferrara, Curcio, & Bertini, 2001; Wimmer et al., 1992). The conclusions drawn from these studies cannot be directly applied to shift working populations as they do not explore the impact of circadian mismatching (whereby individuals are still getting sleep, but at a time counter to their circadian rhythm). Further, given the fact the majority of shift workers are unlikely to face extended periods of sleep deprivation (there is evidence to suggest this cognitive construct is protected for up to 25

hours of sleep deprivation (Alhola et al., 2005)), this sleep deprivation literature lacks occupational relevance.

Studies that have specifically assessed visuomotor performance in shift working populations have produced divergent findings. Titova et al. (2016) found that both current shift workers and individuals who had recently stopped shift working (within the past 5 years) performed worse on the Trail Making Task (TMT) compared to those who had never worked shifts. There was no difference between non-shift workers and those who had stopped working shifts more than 5 years ago (Titova et al., 2016). These findings indicate that the adverse impact of shift working on visuomotor coordination develops quickly and then takes at least 5 years without the circadian misalignment synonymous with shift working to recover. While compelling, these data are caveated due to the fact that only individuals classed as middle aged and elderly (45-75 years old) were included in the study. This limits the generalisability of the findings, given the working population can range between 18 and 65 and age has shown to be negatively correlated with TMT performance (Davies, 1968).

Similarly, assessing the impact on visuomotor performance during a shift, Leonard et al. (1995) observed significant TMT performance reduction in pre-registration medical house officers. A paper version of TMTB was used to assess pre- and post- a 32 hour long shift (with 4.5 hours of sleep) (Leonard et al., 1995). While suggestive of an adverse impact on visuomotor coordination, Leonard et al. also reported impaired performance in the Stroop task in the same participants. Given the Stroop task primarily assesses response inhibition and attention and that the more visuomotor coordination focused TMTA was not performed in these participants, it is challenging to disentangle the impact of shift working on visuomotor coordination as opposed to higher cognitive constructs in this particular population. In addition, the use of a within subject design (without allowing participants to complete a full sleep cycle before the 'post' assessment) means it is impossible to say these findings are not in fact due to the accumulated work related fatigue, more similar to the effect of prolonged wakefulness, as opposed to the effect of shift working lifestyle.

In contrast to this, Machi et al. (2012) assessed emergency physicians, using the TMT, before and after both day and night shifts. They found no evidence of an impact on visuomotor coordination (Machi et al., 2012). This would suggest that, in this situation, participants were resistant to TMT impairment. Alternatively, a minimum performance level may have been reached in that the participants may already have been experiencing an impairment associated with being a shift worker (as characterised by Titova et al.) and the addition of work-related fatigue had no further detectable impact. As no occupationally matched control (emergency physicians' not working shifts) was assessed, it is not possible to establish which conclusion is correct. A further

explanation for this lack of impairment may be linked with the sample being occupationally homogenous. All participants here were likely to be highly educated, and experienced in shift working. As impaired TMT has already been linked with lower education levels (Tombaugh, 2004), this further implies these results are not generalisable. Additionally, participant's age ranged from 31 to 52. This is a much more narrow age range than that of the general working population (18-65). As mentioned previously, age has been shown to impact TMT performance (Davies, 1968). Therefore, while medical professionals offer convenient samples of shift workers, they are not representative of this population which is diverse with respect to occupation, age and education.

Consistent with Machi et al. (2012), Guyette et al. (2012) also found no significant difference between a 12 hour shift and a 24 hour shift group of air medical providers, assessed at the beginning and end of a shift. These findings again suggest a degree of resilience or acquired tolerance within the shift working population but, as with Machi et al., findings may be a result of a minimum performance level being reached. As no non-shift working control was used it is difficult to confirm this. However, performance in the TMTA improved in both groups after a shift, while TMTB performance improved only in the 12 hour shift group. This indicates a potential practise effect, which has been previously reported for the TMT (Spreen & Strauss, 1998). Though why this was only experienced in TMTB in the 12 hour shift group is not clear.

These findings are broadly consistent with the outcomes of a sleep deprivation protocol employed by Alhola et al. (2005), who suggests that visuomotor coordination is immune to short term circadian misalignments and sleep deprivation (up to 25 hours) (Alhola et al., 2005). Taken together, these findings suggest that visuomotor coordination may be resistant to the effects of extended wakefulness up to 25 hours, however beyond this impairments may start to appear (Leonard et al., 1995).

The differences in performance shown in the available literature may also be a reflection of occupational differences. Occupation type may be significant in TMT performance as it has been suggested that individuals may use different strategies to complete the TMT dependant on job type. Proctor et al. (1996) found that machine based workers performed faster but were more error prone than those working non-machine paced jobs (Proctor et al., 1996). This difference in performance may be a result of a speed accuracy trade off, where-by individuals prioritise either accuracy or reaction time at the detriment of the other (Heitz, 2014), with machine paced workers more likely to prioritise speed to ensure they maintain pace with the externally controlled event rate that they are used to working at.

As noted earlier, laboratory sleep deprivation studies have little relevance to the shift working context, given that shift workers rarely have to tolerate such extended periods of wakefulness. Equally, laboratory studies, in which long periods of wakefulness are applied, are of relatively low

ecological validity, with the exception of modelling some sub-types of insomnia (Bjørøy, Jørgensen, Pallesen, & Bjorvatn, 2020). To therefore better understand the impact of disrupted sleep on visuomotor coordination, we also assessed a population widely recognised as regularly experiencing poor quality/limited duration sleep not due to occupational reasons – new parents.

As previously discussed, given the apparent resilience of visuomotor performance to long periods of wakefulness, it is logical that new parents would show limited impairments in this cognitive area, given that they are generally able to sleep at some point each night (Gay et al., 2004). However, as with shift working, it is not possible to directly apply the conclusions of sleep deprivation literature to new parents. Critically, to the best of my knowledge, there has been very little research using the TMT task to assess visuomotor coordination in new parents, nor has visuomotor coordination in this population been thoroughly assessed using other cognitive tasks. As mentioned in Chapter One, Treadway et al (1969) did find a significant increase in the time required to complete the TMT in postpartum woman however Zheng et al (2018) found no differences in a TMT task.

Studies of the neural correlates of the TMT have suggested the involvement of a large number of regions. These include activations in the left frontal regions and the left middle and superior temporal gyrus, with increased activity in these areas for TMTB compared to TMTA (Zakzanis et al., 2005). Further, lesion studies have shown patients with dorsolateral frontal damage showed the most impairment on TMTB, though some patients with a spectrum of frontal lesions also showed impairment (Stuss et al., 2001). In addition, MacPherson et al. (2017) found significant interactions between slower completion time in the TMTB and thinner cortex in inferior parietal regions, as well as frontal and temporal regions (MacPherson et al., 2017). Poorer white matter microstructure of the left anterior thalamic radiation and right uncinate fasciculus were also related to worse performance.

Activations in the frontal cortex, particularly the dorsolateral prefrontal cortex, are likely commensurate with the higher cognitive functions engaged by the TMT (particularly TMTB), such as attention and cognitive flexibility. However, the breadth of activity beyond the prefrontal areas is indicative of TMT engaging a range of other domains including motor control and visual processing, consistent with a multifactorial cognitive profile. This range of regions associated with visuomotor coordination may provide an explanation as to why, in many studies, it appears to be relatively resilient across shift types/short term sleep deprivation. Whilst frontal regions have been shown to be particularly sensitive to even short term sleep deprivation (M. L. Thomas et al., 2000), activations in the left inferior parietal lobule positively correlated with resistance to sleep deprivation (Cui et al., 2015). This may provide a reason as to why TMT performance appears to only deteriorate after 24 hours. Whilst the activations were predominantly left frontal, there were

other clusters around the left hemisphere, supporting the statement that normal TMT performance involves multiple areas of cognition, including, but not limited to, visuomotor coordination. It is not solely reliant upon attention and therefore the impact of sleep deprivation on frontal regions does not result in failure in TMT performance. These differences in activation patterns and performance between the TMTA and TMTB underscore the differential cognitive demands associated with each part of the task. The TMTA has been shown to assess visual search and motor speed skills whereas the TMTB is used to measure higher level executive functions, such as mental flexibility (Bowie & Harvey, 2006).

This chapter utilises an online version of the TMT that was completed by remote participants (i.e. participants who are assessed online in the absence of a 'live' investigator), both within the shift working population and new parents. Most TMTs follow the original set up and are paper based. However, given the use of online testing here this approach was not possible and an online variant was developed as this area of cognition remains underexplored within the target populations. In the present study we aimed to assess the impact of new parenthood and shift work on TMT performance, without the confound of work-related/mental fatigue.

6.2 Specific aims

1. To determine if visuomotor coordination is impacted in shift workers and new parents
2. To evaluate the effectiveness of a Trail Making Task delivered in an online format that is completed by remote participants in the absence of an investigator

6.3 Method

Research presented in this chapter has received ethical approval following review by The Open University's Human Research Ethics Committee (HREC/2016/2444/Breese/2 and HREC/2017/2549/Breese/1) and adheres to all BPS ethics standards (The British Psychological Society, 2018).

A full information sheet and debrief form were provided and each participant was required to provide informed consent before being enrolled. Participants were informed of their right to withdraw at any point (prior to data anonymisation and aggregation). Contact details of the research team were provided at the beginning and end of testing, should participants wish to ask any questions.

6.3.1 Recruitment approach

Data presented in this chapter is an amalgamation of several recruitment drives. All data were collected using the online participant platform Prolific (www.prolific.co) and the Gorilla Experiment Builder (www.gorilla.sc) to create and host all experiments (Anwyl-Irvine et al., 2018). All received financial payment for taking part in the study.

6.3.2 Participants

Three different cohorts were recruited. An in-depth explanation of the differences between sample groups as well as the rationale for each can be found in Chapter Two.

1. Shift worker one (SW1): the first instance of using the TMT task online assessing shift and non-shift workers.
2. Shift worker two (SW2): following data analysis of SW1, changes were made in order to improve understanding (clearer video instructions were given). Again, data were collected from both shift workers and non-shift working controls.
3. New parents (NP): Parents of a child under one year old were asked to complete the TMT. This task had the same parameters as SW2, and therefore a control group (individuals who were not currently new parents or shift workers) was extracted from the SW2 non-shift working participant sample.

No participants were permitted to take part in more than one of these recruitment drives, however some data from the SW2 cohort was used as a control in NP.

Prior to outlier analysis the sample sizes for each cohort (including controls) were as follows:

- SW1 TMTA: 53 participants (25 removed following exclusion screening)
- SW1 TMTB: 65 participants (13 removed following exclusion screening)
- SW2 TMTA: 106 participants (60 removed following exclusion screening)
- SW2 TMTB: 120 participants (46 removed following exclusion screening)
- NP TMTA: 122 participants (18 removed following exclusion screening)
- NP TMTB: 128 participants (12 removed following exclusion screening)

6.3.3 Exclusion criteria

Participants were excluded from analysis if they stated they had had a recent head injury that required hospitalisation, were under the age of 18, if it was not possible to put them in a shift group due to conflicting/absent/uninterpretable description of their work pattern, they were not on a day off from work or did not fully complete the task. One participant in the NP group was removed due to lack of information regarding their sex (therefore prohibiting the grouping into male/female).

Following initial review of the SW1 cohort data it was clear some participants had not understood the task, or had not fully engaged. Therefore additional exclusion criteria were developed to exclude these individuals. These were as follows:

1. Participants who started on a random number and then made an extended string of errors (+4 errors) of random letters/numbers. These were recorded as a non-engagement error.
2. Participants who appeared to have a lack of understanding of the task were excluded and recorded as a lack of understanding error. This included individuals who repeatedly went back to the beginning of the sequence when a wrong number was pressed, those who completed the chain backwards, those who completed TMTB (the letters and numbers section) in the wrong order (e.g. A-1-B-2-C-3 instead of 1-A-2-B-3-C) and participants who sequenced all the letters before the numbers in TMTB.

6.3.4 Design

As explained in Chapter Two, participants were recruited through Prolific and tested using Gorilla Experiment Builder. Participants were all tested once, for the SW1 and SW2 cohorts participants were asked to complete on a day off from work, for the NP cohort participants were asked to complete the assessment after they had woken up in the morning. This was to reduce any direct impacts of work-related fatigue or acute tiredness on cognition.

6.3.5 Testing procedure

Once participants had read the information sheet and given informed consent, each individual received the full questionnaire battery to complete (outlined in Chapter Two). Following this, SW1, SW2 and NP participants completed the TMT and a Psychomotor Vigilance Task (Chapter Three). For the SW2 and NP cohorts this was given in a randomised order, however the SW1 cohort received the PVT first. The randomisation of task order was introduced following SW1 testing in order to counter any effect of order.

The TMT task (Figure 40) was split into two parts, TMTA and TMTB, with participants required to connect different stimuli in ascending order. TMTA required participants to connect the numbers 1 to 26 in ascending order. TMTB required participants to connect letters and numbers in alternating pairs (e.g. 1-A; 2-B; 3-C; until 13-M was reached). Participants had unlimited time to complete each part. These parameters were based on Titova et al. (2016). In the original paper version of this task, testing was conducted in the presence of a researcher who would provide feedback on incorrect responses, and direct participants to correct them. Given the online nature of the task used in the present study, visual feedback indicators were used in place of a researcher. Stimuli were designed to turn blue if correctly pressed and then green once the next correct stimuli had been pressed. This was to enable participants to know where they were last

correct in a sequence. Should an error be made during the task, the stimuli would disappear. The paper version of the task required participants to connect the stimuli with a line (drawn using a pencil). In this task it was not possible to do this, so the last correct stimulus remained blue to provide a clear return point, if an error was made. The TMT was always given in the same order, with TMTA administered first, then TMTB.

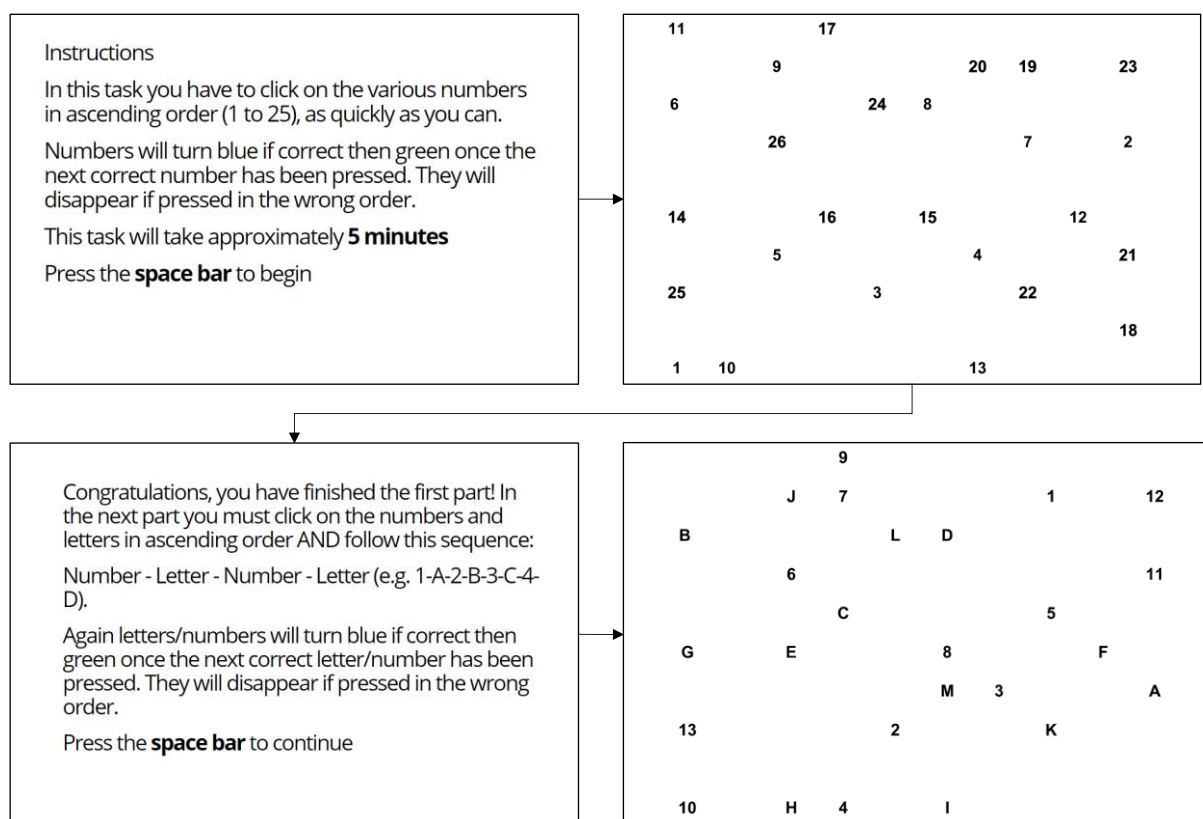


Figure 40 Screen presentation sequence of TMT for the SW1 cohort

Following review of the SW1 data it was clear that many participants did not understand the instructions provided. This conclusion was based on the large proportion of participants making high numbers of errors, and as a result the task had a high exclusion rate. Therefore, an instructional video showing an animation of the task being completed was added before each assessment began and the directions were made clearer (Figure 41) for the SW2 and NP cohorts. The task itself was not changed. This dramatically sped up completion times across all groups and reduced dropout rates, suggesting the modifications were effective.

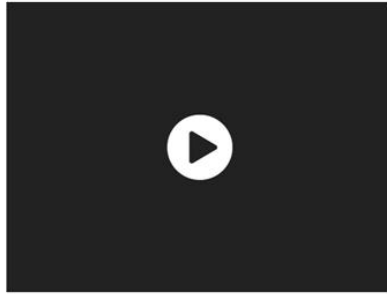
Instructions

In this task you have to click on the various numbers in ascending order (1 to 25), as quickly as you can.

Numbers will turn blue if correct then orange once the next correct number has been pressed. They will disappear if pressed in the wrong order.

Click on the video below to watch a short demonstration

This task will take approximately **5 minutes**



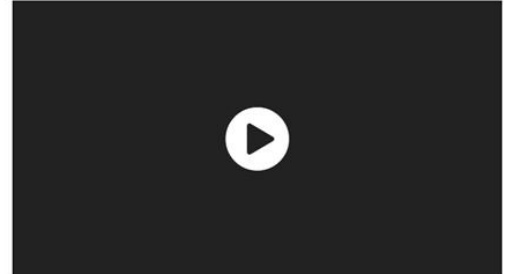
Press the **space bar** to begin the task

Congratulations, you have finished the first part! In the next part you must click on the numbers and letters in ascending order AND follow this sequence:

Number - Letter - Number - Letter (e.g. 1-A-2-B-3-C-4-D).

Again letters/numbers will turn blue if correct then orange once the next correct letter/number has been pressed. They will disappear if pressed in the wrong order.

Click the video for a short demonstration



Press the **space bar** to begin the task

Figure 41 New instructional pages used for the SW2 and NP cohorts

As the TMT is predominantly implemented as a paper test it was important to further examine the test used in the present study to establish any potential methodological differences that may have led to differential outcomes to a paper TMT. Similar to the original TMT (Reitan, 1955), the computerised version asked participants to connect 25 dots in ascending order for TMTA. However, the computerised version of TMTB had one more position (going from 1 to M, rather than 1 to 13). This meant a total of 26 dots had to be connected. Analysis of the distances between the stimuli locations for each of the two parts found no significant difference between TMTA and TMTB relative distances ($t(48)=0.44$, $p=0.66$). This suggests that, despite an additional target stimulus, the distances between stimuli was not a contributing factor to the results presented below. This is in line with the original TMT, where no distance differences were present between TMTA and TMTB.

6.3.6 Output variables

The variables extracted for analysis of TMTA and TMTB are summarised below and are based on those previously used by Titova et al. (2016) in a study of current and former shift workers:

1. Total completion time: Total time taken to complete each part
2. Reaction time of correct responses: Average reaction time of correct responses
3. Percentage of group who made errors: Percentage of participant group who made at least one error
4. Distribution of errors: When during the trial an error occurred

Completion time is the primary variable most commonly extracted from a TMT (Davies, 1968; Płotek et al., 2014; Wahlin, Backman, Wahlin, & Winblad, 1996). However given that this was a relatively new variant of this task reaction time and error analysis were also conducted.

6.3.7 Statistical analysis

Data was downloaded from Gorilla and prepared for statistical analysis using Microsoft Excel 2013 (Microsoft, 2013). Descriptive statistics (mean, standard deviation and range) were generated for demographic data, including age, sex, years working shifts and sleep disorder frequency using GraphPad Prism (version 8.2.1) (GraphPad Software, La Jolla California USA, n.d.) and StatsCloud (www.statscloud.app) and are outlined in Chapter Two.

Cognitive assessment data were analysed using frequentist statistics with JASP (www.jasp-stats.org, version 0.11.1) and GraphPad Prism (version 8.2.1). Data was first screened for normality using the D'Agostino and Pearson test. Outliers were identified with box plots and points identified as being outside the whiskers (set to 1.5x interquartile range above/below the 75th/25th percentile) were removed. If data were normally distributed parametric tests were used (ANOVA and t-test), if data were non-normal non-parametric tests were employed (Kruskal-Wallis, Mann-Whitney, Wilcoxon). To address multiple comparisons, Tukey post hoc analyses were performed as appropriate. Significance was given by a p-value of less than 0.05. Error distribution plots were created using Microsoft Excel 2013 (Microsoft, 2013). Bayesian analysis was conducted using JASP and conclusions based on the thresholds found in Van Doorn et al (2019). These can be found in Table 22.

6.4 Results

For the SW2 and NP cohorts, in order to control for any potential order effect, the design contains group A and B (see Figures 2 and 5 in Chapter Two). Effects of assessment order were controlled by running two testing sequences. Data from both assessment sequences was compared to determine if there was an order effect. Where no significant effect of order was detected, the two sub-groups were merged to increase group size and statistical power. However, it was not always possible to merge groups and as a result, some variables have group A and group B. This suggests that in some variables an order effect may be present. Specifically, variables that could not be merged were TMTB total completion time and TMTB reaction time of correct responses.

6.4.1 TMTA

6.4.1.1 Total completion time showed evidence of visuomotor performance impairment in the night group of the SW2 cohort

Total completion time was operationally defined as the time it took individuals from first being shown the stimuli to pressing the last one in the sequence (seconds). The sample size of each cohort and number of participants removed following outlier analysis is detailed in Table 81. The sample size of each cohort (sex split) is detailed in Table 82.

No main effect of shift was found in the SW1 cohort ($H(2)=0.284$ $p=0.868$, $\eta_H=0.04$) (Figure 42a). A main effect of shift was seen in the SW2 cohort ($H(2)=6.814$, $p=0.033$, $\eta_H=0.05$), with post hoc revealing significant difference between the night group (64.42 ± 28.13) and the rotating group (47.9 ± 15.2 $p=0.033$) (Figure 42b). No significant main effect of group was seen in the NP cohort ($H(3)=3.316$, $p=0.346$, $\eta_H<0.01$) (Figure 42c).

Bayesian statistics showed there was anecdotal evidence for the null hypothesis in the SW1 cohort ($BF_{10}=0.43$). There was moderate evidence for the alternative hypothesis in the SW2 cohort ($BF_{10}=5.23$). There was moderate evidence for the null hypothesis in the NP cohort ($BF_{10}=0.20$). The null hypothesis proposed there is an absence of an effect of group in TMTA completion time.

As this study aims to evaluate the use of a TMT task online, further analysis was conducted on completion time. For SW1 and SW2, participants were split by sex to establish if a sex effect was seen using this form of remote testing (outlier removed data was used). One individual in the SW1 cohort was not included in this analysis due to not providing their sex in the demographics questionnaire.

The SW1 cohort showed no main effect of sex ($F(1,44)=2.329$, $p=0.134$, $\eta^2=0.05$) or a shift by sex interaction ($F(2,44)=1.650$, $p=0.204$, $\eta^2=0.07$) (Figure 43a). The SW2 cohort showed a main effect of sex ($F(1,95)=5.716$, $p=0.019$, $\eta^2=0.05$) (male= 50.3 ± 18.36 , female= 60.12 ± 23.15) but no shift by sex interaction ($F(2,95)=1.586$, $p=0.210$, $\eta^2=0.03$) (Figure 43b).

Table 81 Sample sizes of TMTA completion time

Cohort	Groups	n	Removed through outlier analysis
SW1	Night	7	0
	Rotating	26	2
	Day	18	0
SW2	Night	24	0
	Rotating	41	4
	Day	36	1
NP	NP male	24	3
	NP female	57	5
	C male	20	1
	C female	12	0

Table 82 Sample sizes of TMTA completion time (sex split)

Cohort	Groups	n
SW1 Male	Night	1
	Rotating	11
	Day	8
SW1 Female	Night	6

	Rotating	14
	Day	10
SW2 Male	Night	12
	Rotating	25
	Day	23
SW2 Female	Night	12
	Rotating	16
	Day	13

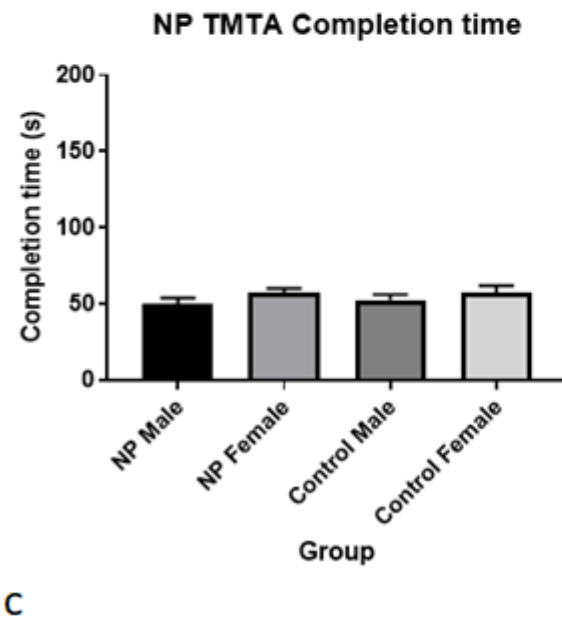
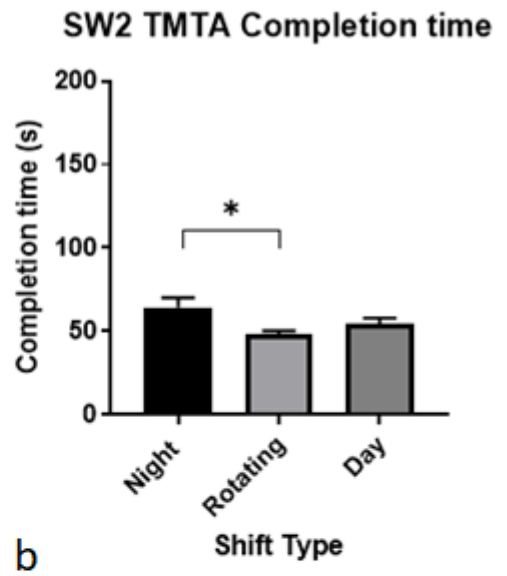
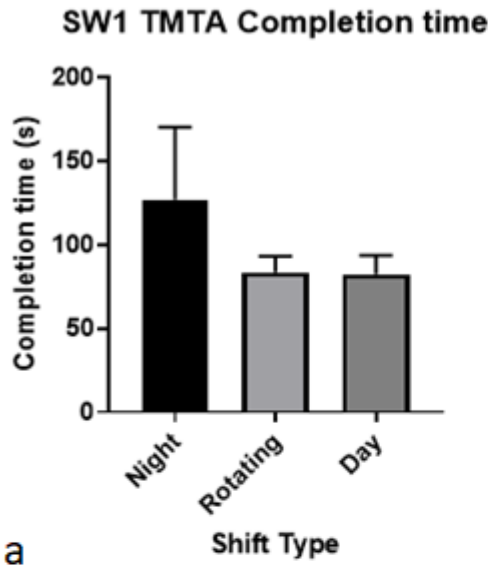
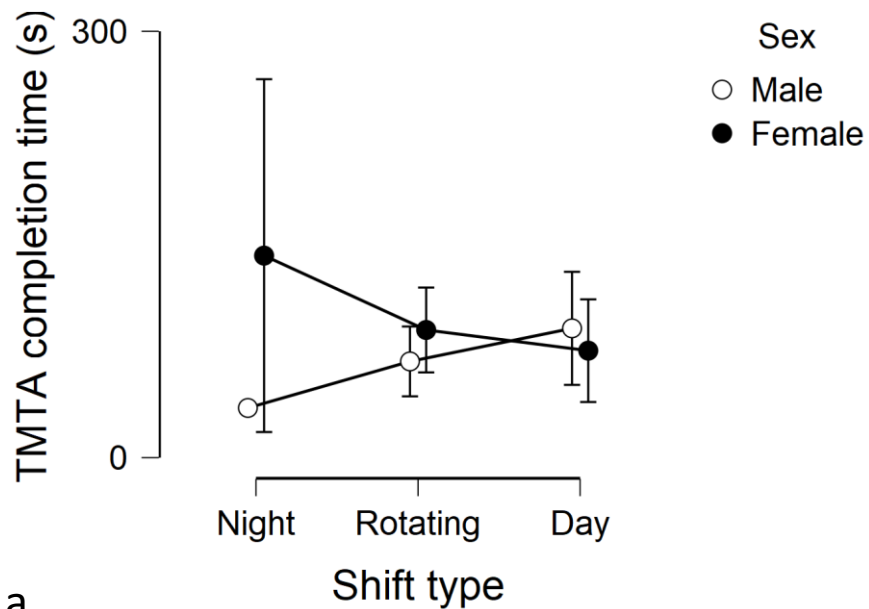
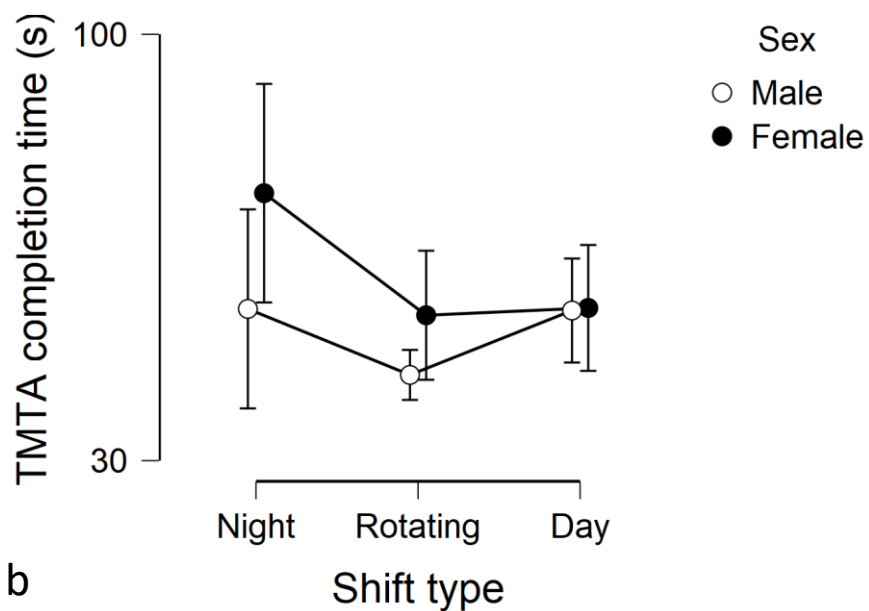


Figure 42 TMTA total completion time (s) a) SW1 cohort b) SW2 cohort c) NP cohort * refers to a p value < 0.05. Error bars indicate SEM.



a



b

Figure 43 TMTA completion time, split by sex a) SW1 cohort b) SW2 cohort. Error bars indicate SEM.

Analysis was run with shift groups split by BSWSQ score. Table 83 details the statistical analysis for each BSWSQ score and sample. Where data did not pass a normality test it was transformed. The transformation applied is indicated in the table. Where data could not be made normal, nonparametric analysis was used.

Table 83 TMTA Completion time BSWSQ score grouping

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	F(3,41)=0.35, p=0.79, $\eta^2=0.03$ (log transformed)	F(3,27)=0.47, p=0.71, $\eta^2=0.05$ (log transformed)	t(30)=1.44, p=0.16, $\eta^2=0.06$ (log transformed)	F(3,44)=0.58, p=0.63, $\eta^2=0.04$ (log transformed)
SW2	H(3)=1.91, p=0.59 $\eta_H=0.02$	t(34)=1.35, p=0.19, $\eta^2=0.05$ (1/ Transformed)	t(59)=1.12, p=0.27, $\eta^2=0.02$ (1/ Transformed)	H(3)=0.82, p=0.85 $\eta_H=0.02$

No significant differences were seen between High and Low Bergen shift and control groups when examining TMTA completion time.

Further correlation analyses was run between BSWSQ score and TMTA total completion time.

Table 84 details the statistical analysis for each BSWSQ score and sample.

Table 84 TMTA Completion time correlations

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	$r_s(43)=-0.01$, p=0.95, observed power=0.12	$r_s(29)=0.08$, p=0.65, observed power=0.14	$r_s(30)=-0.18$, p=0.32, observed power=0.35	$r_s(46)=0.04$, p=0.80, observed power=0.05
SW2	$r_s(71)=0.06$, p=0.63, observed power=0.15	$r_s(34)=-0.09$, p=0.61, observed power=0.06	$r_s(59)=-0.15$, p=0.24, observed power=0.27	$r_s(91)=<0.01$, p=0.98, observed power=0.05

No significant correlations between BSWSQ score and TMTA completion time were found in either cohort.

ANCOVAs were run using the BSWSQ rest score groupings. In SW1 the covariate, age, was significantly related to TMTA completion time ($F(1,43)=9.771$, $p=0.003$, $\eta^2=0.17$). However there was no effect of BSWSQ group on TMTA completion time after controlling for age ($F(3,43)=1.32$, $p=0.28$, $\eta^2=0.07$). The covariate 'years worked shifts' was not significantly related to TMTA completion time ($F(1,43)=0.59$, $p=0.45$, $\eta^2=0.01$). There was also no effect of BSWSQ group on TMTA completion time after controlling for years worked shifts ($F(3,43)=0.60$, $p=0.62$, $\eta^2=0.04$).

In the SW2 cohort sex, country of testing, activity levels and time awake were not significantly related to TMTA completion time. Further, there was no effect of group on TMTA completion time when these demographic variables were controlled for. The covariate sleep time, was significantly related to TMTA completion time ($F(1,88)=4.86$, $p=0.03$, $\eta^2=0.05$) however there was no effect of BSWSQ group on TMTA completion time after controlling for sleep time ($F(3,88)=0.38$, $p=0.77$, $\eta^2=0.01$). ANCOVA statistics can be found in Table 85.

Table 85 TMTA Completion time x demographic variable ANCOVAs

Demographic variable	Main effect	Effect of group when demographic controlled for
Sex	F(1,89)=1.57, p=0.21, $\eta^2=0.02$	F(3,89)=0.39, p=0.76, $\eta^2=0.01$
Country	F(1,89)=0.61, p=0.44, $\eta^2=0.01$	F(3,89)=0.52, p=0.67, $\eta^2=0.02$
Activity level	F(1,89)=0.92, p=0.34, $\eta^2=0.01$	F(3,89)=0.46, p=0.71, $\eta^2=0.02$
Sleep time	F(1,88)=4.86, p=0.03, $\eta^2=0.05$	F(3,88)=0.38, p=0.77, $\eta^2=0.01$
Time awake	F(1,86)=0.30, p=0.58, $\eta^2=0.003$	F(3,86)=0.55, p=0.65, $\eta^2=0.02$

6.4.1.2 Reaction time of correct responses showed no differences between groups

Average reaction time of correct response for each group was calculated for all three cohorts. No significant main effect of group were found in the SW1 cohort ($H(2)=0.487$, $p=0.784$, $\eta_H=0.03$) (Figure 44a), the SW2 cohort ($H(2)=3.119$, $p=0.210$, $\eta_H=0.01$) (Figure 44b) or the NP cohort ($H(3)=1.231$, $p=0.746$, $\eta_H=0.02$) (Figure 44c). The sample size of each cohort and number of participants removed following outlier analysis is detailed in Table 86.

Table 86 Sample sizes of TMTA mean reaction time of correct responses

Cohort	Groups	n	Removed through outlier analysis
SW1	Night	7	0
	Rotating	26	2
	Day	18	0
SW2	Night	24	0
	Rotating	42	3
	Day	36	1
NP	NP male	24	3
	NP female	58	4
	C male	20	1
	C female	12	0

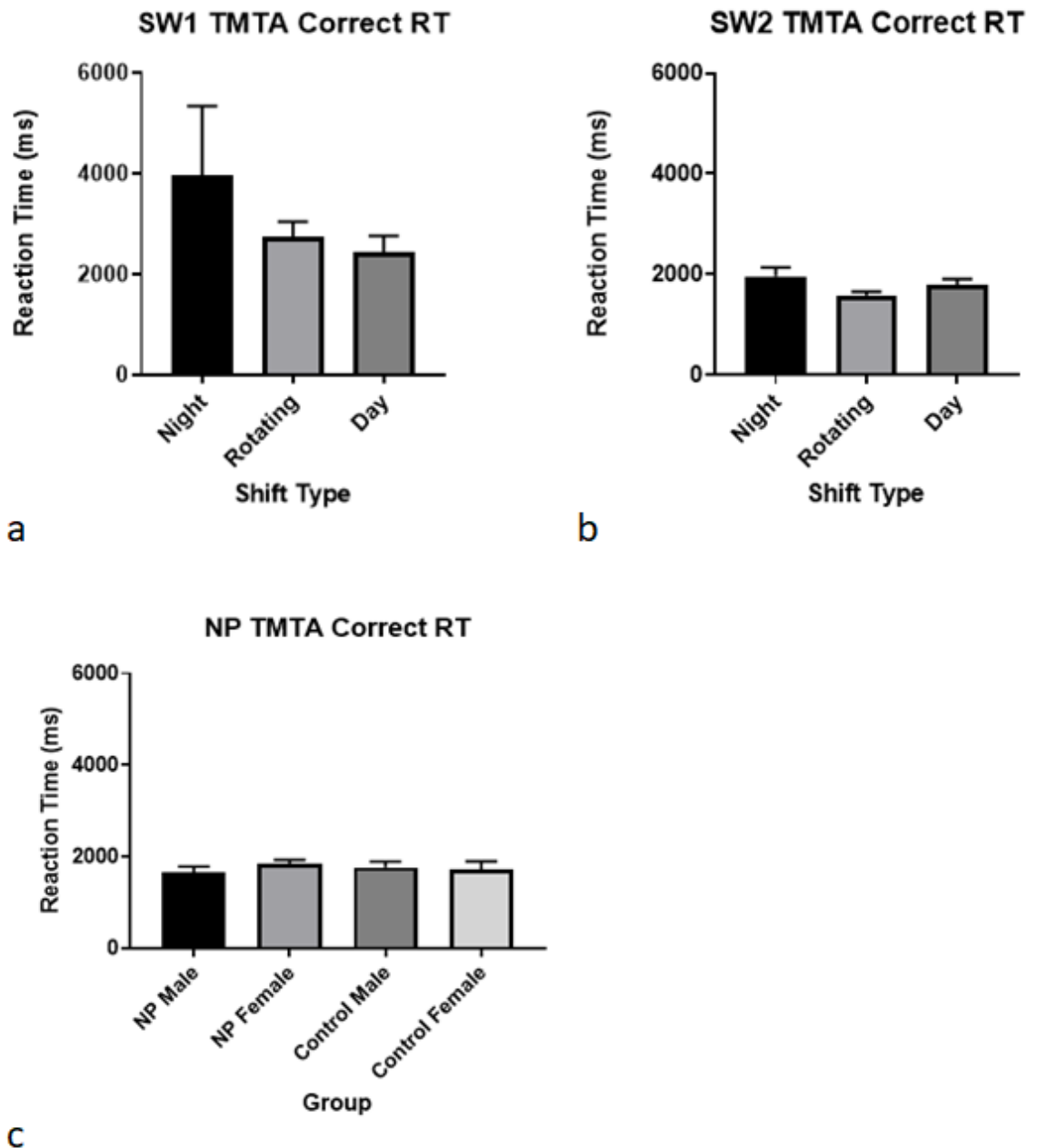


Figure 44 TMTA reaction time of correct responses a) SW1 cohort b) SW2 cohort c) NP cohort. Error bars indicate SEM.

6.4.1.3 Percentage of group who made at least one error indicates a potential speed accuracy trade off in response method

As this was a relatively novel way of delivering the TMT task, it was important to assess multiple outcome measures to test if participants understood the task in this format. Further, these provide information on how frequently an individual was experiencing a lapse in visuomotor capabilities.

Given the low rate of errors across the participant groups, percentage of group who has at least one error was used. Through visual inspection of the data, it was clear that whilst the majority of

participants made no errors during the TMTA, the errors that were made could be categorised into two types: missed number errors and wrong number errors (outlined in Chapter Two).

Missed number errors were operationally defined as cases where a participant jumped one number in the sequence, for example pressing 1-2-3-5, rather than 1-2-3-4-5. Wrong number errors were operationally defined as any errors where a participant skipped more than one number e.g. 1-2-3-8 or went backwards e.g. 5-6-7-6-5. The sample size of each cohort is detailed in Table 87. As this was a group percentage this data did not go through outlier analysis.

Table 88 shows the distribution of these errors within each group. For the SW1 cohort there was very little difference in error type, the SW2 cohort showed more missed number errors across participant groups, which also occurred in the NP cohort. Figure 45 shows the percentage of each group who made at least one error.

Table 87 Sample sizes of TMTA percentage of group who made at least one error

Cohort	Groups	n
SW1	Night	7
	Rotating	28
	Day	18
SW2	Night	24
	Rotating	45
	Day	37
NP	NP male	27
	NP female	62
	C male	21
	C female	12

Table 88 Number of participants making at least one error with total group size, split by type of error

Participant group	Missed number			Wrong number		
	Night	Rotating	Day	Night	Rotating	Day
SW1	3/7	8/28	5/18	3/7	11/28	5/18

Participant group	Missed number			Wrong number		
	Night	Rotating	Day	Night	Rotating	Day
SW2	4/24	11/45	16/37	3/24	6/45	10/37

Participant group	Missed number				Wrong number			
	NPM	NPF	CM	CF	NPM	NPF	CM	CF
NP	8/27	21/62	9/21	4/12	7/27	11/62	6/21	3/12

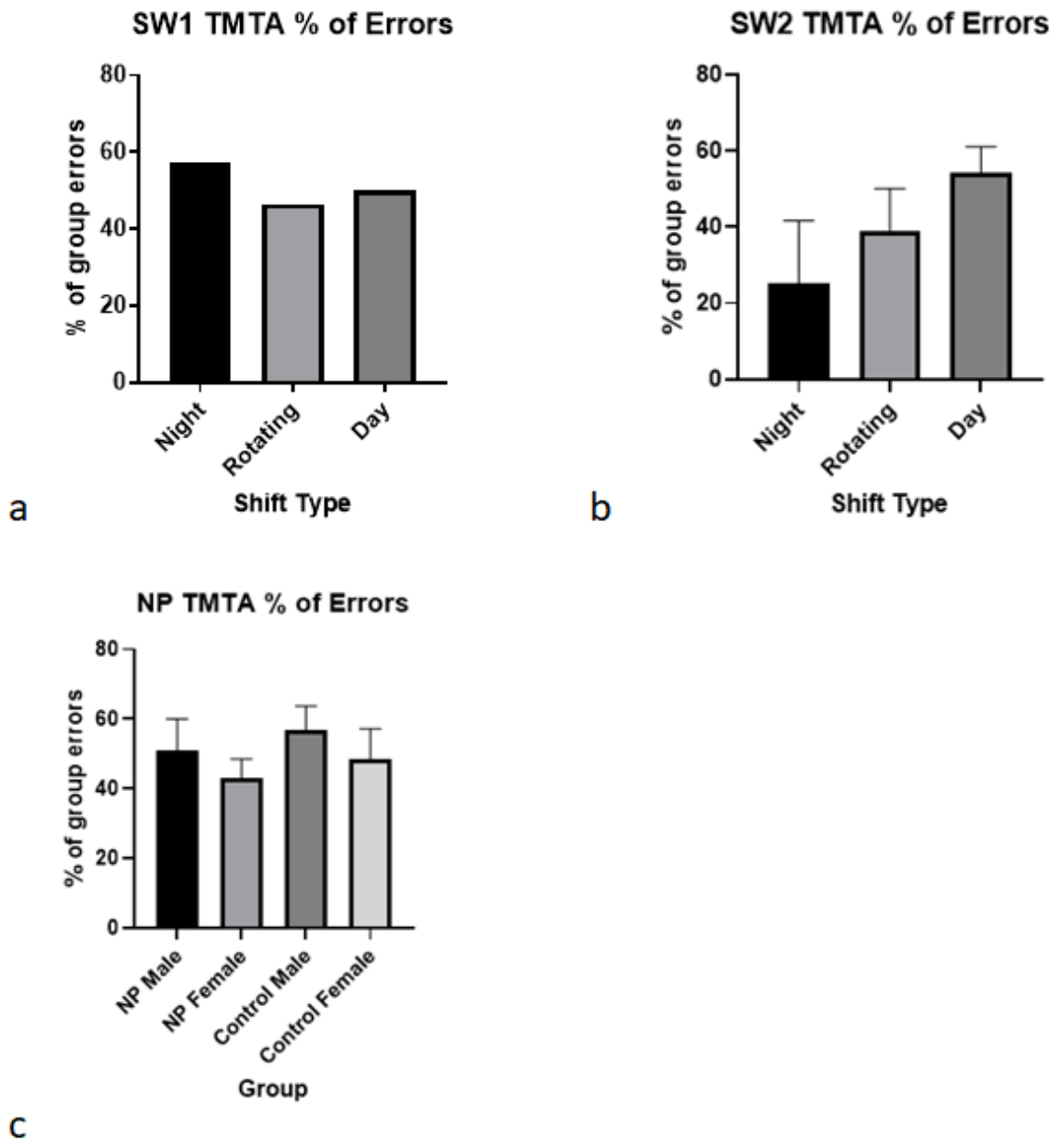


Figure 45 TMTA Percentage of group who made at least one error a) SW1 cohort b) SW2 cohort c) NP cohort. Error bars indicate SEM.

6.4.1.4 Distribution of errors showed some clustering, indicative of fatigue

While a significant proportion of participants made no errors in TMTA (SW1=50.94%, SW2=59.43%, NP=51.64), the point during task performance at which any errors were made was extracted for each group for further analysis. These were presented in the form of 'heat maps' representing the performance of each participant across each letter choice in the task. Red indicated an error was made, while green indicated a correct response.

In the SW1 cohort there appeared to be a clustering of errors towards the beginning of the task, perhaps representative of participants learning how to respond to the task and understanding the meaning of the feedback cues (Figure 46). This was replicated in the night and rotating groups of the SW2 cohort with an additional clustering towards the end of the task, perhaps suggesting a fatigue effect. However, day controls showed errors distributed evenly across the task, with no clear clustering present (Figure 47).

Analysis of the NP cohort indicated that NP males, NP females and Control males also showed no clear clustering, with errors being made throughout the task. However control females produced very few errors, with all but one being towards the end of the task (Figure 48).

The sample size of each cohort is detailed in Table 89. As this was a distribution analysis this data did not go through outlier analysis.

Table 89 Sample sizes of TMTA distribution of errors

Cohort	Groups	n
SW1	Night	7
	Rotating	28
	Day	18
SW2	Night	24
	Rotating	45
	Day	37
NP	NP male	27
	NP female	62
	C male	21
	C female	12

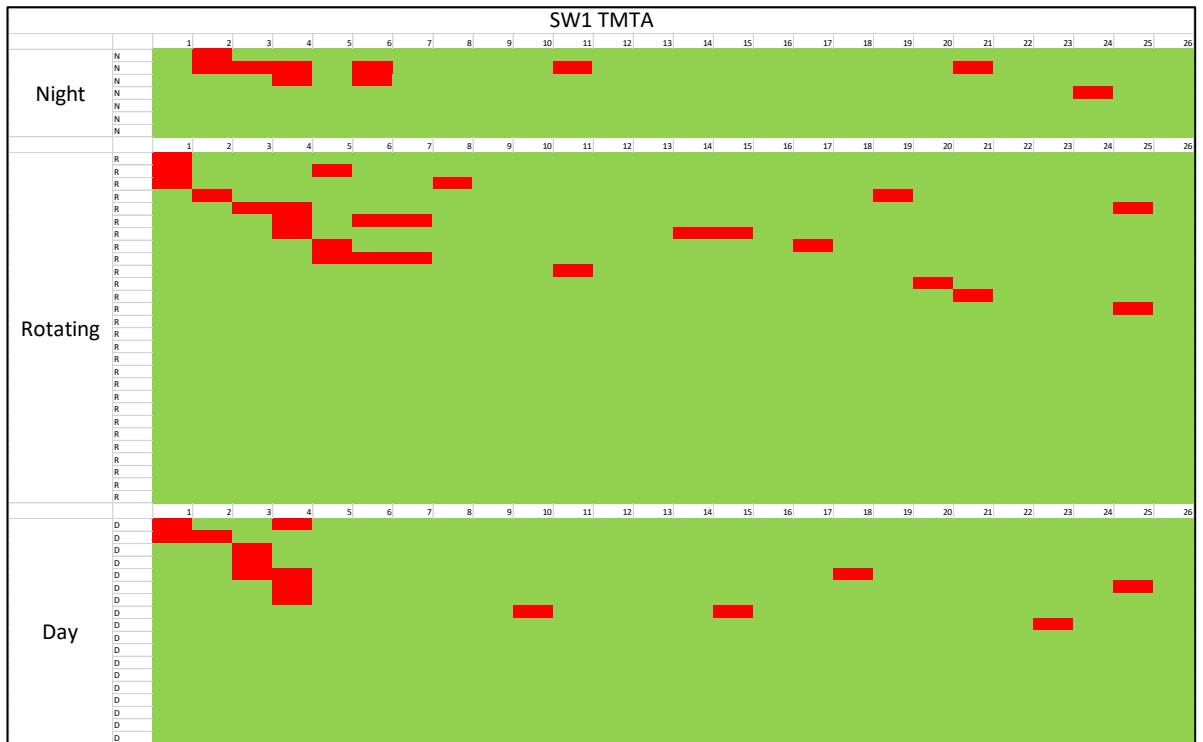


Figure 46 SW1 Error 'heat maps' Red indicates an error was made while green indicates a correct response. Each row represents an individual participant, each column represents a 'step' in the sequence.

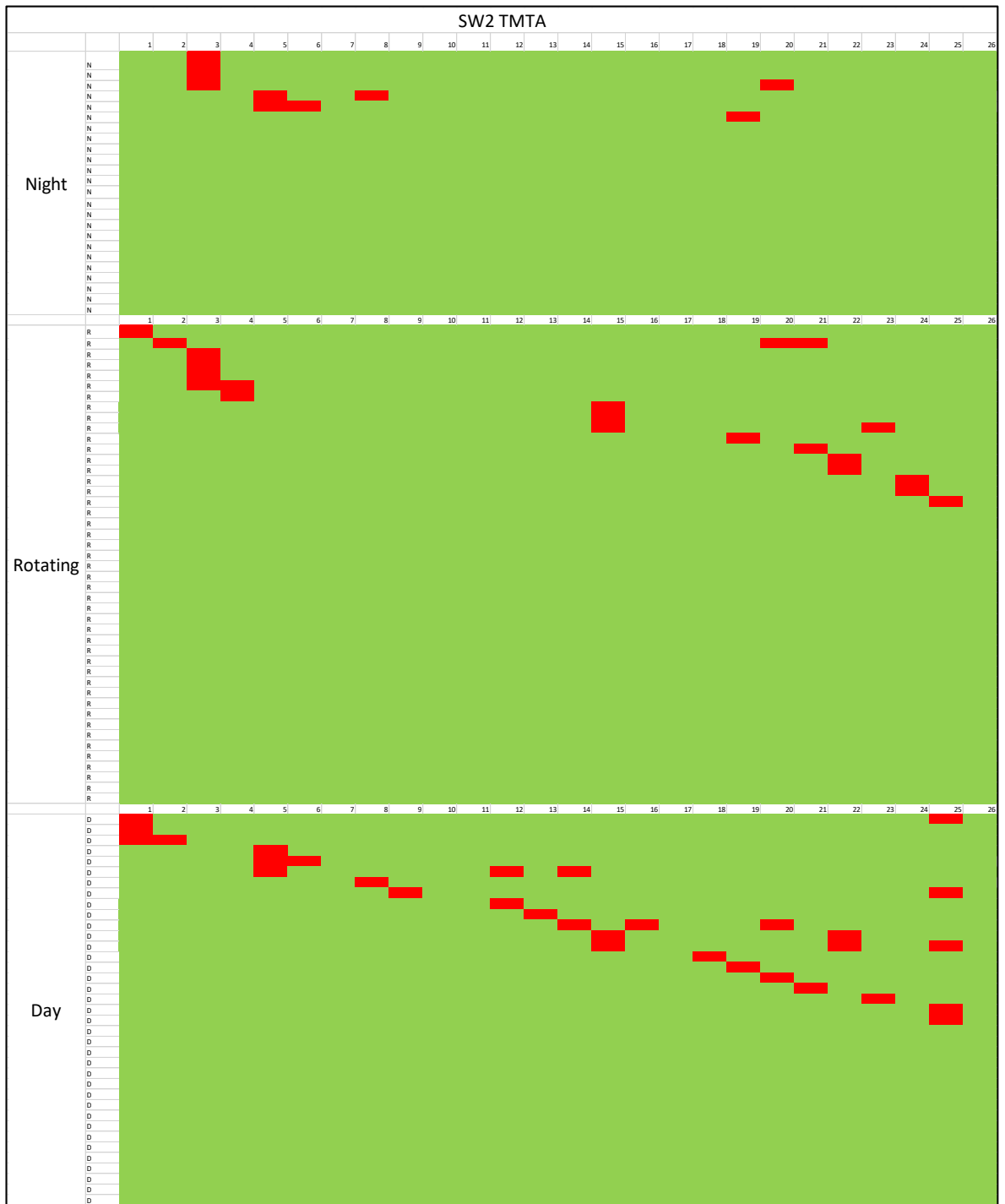


Figure 47 SW2 Error 'heat maps' Red indicates an error was made while green indicates a correct response. Each row represents an individual participant, each column represents a 'step' in the sequence.

No main effect of shift was detected in the SW1 cohort ($H(2)=2.199$, $p=0.333$, $\eta_H<0.01$) (Figure 49a). In the SW2 cohort, as previous analysis had revealed significant differences between order groups, they were not merged for this analysis. There was a significant main effect of shift seen in the SW2 cohort ($F(5,105)=3.763$, $p=0.004$, $\eta^2=0.15$) with post hoc revealing a significant difference between rotating B (90.26 ± 37.23) and day A (63.47 ± 19.63 , $p=0.049$) (Figure 49b). A significant main effect of group was also found in the NP cohort ($H(4)=11.86$, $p=0.018$, $\eta_H=0.07$), however post hoc did not reveal any further differences (Figure 49c).

Bayesian statistics showed there was anecdotal evidence for the null hypothesis in the SW1 cohort ($BF_{10}=0.39$). The null hypothesis proposed there is an absence of an effect of group in TMTB completion time. There was strong evidence for the alternative hypothesis in the SW2 cohort ($BF_{10}=10.71$). There was anecdotal evidence for the alternative hypothesis in the NP cohort ($BF_{10}=1.53$). The alternative hypothesis proposed there is an effect of group on TMTB completion time.

As with TMTA, SW1 and SW2 participants were split by sex and outlier removed data was used. This was to provide more information on how this variant of the TMT performs. One individual in SW1 was not included in this analysis due to not providing their sex in the demographics questionnaire.

In the SW1 cohort there was no main effect of sex ($F(1,54)=0.498$, $p=0.483$, $\eta^2=87.70e-3$) nor an interaction of shift by sex ($F(2,54)=0.513$, $p=0.602$, $\eta^2=0.02$) (Figure 50a). In the SW2 cohort as previous analysis had revealed significant differences between order groups, they were not merged for this analysis. Analysis revealed a main effect of sex ($F(1,99)=4.755$, $p=0.032$, $\eta^2=0.04$) however no interaction of shift type and sex ($F(5,99)=0.847$, $p=0.520$, $\eta^2=0.03$) (Figure 50b).

The sample size of each cohort and number of participants removed following outlier analysis is detailed in Table 90. The sample size of each cohort (sex split) is detailed in Table 91.

Table 90 Sample sizes of TMTB completion time

Cohort	Groups	n	Removed through outlier analysis
SW1	Night	8	1
	Rotating	32	2
	Day	21	1
SW2	Night A	9	1
	Night B	14	1
	Rotating A	24	2
	Rotating B	23	1
	Day A	19	3
	Day B	22	1
NP	NP male	25	3
	NP female	57	1
	C male A	14	1
	C male B	13	0
	C female	12	2

Table 91 Sample sizes of TMTB completion time (sex split)

Cohort	Groups	n
SW1 Male	Night	2
	Rotating	12
	Day	9
SW1 Female	Night	6
	Rotating	19
	Day	12
SW2 Male	Night A	5
	Night B	8
	Rotating A	15
	Rotating B	13
	Day A	13
	Day B	15
SW2 Female	Night A	4
	Night B	6
	Rotating A	9
	Rotating B	10
	Day A	6
	Day B	7

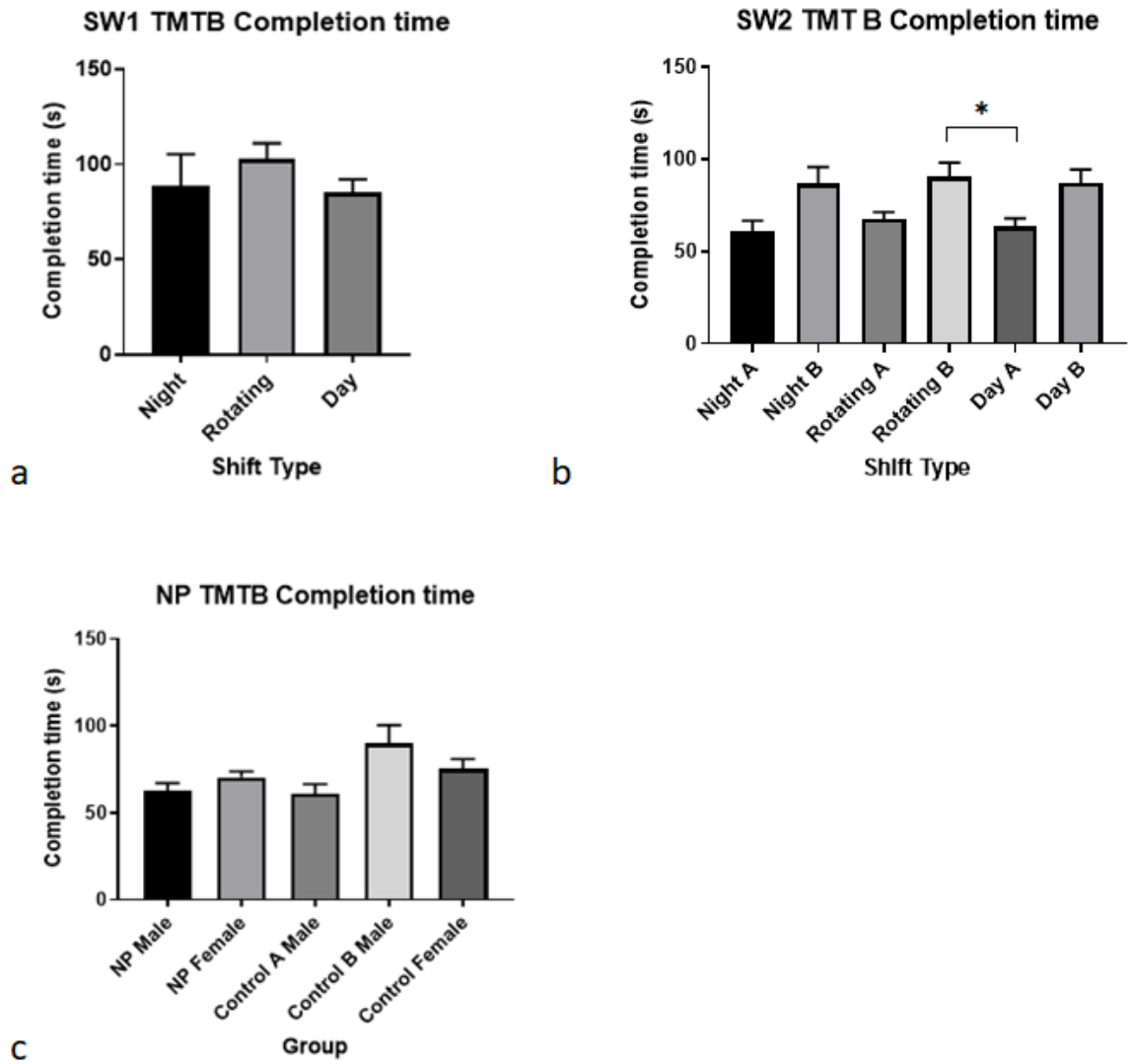


Figure 49 TMTB Total completion time **a)** SW1 cohort **b)** SW2 cohort **c)** NP cohort. * refers to a *p* value <0.05. Error bars indicate SEM.

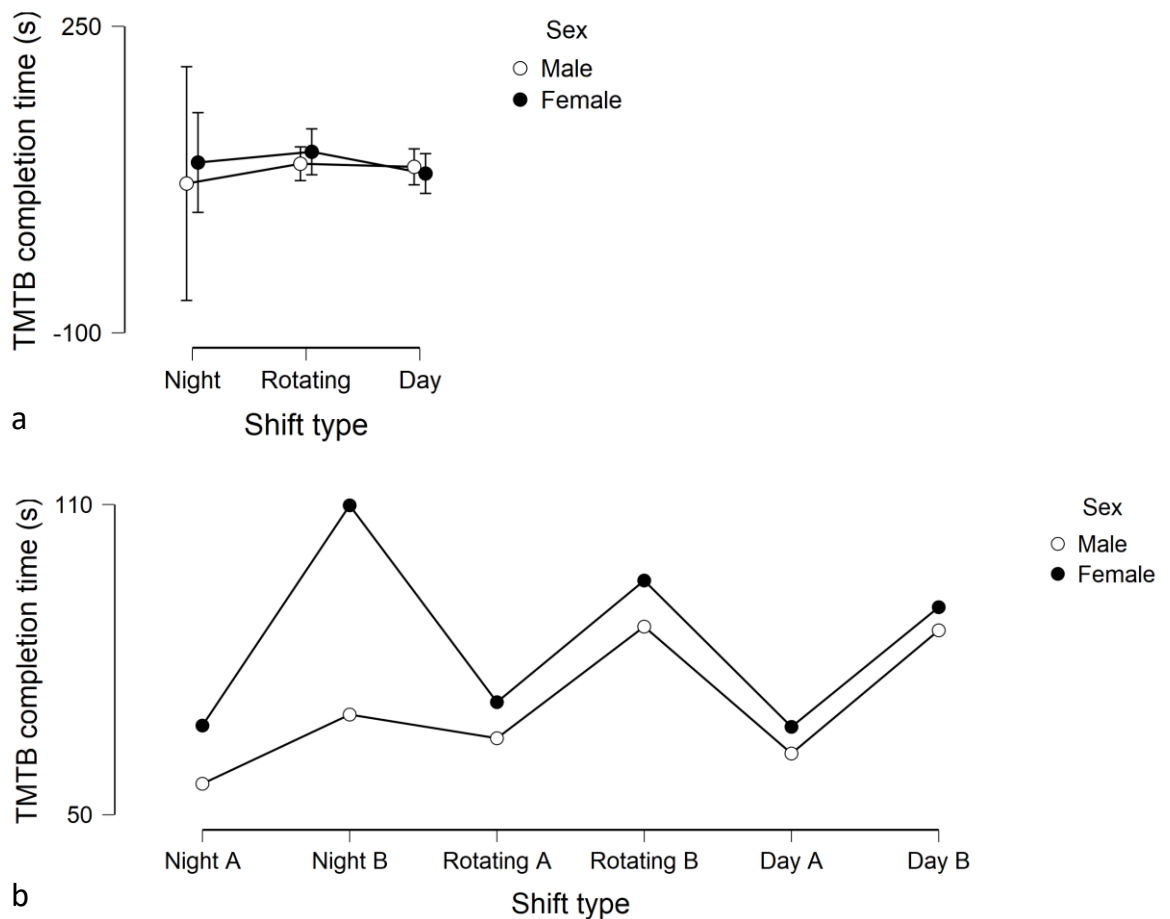


Figure 50 TMTB completion time, split by sex a) SW1 cohort b) SW2 cohort. Error bars indicate SEM.

As with previous variables, analysis was run again with shift groups split by BSWSQ score. Table 92 details the statistical analysis for each BSWSQ score and sample. Where data did not pass a normality test it was transformed.

Table 92 TMTB Completion time BSWSQ score grouping

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	F(3,48)=1.44, p=0.24, $\eta^2=0.08$	F(3,33)=0.64, p=0.59, $\eta^2=0.06$ (1/ Transformed)	t(35)=0.25, p=0.81, $\eta^2=0.002$ (1/ Transformed)	H(3)=3.56, p=0.31 $\eta_H=0.01$
SW2	F(3,77)=2.09, p=0.11, $\eta^2=0.08$ (Log Transformed)	t(38)=0.83, p=0.41, $\eta^2=0.02$	t(64)=0.49, p=0.63, $\eta^2=0.004$ (Log Transformed)	F(3,99)=2.00, p=0.12, $\eta^2=0.06$ 1/ Transformed)

No significant differences were seen between High and Low Bergen shift and control groups when examining TMTB completion time.

Further correlation analyses was run between BSWSQ score and TMTB total completion time.

Table 93 details the statistical analysis for each BSWSQ score and sample.

Table 93 TMTB Completion time correlations

Sample group	Day (A)	Evening (B)	Night (C)	Rest (D)
SW1	$r_s(50)=-0.23$, $p=0.11$, observed power=0.31	$r_s(35)=0.07$, $p=0.69$, observed power=0.05	$r_s(35)=0.04$, $p=0.83$, observed power=0.05	$r_s(54)=0.07$, $p=0.61$, observed power=0.18
SW2	$r_s(79)=-0.12$, $p=0.31$, observed power=0.23	$r_s(38)=-0.04$, $p=0.82$, observed power=0.03	$r_s(64)=0.07$, $p=0.57$, observed power=0.04	$r_s(101)=-0.16$, $p=0.12$, observed power=0.195

No significant correlations between BSWSQ score and TMTB completion time were found in either cohort.

ANCOVAs were run using the BSWSQ rest score groupings. In the SW1 cohort the covariate, age, was significantly related to TMTB completion time ($F(1,51)=5.02$, $p=0.03$, $\eta^2=0.08$). Post hoc analysis revealed no further interactions. There was no effect of BSWSQ group on TMTB completion time after controlling for age ($F(3,51)=1.27$, $p=0.29$, $\eta^2=0.06$). The covariate ‘years worked shifts’ was not significantly related to TMTB completion time ($F(1,51)=2.02$, $p=0.16$, $\eta^2=0.04$). There was also no effect of BSWSQ group on TMTB completion time after controlling for years worked shifts ($F(3,51)=0.82$, $p=0.49$, $\eta^2=0.04$).

In the SW2 cohort none of the demographics tested significantly related to TMTB completion time. Further there was no effect of group on TMTB completion time when demographic variables were controlled for. ANCOVA statistics can be found in Table 94.

Table 94 TMTB Completion time x demographic variable ANCOVAs

Demographic variable	Main effect	Effect of group when demographic controlled for
Sex	$F(1,98)=3.63$, $p=0.06$, $\eta^2=0.03$	$F(3,98)=1.30$, $p=0.28$, $\eta^2=0.04$
Country	$F(1,98)=3.10$, $p=0.08$, $\eta^2=0.03$	$F(3,98)=1.47$, $p=0.23$, $\eta^2=0.04$
Activity level	$F(1,98)=0.21$, $p=0.65$, $\eta^2=0.002$	$F(3,98)=1.06$, $p=0.37$, $\eta^2=0.03$
Sleep time	$F(1,97)=0.002$, $p=0.96$, $\eta^2<0.001$	$F(3,97)=1.07$, $p=0.37$, $\eta^2=0.03$
Time awake	$F(1,95)=1.84$, $p=0.18$, $\eta^2=0.02$	$F(3,95)=1.14$, $p=0.34$, $\eta^2=0.03$

6.4.2.2 Reaction time of correct responses showed no differences

Due to significant differences between testing groups no groups could be merged in the SW2 cohort and control males could not be merged in the NP cohort.

No main effect of shift was seen in the SW1 cohort ($H(2)=2.419$, $p=0.298$, $\eta_H=0.01$) (Figure 51a). Significant main effect of shift was observed in the SW2 cohort ($H(5)=17.52$, $p=0.0036$, $\eta_H=0.12$) with post hoc revealing there to be a significant difference between rotating B (3208 ± 1446) and

day A (2164±706.2) (Figure 51b). No main effect of group was seen in the NP cohort ($H(4)=9.127$, $p=0.058$, $\eta_H=0.04$)(Figure 51c). The sample size of each cohort and number of participants removed following outlier analysis is detailed in Table 95.

Table 95 Sample sizes of TMTB mean reaction time of correct responses

Cohort	Groups	n	Removed through outlier analysis
SW1	Night	8	1
	Rotating	32	2
	Day	21	1
SW2	Night A	9	1
	Night B	14	1
	Rotating A	25	1
	Rotating B	24	0
	Day A	20	2
	Day B	22	1
NP	NP male	26	2
	NP female	58	0
	C male A	14	1
	C male B	13	0
	C female	12	2

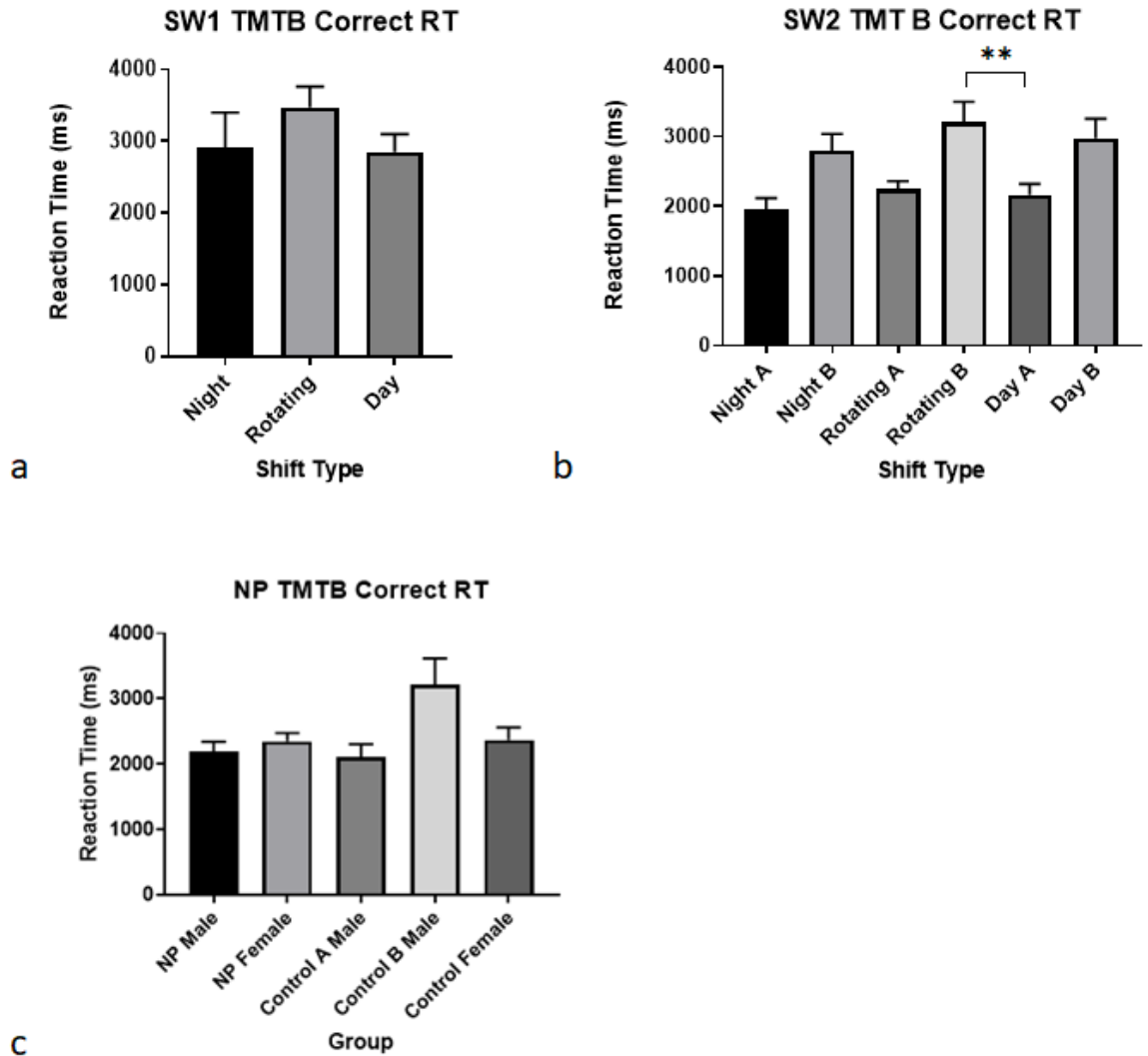


Figure 51 TMTB Reaction time of correct responses a) SW1 cohort b) SW2 cohort c) NP cohort. ** refers to a p value <0.01 . Error bars indicate SEM.

6.4.2.3 Percentage of group who made errors showed considerable variation within testing group. The sample size of each cohort is detailed in Table 96. As this was a group percentage this data did not go through outlier analysis.

TMTB showed a similar pattern to TMTA, in that a significant proportion of participants (SW1=47.69%, SW2=55.00%, NP=60.16%) made no errors during the task.

The SW1 cohort appeared to show night shift workers were more error prone than other groups with 77.78% of night shift workers making at least one error, compared to 52.94% of rotating shift workers and 40.91% of day shift workers (Figure 52a). The SW2 cohort showed no differences in percentage of group to make at least one error (Figure 52b). In the NP cohort, females showed

the greatest difference with NP females being the least error prone but control females being the most (Figure 52c).

Again the errors were classified into two types (missed number and wrong number) and the distribution is outlined in Table 97. Whilst SW1 showed similar error profiles between the two types of error, the SW2 and NP cohorts showed a much more varied distribution between the two error types.

Table 96 Sample sizes of TMTB percentage of group who made at least one error

Cohort	Groups	n
SW1	Night	9
	Rotating	34
	Day	22
SW2	Night	25
	Rotating	50
	Day	45
NP	NP male	28
	NP female	58
	C male	28
	C female	14

Table 97 Number of participants making at least one error with total group size, split by type of error

Participant group	Missed number			Wrong number		
	Night	Rotating	Day	Night	Rotating	Day
SW1	5/9	13/34	6/22	5/9	13/34	7/22

Participant group	Missed number			Wrong number		
	Night	Rotating	Day	Night	Rotating	Day
SW2	6/25	16/50	14/45	9/25	15/50	17/45

Participant group	Missed number				Wrong number			
	NPM	NPF	CM	CF	NPM	NPF	CM	CF
NP	10/28	11/58	8/28	6/14	7/28	9/58	8/28	7/14

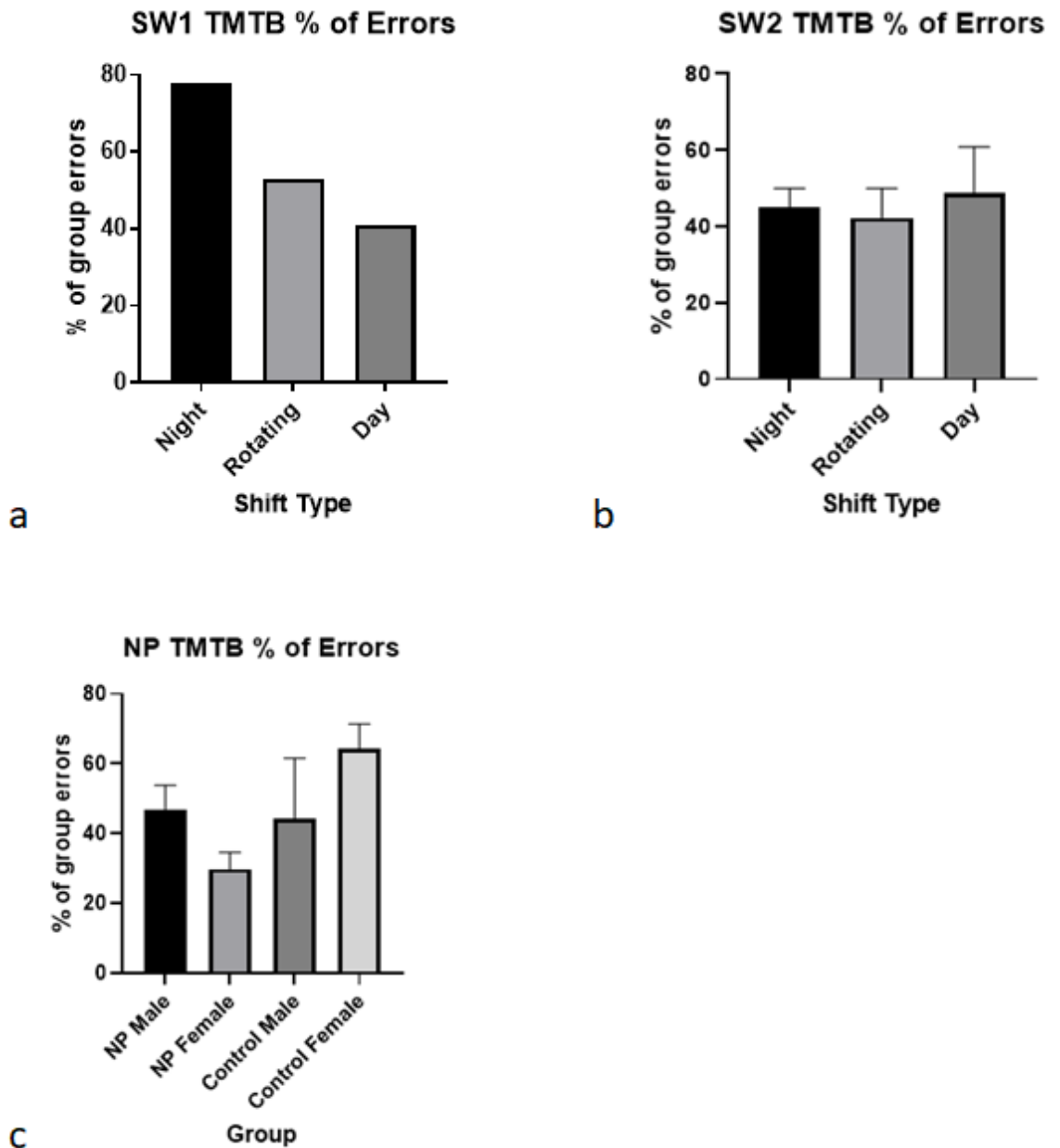


Figure 52 TMTB percentage of group who made at least one error a) SW1 cohort b) SW2 cohort c) NP cohort. Error bars indicate SEM.

6.4.2.4 Analysis of the distribution of errors indicated some clustering in night shift workers errors. While a large proportion of participants (SW1=47.69%, SW2=55.00%, NP=60.16%) produced no errors, as in the analysis of TMTA, error distribution ‘heat maps’ were created for TMTB. Errors produced early in the task may represent learning issues as participants may not understand what is expected of them. Given the TMTB is more difficult than TMTA it is not necessarily expected that participants would immediately know what to do for TMTB (though instructions were provided). Errors seen in the middle of the task may be indicative of participants losing their place

in the sequence and forgetting whether they are meant to be searching for the next number or letter. Errors present at the end may be suggestive of task fatigue.

In the SW1 night shift workers there was a clustering of errors toward the end of the task, suggesting task fatigue causing more of these individuals to be more error prone. In the rotating and day group, whilst many participants did make errors, these were more evenly distributed throughout the task (Figure 53).

No clear clustering was seen in the SW2 or NP cohorts with errors being made relatively consistently throughout the task (Figure 54 and 55). The sample size of each cohort is detailed in Table 98. As this was a distribution analysis this data did not go through outlier analysis.

Table 98 Sample sizes of TMTB distribution of errors

Cohort	Groups	n
SW1	Night	9
	Rotating	34
	Day	22
SW2	Night	25
	Rotating	50
	Day	45
NP	NP male	28
	NP female	58
	C male	28
	C female	14

Figure 53 SW1 Error 'heat maps' Red indicates an error was made while green indicates a correct response. Each row represents an individual participant, each column represents a 'step' in the sequence.

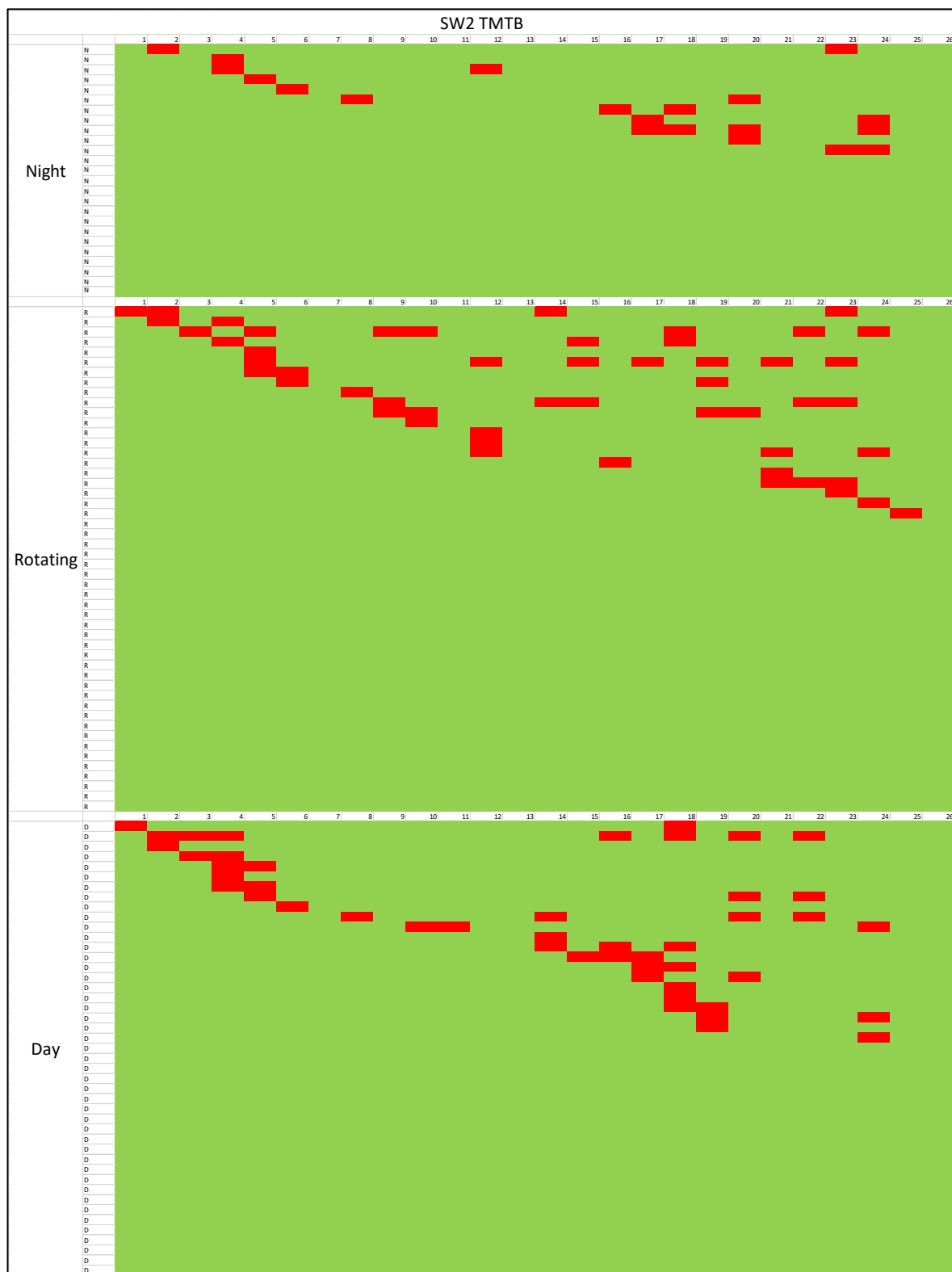


Figure 54 SW2 Error 'heat maps' Red indicates an error was made while green indicates a correct response. Each row represents an individual participant, each column represents a 'step' in the sequence.

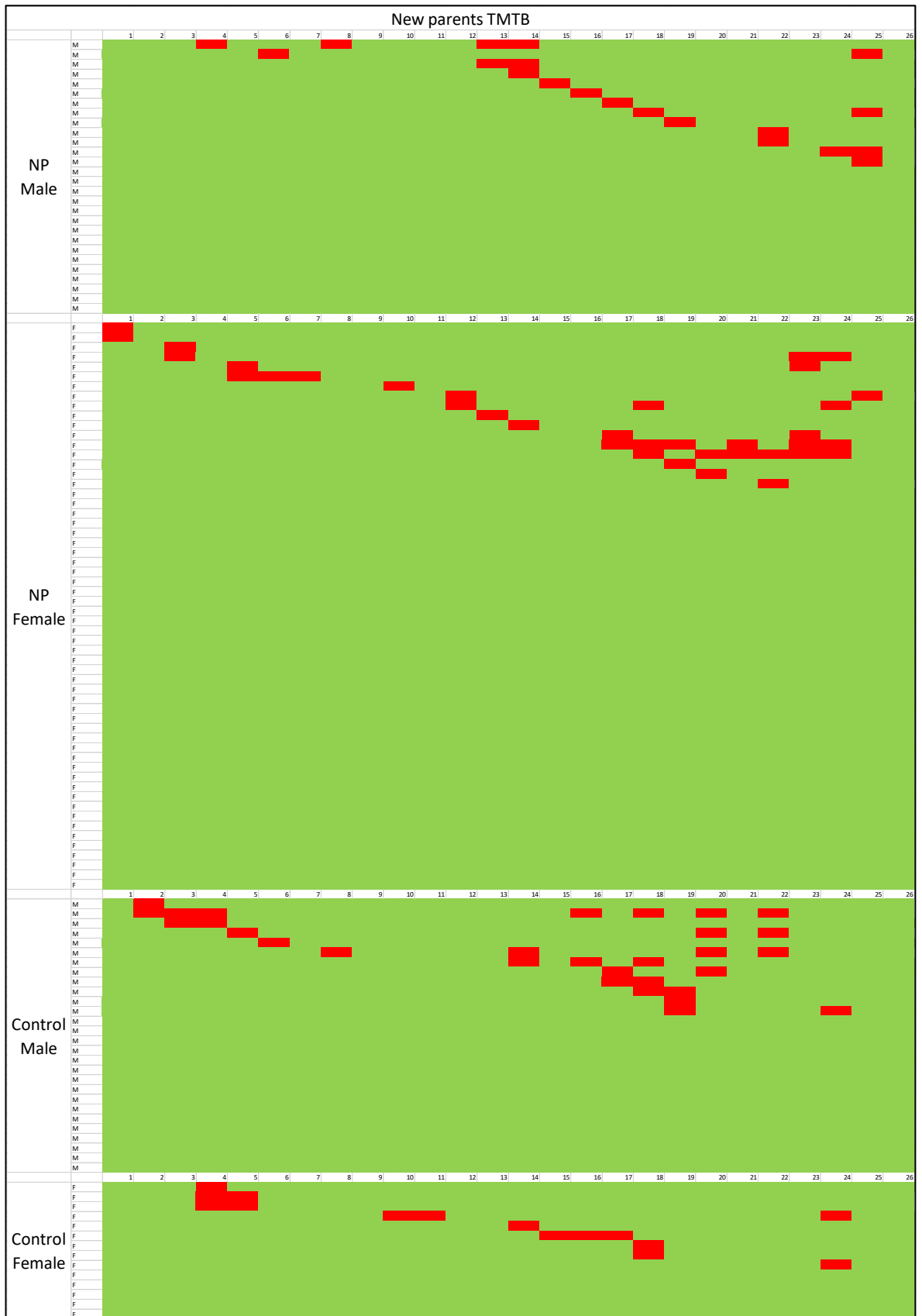


Figure 55 NP Error 'heat maps' Red indicates an error was made while green indicates a correct response. Each row represents an individual participant, each column represents a 'step' in the sequence.

6.4.3 Sensitivity measures

Due to the online nature of this task it was important to examine the task sensitivity. This involved comparing the two levels of the TMT in terms of completion time, with the assumption that the more difficult portion of the task, TMTB, would take longer to complete. In order to examine this the SW2 and NP were collapsed to increase the sample size, and thus power, and a comparison run to compare completion times of TMTA and TMTB. SW1 was not included in this analysis as a different task design was used. No secondary outlier removal was conducted. Efforts were made to normalise the dataset however this was not possible and therefore non-parametric statistics were used. A statistical difference between task completion times ($T=12509$, $p<0.0001$ ****) with TMTB taking significantly longer to complete than TMTA (Figure 56). This suggests that TMTB is harder than TMTA, and as a result takes participants longer to complete, in line with the original TMT. As it appears that the online task is broadly comparable to the original TMT with respect to performance, this suggests that the task should be sensitive enough to show expected task differences.

TMT completion time comparisons

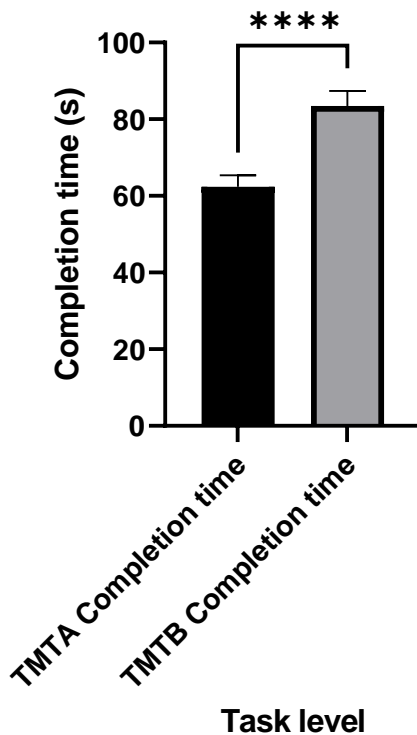


Figure 56 TMT Completion time comparisons. Error bars indicate SEM.

Increasing age has been linked to a decrease in performance on the paper version of the TMT (Davies, 1968). Therefore, as with the previous cognitive tasks, correlation analysis was also run between completion time and age, however shift groups and task levels were examined

separately as the original analysis had suggested some impact of shift. Age analysis was only run on SW2 as this population had the largest sample size.

TMTA showed no correlation between age and completion time in the night ($P(22)=0.34$, $p=0.11$, observed power=0.52) or the day group ($r_s(35)=0.23$, $p=0.17$, observed power=0.25). Similarly no correlation was seen following outlier removal. There was however a significant correlation found in the Rotating group ($P(43)=0.34$, $p=0.02$, observed power=0.16) (Figure 57).

TMTB showed no correlation between age and completion time in any of the three groups (night: $P(23)=0.21$, $p=0.31$, observed power=0.31, rotating: $P(48)=-<0.01$, $p=0.98$, observed power=0.03, day: $P(43)=0.17$, $p=0.26$, observed power=0.03). Again no correlation was found following outlier removal.

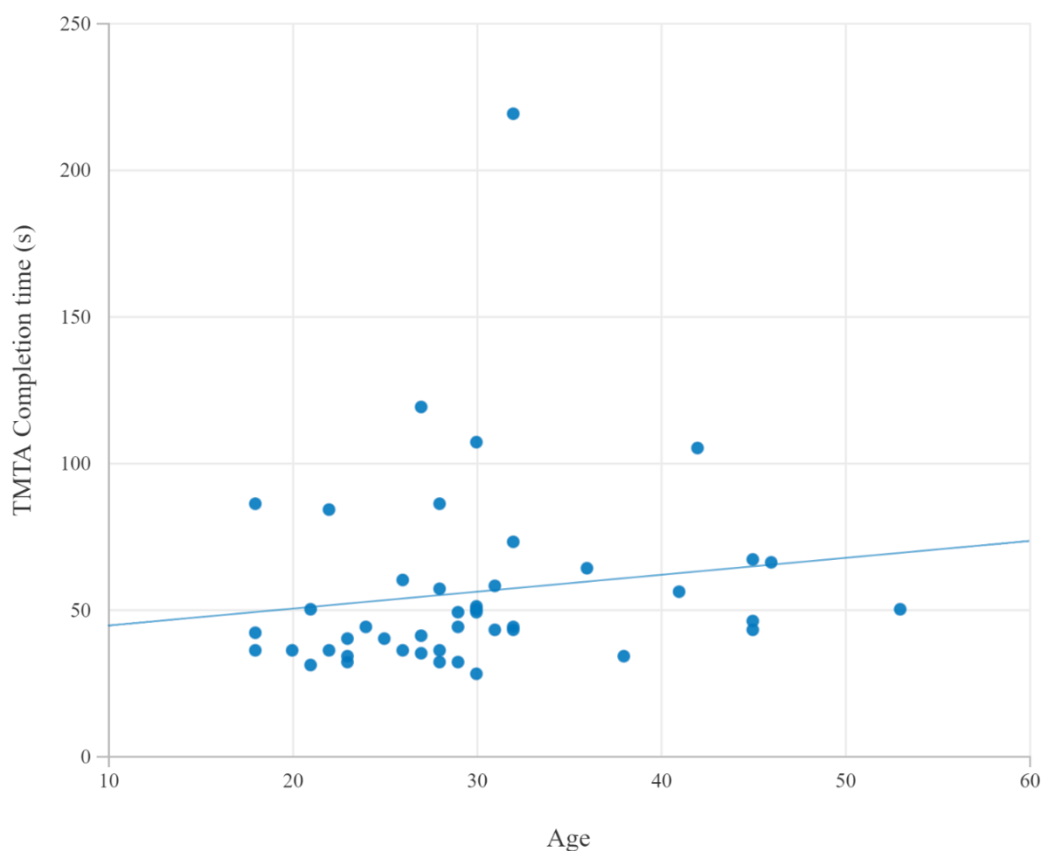


Figure 57 Rotating correlation analysis

Taken together these findings suggest that whilst TMTB was more difficult than TMTA, neither task may have been sensitive enough to detect impairments when used in an online version. It is therefore important to take this into consideration when drawing conclusions about the usefulness of the data.

In order to further explore the sensitivity of this task comparisons were made between the day shift workers in cohorts SW1 and SW2, the controls in the NP cohort and control data found in the

literature. When drawing these comparisons it is important to highlight the differences in methods used for a paper TMT and an online TMT, as described in section 6.3.6. Specifically, the online TMT used here required participants to connect 26 stimuli in TMTB compared to the original paper TMT which required participants to connect 25 stimuli in TMTB. Tombaugh (2004) examined the relationship between TMT and age, grouping participants in age categories. The mean of the control data in the SW1, SW2 and NP cohorts were 35, 33, and 33 respectively. Therefore the mean completion time for the age grouping 25-34 was used for comparison. Further, the range of responses from the groups 18 to 59 were included to give a sample more similar in age to the SW1, SW2 and NP cohort samples. However as the Tombaugh data set was not available it was not possible to calculate the mean completion times for this. Results can be found in Table 99.

Table 99 TMT comparisons

Cohort	Mean age (SD)	Whole group age min-max	TMTA mean completion time (s) (SD)	TMTA completion time minimum-maximum	TMTB mean completion time (s) (SD)	TMTB completion time minimum-maximum
SW1	35 (1.0)	20-61	82.28 (48.44)	30-186	85.19 (31.62)	37-164
SW2	33 (8.3)	21-60	54.81 (18.58)	30-105	76.15 (30.20)	42-174
NP	33 (8.4)	21-60	54.19 (16.41)	30-83	74.92 (29.63)	43-175
Tombaugh ages 25-34	29.4 (2.9)	25-34	24.40 (8.71)	10-45	50.68 (12.36)	29-78
Tombaugh ages 18-59		18-59		10-72		29-127

The mean completion times of the day workers in the SW1 and SW2 cohorts and control in the NP cohort are slower in both TMTA and TMTB compared to the mean completion times shown in Tombaugh. Further, the range of completion times is larger in the online version compared to the paper TMT. This suggests that overall the online task led to participants performing slower. With regards to sensitivity a large proportion of the completion times did sit between the minimum and maximum values seen in the Tombaugh paper. This suggests that whilst the online version may have been more difficult leading to longer completion times as a whole, the participant sample still produced a range of responses similar to that of a paper version. These longer times may have been due to a lack of control over the testing environment, a limitation of online cognitive testing. Both the online study presented here and Tombaugh saw increases in mean reaction time for TMTB compared to TMTA, as well as increases in variability of performance, suggesting similarities in cognitive element measured, despite differences in task delivery.

6.5 Discussion

This chapter aimed to assess the impact of a shift working lifestyle and sleep disruption associated with new parenthood on visuomotor coordination. Visuomotor coordination was measured using a computerised TMT. Data taken from the SW2 cohort suggests there may be unique differences dependant on the type of shift worked, that persist even after recovery sleep has occurred. However, these findings were not replicated in the SW1 cohort and were only present in one variable of the TMTA portion of the task. The NP cohort showed little evidence of visuomotor impairment. Therefore, it appears that in a scenario of minimal fatigue, new parents are resilient to visuomotor impairment linked with sleep deprivation. However, the precise impact of shift work remains unclear.

Sleep deprivation studies suggest that extended periods of wakefulness lead to an impairment in visuomotor coordination (De Gennaro et al., 2001; Wimmer et al., 1992). However, evidence also indicates that this period of sleep deprivation needs to be longer than 25 hours in order to be harmful to visuomotor coordination (Alhola et al., 2005). This makes visuomotor coordination somewhat distinct from many other areas of cognition as it appears to show resilience towards short term sleep deprivation. This is perhaps unsurprising, given that, from an evolutionary perspective, the ability to properly co-ordinate movement depending on the visual environment, irrespective of fatigue, is likely critical to survival, through ensuring avoidance of hazards and enabling hunting and gathering of food.

However laboratory sleep deprivation studies, whilst informative, do not have occupational relevance to shift workers. This is because shift workers do not often have to spend more than 24 hours awake with no naps/breaks. Understanding the effect of shift work on visuomotor coordination is important to ensure shift workers safety. Further, understanding if the shift working lifestyle has lasting persistent impacts on this cognitive domain is imperative. Indeed, Titova et al. (2016) suggests it may take at least 5 years without the circadian misalignment synonymous with shift working to recover TMT performance. Beyond the more occupationally relevant insights associated with evaluating shift workers, given that laboratory sleep deprivation studies only serve as an effective model of insomnia, the impact of less profound sleep disruption (in the absence of the circadian misalignment experienced by SWs) on visuomotor coordination is unknown. Therefore, assessment of visuomotor coordination in a sample of new parents, a population known to frequently experience disruption to sleep, represents a useful advance.

The data presented in this chapter aims to address some of these issues, by testing in a shift working population, whilst attempting to limit fatigue by testing on a day off from shift work. This isolation of the impact of work related fatigue is necessary to examine whether the cognitive impairments associated with shift work persist following a period of recovery sleep. Additionally,

in order to provide a bridge between the current sleep deprivation and shift working literature, an ecologically relevant sample of sleep deprivation (new parents) was also collected.

Further, given that to the best of our knowledge, this is one of the first instances of a Trail Making Task being used for distance online testing, the present study aims to evaluate this testing format by exploring error outputs, as well as the completion time and reaction time data normally collected from a TMT. Computerised TMT's have been utilised previously (Kokubo, Inagaki, Gunji, & Kobayashi, 2012; Kokubo et al., 2018), though in these instances a touchscreen was used and testing was done in person. Testing online presents further challenges as it is not possible for an investigator to be present and ensure testing is completed correctly, as is usually done in a paper version of a TMT (Corrigan & Hinkeldey, 1987). Instead, colour changing stimuli were used to indicate not only when an error occurred but also to signpost where the last correct press was.

The TMT used to assess visuomotor capabilities within these cohorts involves two parts (TMTA and TMTB), it assesses both visuomotor coordination, attention and visual search speed (Salthouse, 2011). Specifically TMTA assesses visual search and motor speed skills, whereas TMTB measures higher level executive functions, such as mental flexibility (Bowie & Harvey, 2006). While the results from TMTA and TMTB were not drastically different, it is important to interpret them separately, with respect to the cognitive elements they assess. Two variables were used to measure this: completion time and average reaction time of correct responses. These are the same variables that are commonly extracted from a paper version of the TMT.

6.5.1 The impact of circadian mismatching on visuomotor coordination in a study of shift workers

Two shift working cohorts were used to examine the effects of a shift working lifestyle on visuomotor coordination. In TMTA, no differences in completion times were seen in the SW1 cohort, with anecdotal evidence in support of the null hypothesis. However, in the SW2 cohort, night shift workers responded more slowly to stimuli than rotating shift workers (with moderate support for the alternative hypothesis). Similar findings were found in TMTB completion time, with no differences seen in the SW1 cohort (anecdotal evidence in support of the null hypothesis). Although in this case the SW2 cohort showed significant differences between rotating (B) and day (A). Bayesian statistics showed strong evidence in support of the alternative hypothesis. This difference is challenging to interpret given the potential for task cross-over effects to have impacted these data. Specifically, in the SW2 cohort, group A consistently produced quicker completion times than group B, suggesting an order effect was present. Group A had received a PVT task prior to the TMT, and the difference in completion times suggests that the PVT may have primed the participants to perform the TMT task faster. Future implementations of this study

should ensure this is taken into account, ideally by running each task in separate testing sessions to minimise any potential task cross-over effect.

The difference between the SW1 cohort and the SW2 cohort may be explained by an improvement in task understanding. Following the SW1 data collection, analysis revealed a high number of errors and a high dropout rate. Further, many individuals were completing the task incorrectly by solving TMTA backwards (26-25-24-23) or getting the letters and numbers the wrong way round in TMTB (A-1-B-2-3-C). Therefore, it was concluded that many participants were not aware of what was required of them in the task, and as a result, took much longer to correctly complete (if at all). Consequently, additional instructions and a demonstration video were added for the SW2 and NP cohorts. This dramatically sped up completion times across all groups and reduced dropout rates.

Overall, the analysis of the completion time data from TMTA and TMTB suggests that there may be changes in visuomotor performance in shift workers compared to non-shift workers (evidenced by SW2 differences in completion time). Specifically, data suggests there may be differences between night and rotating shift workers in regards to their visual search and motor speed (demonstrated by the differences seen in TMTA). This impairment was present even after a period of recovery sleep had occurred, suggesting that the cognitive domains assessed by TMTA may be more vulnerable to shift work, specifically night shift work, than those measured in TMTB. Few studies assess rotating and permanent night shift workers separately, and the conclusions from these are often applied to shift workers as a population. The data presented here suggests there may be unique differences dependant on the type of shift worked, that persist even after recovery sleep has occurred. However, given this indication of visuomotor impairment was only present in one variable in the TMTA in one shift working groups the robustness of this finding is questionable.

This conclusion is further questioned by the lack of significant differences seen when participants were grouped based on BSWSQ score. Neither TMTA nor TMTB completion times showed a significant difference between groups. Further, no correlation was seen between these cognitive variables and BSWSQ score. Some demographic variables were found to significantly interact with the completion times for both TMTA and TMTB, however there was no effect of BSWSQ group, when analysis was run controlling for these demographic confounds. Again these highlight the complexity of both the sample population and visuomotor coordination.

Average reaction time for correct responding was extracted to establish if there were any differences between groups, possibly indicating a speed accuracy trade-off (where individuals prioritise either speed or accuracy in a task (Heitz, 2014)). However, in TMTA no differences in correct reaction times were observed in either of the shift working cohorts. Similarly, no

differences were observed in TMTB for SW1. There was a significant difference in SW2, specifically rotating (B) being slower than day (A), though given this relationship was also observed in total completion time this was not unexpected. Further, this relationship is difficult to interpret given that, in the SW2 cohort, group B were consistently slower than group A suggesting a potential order effect. This outcome measure assesses participant's attention as well as search speed. Overall however, there appears to be no difference in the speed with which individuals responded to correct stimuli and therefore no attentional differences between groups. This supports the attentional findings discussed in Chapter Three, where no attentional impairments were observed in two groups of occupationally heterogeneous shift workers nor a more occupationally homogenous group of UK police force staff.

Taken together, these data suggest that generally there appears to be very little detriment to visuomotor coordination as a result of a shift working lifestyle. These findings are in contrast with the findings of Titova et al., who observed visuomotor impairments in current and recent shift workers (Titova et al., 2016), suggesting there was a lasting impairment in shift workers, even once individuals were no longer performing shift work. However, not only was fatigue not controlled for in the collection of Titova's data, the participant age of this study was very specific, namely 45-75 year olds. Since age is known to impact global cognitive capabilities (Murman, 2015) as well as TMT performance (Davies, 1968), it is plausible that the relative resilience of visuomotor coordination in the shift working groups observed was reduced, thereby increasing the possibility of impairment detection. Further, no screening for age-dependant neurological diseases that are known to impact cognition, for example dementia or mild cognitive impairment, was conducted by Titova et al. The presence of these in any sample would contribute to the overall impairment observed. Indeed, mild cognitive impairment in individuals aged 65 and over is estimated to be between 21.5 and 71.3% per 1000 people, suggesting a large proportion of the elderly population are affected (Tricco et al., 2012). Based on this, it is possible that participant data collected from 65-75 year olds by Titova et al. could have been confounded with the effect of mild cognitive impairment. Further, the use of a computerised task in an older population, may have led to issues often associated with old age, such as manual dexterity, vision and computer proficiency, skewing results. Given that in the present study, recruitment occurred through an online platform it is likely that participants were all computer literate.

The findings presented here are more consistent with that of Machi et al. (2012) who found no impairment of visuomotor coordination, when comparing day and night shifts of emergency physicians, and of Guyette et al. (2012) who observed no differences between air medical providers working 12 hour and 24 hours shifts (Guyette et al., 2012; Machi et al., 2012). These findings support the conclusion that visuomotor coordination may be resilient to the effects of

sleep disruption linked with shift work. This is made more robust when the differences in testing design (both testing before and after a shift vs. on a day off from work) are considered.

However, Machi et al. (2012) and Guyette et al. (2012) both used occupationally homogenous participant groups. Due to their job role, all individuals in these studies would have had a high level of education. The level of participant education has been shown to have an impact on visuomotor coordination, with lower levels of education associated with poorer TMT performance (Tombaugh, 2004). The age of the testing groups may also have impacted the findings with Machi et al. testing individuals aged 31-52 and Guyette et al. testing participants with a mean age of 36.4 (12 hour shifts) and 38.8 (24 hour shifts). Both education level and age may provide an explanation as to why these findings are different to those of Titova et al. (2016), implying that the observed impairment in visuomotor performance is predominantly age related.

The discordance among these findings may also be linked to job type and responding techniques. As mentioned above, Proctor et al. (1996) observed that machine based workers were more error prone but performed faster than those working non-machine paced jobs (Proctor et al., 1996). Speed accuracy trade-off is where individuals prioritise either accuracy or speed, at the detriment of the other (Heitz, 2014). In the present study, it is not known whether shift workers were machine based or not (full demographic profile outlined in Chapter Two), however as a large proportion of participants in all three cohorts made no errors on both the TMTA and TMTB it is likely they were prioritising accuracy over speed. To assess this relationship further, future testing could retest participants under a strict time limit to try and bias their responding strategy from accuracy over speed to speed over accuracy. This would provide an insight into how each shift worker group responds to stress, and how this impacts TMT performance.

Due to the new implementation of the TMT used in this study, extra variables were extracted to begin to provide a resource for establishing normative performance baselines. Firstly, this involved assessing the completion time data on the basis of sex. No sex differences were seen in the SW1 cohort in either TMTA or TMTB. The SW2 cohort did show a main effect of sex, with females consistently performing slower in both parts of the task. Tombaugh (2004) reviewed several normative TMT data set in order to establish if this task was affected by a variety of variables, including sex. In a sample of 911 participants, sex was not significantly correlated with TMT scores (Tombaugh, 2004). This supports the findings of the SW1 cohort. The findings of the SW2 cohort are consistent with Płotek et al. (2014) which, as described below, reports a sex difference in TMT performance. However this relationship was the reverse of what was seen in the present study. The disparity between previous studies and the findings presented here highlight the need for further TMT testing on a large normative sample to robustly determine the effect of sex on TMT.

Error analysis of the TMT is rarely reported, though it has been used in disease related research, for example to assess specific operations underlying impairment seen with Alzheimer's disease (Amieva et al., 1998) and to establish the impact of brain damage in different regions (Stuss et al., 2001). Here error analysis was conducted to examine the impact of an online testing design. In a paper version an investigator would be present to correct errors. In comparison, the online version of the task involved colour changes and stimuli removal to indicate correct and incorrect responses. This relies upon the participant maintaining a higher level of attention to the whole stimulus screen. Given that a large proportion of all cohort groups made no errors, it suggests that this version of the TMT is a viable testing option, even without the presence of an investigator to correct errors. The percentage of group who made at least one error was used due to most individuals not making any errors, therefore total number of group error would be deceptive.

TMTA revealed differences in both shift working cohorts. Night shift workers were consistently more error prone in the SW1 and SW2 cohort. TMTB also showed night shift workers to be more error prone in the SW1 cohort, however there were no shift dependant differences in the SW2 cohort. The TMTB and TMTA assess different components of cognition, and as such different error profiles between the two are not unexpected. For example, TMTB has been deemed a more difficult task, with respect to attentional demand, than TMTA due to the addition of letter stimuli (Gaudino et al., 1995).

As night shift workers were consistently more error prone in TMTA, this may reflect an impairment not only in visuomotor coordination but also in attention. This is further supported by the TMTB performance in SW1 which also showed night shift workers to be more error prone. Indeed, attention has been shown to be vulnerable to shift work (Chellappa et al., 2019; Wilson, Permito, English, Albritton, Coogler, & Van Dongen, 2019). However, in the SW2 cohort TMTB, this was not observed suggesting this relationship may be more complex.

In the paper version of the TMT, the effect of errors is accounted for in the total time to complete the test as the investigator typically stops the participant and returns them to the last correct response. This means that the error is not normally recorded. However, in an online version of the task, it is down to the participant to realise their mistake (via the feedback provided to them through the use of stimulus colour change) and correct it, therefore errors are recorded. This enables analysis of the type of errors made to be conducted. Specifically in this task, two types of errors were categorised – missed number and wrong number. Missed number errors were operationally defined as cases where a participant jumped one number in the sequence. Wrong number errors were operationally defined as any errors where a participant skipped more than one number. Examples of each can be found in Chapter Two.

No differences were observed between groups in the SW1 cohort. However, in the SW2 cohort TMTA showed individuals making more missed errors than wrong numbers, regardless of shift group. The SW2 cohort TMTB showed no clear relationship between the two error types in any shift group. A missed number error is suggestive of a failure of visual search to identify the correct target, and as such the next number in the sequence is pressed. A wrong number error is indicative of a working memory failure, particularly during TMTB. The data presented here suggests that failures in visual search were more likely than working memory impairments in TMTA. However, during TMTB the number of people making missed errors appears to have decreased, meaning there is no longer a difference between groups. This may be due to participants having completed the TMTA first, in that they are more practised at noticing the colour change indicating an error in TMTB and as such make less visual search errors.

Finally, the distribution of errors across the task was assessed. Errors made early on in the task may be suggestive of a lack of initial task understanding, errors made in the middle could be indicating an impairment in sustained attention and errors made in the late stage of the task may be representative of task related fatigue. TMTA showed varying clustering, with all of the SW1 cohort and the night and rotating groups of the SW2 cohort showing clustering at the beginning, suggestive of lack of understanding of task, some showing clustering at the end, suggestive of task fatigue and some showing a combination of both.

This clustering, particularly at the beginning of TMTA, emphasises the fact that despite the task being very simple, when participants are tested online with a response interface they are not familiar with, some individuals will still make errors even with stimuli they will be familiar with i.e. understanding that '2' follows '1'. Therefore, it is clear that in asking participants to complete assessments at a distance with no investigator input available at the time of completion, a small number of participants will confound their own performance. It is vital, when designing tasks for use in an online platform to make instructions as clear as possible.

TMTB error profile showed a clustering of errors towards the end of the task in night shift workers in the SW1 cohort, indicative of task fatigue causing more of these individuals to be more error prone. This was not present in the rotating or day shift workers, nor in the SW2 cohort. The differences in night shift workers in the SW1 and SW2 cohorts may be due to sample size, with SW1 having less participants. The lack of any clustering towards the beginning of the task suggests that all participants were aware of what they had to do, possibly due to having already completed TMTA.

6.5.2 The impact of naturalistic sleep deprivation on visuomotor coordination in the new parent cohort

A cohort of both male and female new parents and controls was used to examine the effects of new parenthood on visuomotor coordination. The NP cohort showed no significant differences in TMTA completion time, with moderate Bayesian evidence in support of the null. A significant difference in total completion time of the TMTB was seen in this cohort, however post hoc revealed no further differences. Bayesian analysis revealed anecdotal evidence in support of the alternative hypothesis. This suggests that whilst a relationship is present the sample did not have enough power to reveal the direction of this relationship.

The lack of any significant differences in the NP cohort TMTA and the lack of any post hoc findings in TMTB could also suggest that the sleep disruption experienced by these individuals is insufficient to substantially impact visuomotor coordination. Further, the lack of differences between male and female new parents suggests this cognitive domain is not vulnerable to sex effects, despite there being evidence to suggest the impact of new parenthood on sleep patterns is sex dependent (Gay et al., 2004). This is in contrast to Munro et al. (2012), who found men performed worse than women on TMTA with no differences between men and women in TMTB (Munro et al., 2013). It is important to note however that the individuals in Munro et al.'s study were aged 67-89 years and as mentioned previously, TMT performance is vulnerable to age (Davies, 1968). The sex differences may only be apparent in older individuals and therefore would not be seen in the new parent cohort.

TMTA average reaction time showed no differences in correct reaction times in the NP cohort. Similarly no differences were observed in TMTB. As described above, this outcome measure assesses participant's attention as well as search speed. Overall however, there appears to be no difference in the speed with which individuals responded to correct stimuli and therefore no attentional differences between groups. This supports the attentional findings discussed in Chapter Three, where no attentional impairments were found in either male or female new parents.

The lack of impairment in these variables suggests that TMT performance was not impacted by the sleep disruption associated with new parenthood to a point that could not be alleviated by recovery sleep. Again of note is the lack of sex differences in performance, given the reported sex differences in new parent sleep and fatigue (Gay et al., 2004). No significant differences were found between male and female participants in either new parents or controls. The TMT test has previously shown sex dependant differences, with women performing better than men when the difference in TMTA and TMTB completion times was assessed (TMTA completion time was subtracted from TMTB completion time) (Płotek et al., 2014). Contrasting this are the findings of

Tombaugh (2004), who reviewed a sample of 911 participants and found sex was not significantly correlated with TMT scores (Tombaugh, 2004). More generally, visuomotor performance has also shown to be impacted by sex, with men performing throwing tasks with more accuracy (Moreno-Briseño, Díaz, Campos-Romo, & Fernandez-Ruiz, 2010) and men performing better on an inverted tracking task (a joystick was turned upside down and participants had to follow a moving dot) (Joseph & Willingham, 2000). However, Joseph and Willingham also found no sex differences in a speeded tracking task (a dot moved around the screen at a faster pace and participants were required to follow it). They concluded that sex differences often seen in normal pursuit tracking may be a result of differences in perceptual motor experiences, rather than due to sex. In the present study, no sex differences were found in the NP cohort, suggesting that the profound generalised impact of becoming a parent affects both sexes equally with respect to TMT performance.

As explained above, error analysis of this task is not often reported and was utilised here to examine the impact of online testing. The percentage of group who made at least one error was used due to most individuals not making any errors, therefore total number of group error would be deceptive. TMTA revealed differences in the NP cohort. Males were more error prone in both new parent and control groups. In the TMTB, NP females were the least error prone whereas control females were the worst, whilst males appeared to be consistent regardless of parenthood status. The TMTA and TMTB assess different components of cognition, and as such different error profiles between the two are not unexpected. For example, TMTB has been deemed a more difficult task, with respect to attentional demand, than TMTA due to the addition of letter stimuli (Gaudino et al., 1995).

In the NP sample, males were more error prone in TMTA but TMTB showed control females to produce more errors. Sex differences, as described previously, have been explored using the TMT (Płotek et al., 2014; Tombaugh, 2004), however these have focussed on completion times and not error profiles. The findings presented here suggest that being a new mother causes improvement in errors on the TMTB compared to female controls. In contrast, males perform to a similar level regardless of parenthood status. It is possible that the hormone related changes that occur in new mothers, but not in new fathers, led to an improvement in TMT performance, suggesting it is not directly related to disrupted sleep.

As described above, the design of this task enabled precise recording of the type of error participants produced. Two types of errors were categorised – missed number and wrong number. A missed number indicates a possible failure of visual search to identify the correct target. A wrong number suggests a working memory failure, particularly during TMTB. Examples of each can be found in Chapter Two. In the NP cohort, TMTA showed individuals making more

missed errors than wrong numbers, regardless of parent group. This suggests that more failures in visual search were present in this cohort, as opposed to working memory failures. The TMTB showed no clear relationship between the two error types in any parent group. During the second part of the TMT (TMTB), the number of people making missed errors appears to have decreased, meaning there is no longer a difference between groups. This may be due to participants having completed the TMTA first, in that they are more practised at noticing the colour change indicating an error in TMTB and as such make less visual search errors.

The final variable examined in this cohort is the distribution of errors across the task. In the TMTA NP males, NP females and Control males showed no clear clustering, with errors made throughout the task. This suggests there was no lack of task understanding (indicated by an error clustering toward the beginning), nor impairment in sustained attention (error clustering in the middle) nor the presence of task related fatigue (error clustering towards the end of the task). Control females however did show some clustering towards the end of the task (indicative of task related fatigue), though it is important to note the group as a whole produced very few errors. No clustering was present in the TMTB portion of the task, with errors made consistently throughout the task.

6.5.3 Limitations and future directions

There are limitations to consider when discussing these findings. For example, it is important to note that whilst individuals were asked to complete this test on a day off from work and as close to waking up as possible, in order to minimise the effect of fatigue, due to the online nature of the study it is impossible to fully control this. Further inconsistencies which may be present due to lack of control with online testing include screen size and distance between participant and response equipment (which could have included a mouse, keyboard, response box or touchscreen).

Inconsistencies extend to group sizes, with there being considerable variation within all three cohorts. Specifically, an increase in night shift workers and control females in the NP cohort would create more even group sizes and provide a more representative overview of these populations. As with many studies, an increased overall sample size would be desirable in order to increase statistical power.

A further limitation is the lack of a stress questionnaire to examine stress levels within these cohorts. As described previously, much of the existing literature regarding shift workers is occupationally homogenous, and as such contains individuals who are likely to experience similar stress levels as a result of their job. Stress has shown to impact TMT completion time in particular, with a positive correlation being seen between perceived stress scale score and the time taken to complete the task (Orem, Petrac, & Bedwell, 2008). Therefore, it is important to consider participant stress in future studies of visuomotor coordination in shift working samples.

As discussed previously, differences between the online TMT and the paper copy were examined. TMTB on average took longer to complete despite there being no differences in the distance covered when connecting the stimuli. When completion times were compared to those found in the literature, the times from the online task were slower. This may be related to the lack of control over the testing environment leading to more distractions. However Backx et al. (2020) suggest that reaction times are not as easily translatable from in-person to online testing, due to the variations in computer hardware and response detection equipment (Backx, Skirrow, Dente, Barnett, & Cormack, 2020). This suggests that comparisons with the literature may be of limited value in some cases.

The use of this task online prohibits researchers being able to give direct feedback when an incorrect response is made. Whilst this issue was overcome with the use of disappearing wrong pressed stimuli and colour changing stimuli to indicate where the last correctly pressed stimulus was, there is potential for colour-blind individuals to have been included in analysis. They may not have been able to distinguish between feedback stimuli, therefore increasing total completion time.

Finally, due to the design of the task, stimuli disappeared if they had been pressed incorrectly. This would have meant visual search would get increasingly easy if an error had been made, with wrong answers disappearing until the correct stimulus was pressed. Whilst this would not have impacted the number of errors made (as errors were assessed on a trial basis, rather than consecutive errors), this may have sped up completion times. One solution to this can be found in Kokubo et al. (2012) who also used a computerised TMT. Here stimuli disappeared once pressed correctly and were replaced by a dummy stimulus elsewhere. This ensured the same number of stimuli were always present although the search area configuration changed. However, there is no indication of how errors were corrected using this TMT variant. An optimal solution would be a combination of these two computerised TMTs.

6.5.4 Conclusions

The Trail Making Task has been shown to assess visuomotor coordination as well as a range of other cognitive domains. Based on previous studies, a TMT was adapted for use online and used to assess shift working and new parent samples. This appeared to work successfully with a large proportion of all participants making no errors during both TMTA and TMTB. The findings from the shift working cohorts and new parent cohort show little evidence of visuomotor impairment.

The present findings, when considered with the existing literature, suggest that visuomotor performance may in fact be resilient to the effects of the shift working lifestyle and new parenthood, when fatigue is eliminated, but that it is susceptible to long periods of sleep deprivation. However, given the findings of one shift working cohort (SW2), possibly indicating

the presence of an impairment, further research is vital to further explore this cognitive domain in shift workers.

7.1 Introduction: electrophysiological assessment of the shift working brain

As discussed in previous chapters, the majority of the literature in this area suggests that shift work appears to have a negative impact on cognition. Further, much of this literature seems to indicate that the negative cognitive effects seen in shift workers are simply because they are more fatigued or have poorer quality/length sleep. However, individuals who have stopped working shifts within the last five years also appear to still have some negative cognitive impact associated with shift work (Titova et al., 2016). This suggests that shift work exposure can have persistent effects (for at least five years), that cannot be immediately recovered by simply reverting to a non-shifting lifestyle. The neural mechanisms underlying these effects are still uncertain. Given that sleep deprivation can change brain physiology (evidence also exists for functional signature differences, shown in sleep deprived individuals) (Basner, Rao, Goel, & Dinges, 2013), it is plausible that there are physiological changes occurring during shift work that cannot be immediately undone by stopping shift work.

The experiments presented in this chapter aim to determine if SW exposure produces a physiological signature in the brain. As mentioned, Titova et al. (2016) suggests that there may be a long term impact of shift work. The work in this chapter aims to further examine whether any changes persist beyond the end of the shift.

Shift workers have been found to have reduced productivity and have an increased risk of occupational injuries during a night shift (Folkard & Tucker, 2003; Ryu et al., 2017). Reviewing the available literature, Folkard and Tucker (2003) found efficiency measures showed a decline during the night, with the trough occurring at 3am. This was further supported by Vidaček et al. (1986), who found that, on average, productivity was 5% lower at night compared to the day (Vidaček, Kaliterna, Radošević-Vidaček, & Folkard, 1986). Folkard et al. (2003) also highlighted that several factors influenced the overall safety and productivity risk of shift work, including the length of the shift, the number of consecutive shifts in a cycle and the number of breaks provided.

Alongside occupational risks, shift workers regularly report being tired and fatigued when working shifts (Åkerstedt & Wright, 2009; Son et al., 2005). This reported fatigue appears to be supported by the presence of 'sleep like' EEG traces, in train drivers, whilst they are awake (Åkerstedt, Torsvall, & Gillberg, 1987; Torsvall & Åkerstedt, 1987).

Indeed, evidence shows that shift workers experience a degree of SD, with indications of poorer quality and shorter length sleep reported (Harrington, 2001; Monk et al., 2013; Tilley, Wilkinson, Warren, Watson, & Drud, 1982). Shift workers who are classified as suffering from shift work disorder (SWD)(defined as sleepiness and insomnia that can be attributed to a person's work schedule) (Flo et al., 2012) have been found to have shorter periods of light sleep on a day off compared to those who do not have SWD. This was attributed to the differences in the groups' compensatory sleep. However, there were no further differences in terms of sleep stages in any shift type or on days off, suggesting that regardless of SWD the impact of shift work on sleep is the same (Vanttola et al., 2019).

Within the context of sleep deprivation, studies have shown a reduction in a number of cognitive domains and changes in brain function. Ma et al. (2015) conducted a meta-analysis of neuroimaging studies assessing the effects of sleep deprivation on the brain. Significant reductions in brain activation, measured using fMRI, in a number of regions following sleep deprivation when compared to rested wakefulness were reported. These regions included the fronto-parietal attention network (a source of attentional control) and the salience network (linked with communication and social awareness). Increased activation was seen only in bilateral thalamus (involved in the regulation of sleep and alertness) following SD. In an fMRI study conducted by Farahani et al. (2019), following a week of sleep restriction (35% sleep restriction), participants exhibited alterations in the limbic system, default mode network (DMN) and visual network. These changes were seen bilaterally for both the limbic system and DMN, however only in the right hemisphere for the visual network (due to the participants' right eye dominance) (Farahani et al., 2019). Kaufmann et al. (2016) observed similar changes in 41 short term SD participants (one night of SD) when compared to a control group (Kaufmann et al., 2016). They found altered connectivity in the dorsal attention network, the DMN and in hippocampal networks, suggesting that these changes can be seen with both chronic and acute SD. While it is apparent that SD can have measurable impacts across a number of brain regions and networks, the extent to which these impacts persist or whether they can be normalised by recovery sleep or reverting to a standard circadian rhythm is unclear.

Recent literature has provided further mechanistic insight into the impact of SD on brain function. Nir et al. (2017) found selective neuronal lapses occurred before cognitive lapses, following a period of SD. Specifically, diminished, delayed and lengthened spiking responses occurred in individual neurons in the medial temporal lobe, an area known to be involved in long term memory storage (Nir et al., 2017). Furthermore, D'Ambrosio et al. (2019) suggests that parts of the brain can establish a sleep like state whilst others are active in order to minimise impact. This may account for some of the cognitive decrements seen following a period of sleep deprivation (D'Ambrosio et al., 2019).

Taken together, this would suggest that being tired and fatigued impacts the brain on a physiological level, both after sleep deprivation and shift work. However, it is not fully established whether shift workers are persistently physiologically compromised i.e. if there is indeed a 'signature of shift work'. Further, whether this could in fact be a benefit, representing a compensatory change and explain apparent cognitive coping mechanisms often exhibited by shift workers.

The limited literature evaluating neural structure and function in SWs has revealed some evidence to suggest that changes occur within grey matter of the brain. Grey matter volume reductions have been observed in rotating shift working military servicemen, specifically within the pontomesencephalic tegmentum, an area that has recently been linked with wakefulness and REM sleep (Bin Kim & Kim, 2017). Grey matter volume reduction has been observed in many areas linked with compromised cognitive function. These include aging (Ramanoël et al., 2018), in smokers (Vňuková, Ptáček, Raboch, & Stefano, 2017) and in mental illness (Grieve, Korgaonkar, Koslow, Gordon, & Williams, 2013; Zhang et al., 2016). Therefore, if shift workers have a reduction in grey matter volume this may partially explain the cognitive compromise described in the current literature.

More recently, Park et al. (2019) found altered regional cerebral blood flow in nurses following two consecutive night shifts, using cerebral perfusion MRI. Importantly, all shift workers had been employed in their current work for at least two years. They found significantly reduced cerebral perfusion in the cuneus, fusiform and parahippocampal gyri, and cerebellum (right hemisphere) in the shift working group and an increase in the inferior occipital gyrus (left hemisphere). Further, whilst there were no demographic differences in the groups, levels of insomnia, depression and anxiety were higher in the shift workers. They conclude that shift workers have altered functional changes that may partly explain the impact of this lifestyle on the development of affective disorders (Park et al., 2019).

However, the biggest caveat with much of the current physiological literature is the lack of workplace and job relevance. These studies are frequently conducted outside of the workplace (which, in these samples, is often a high stress environment), and involve many changes to the workers' usual routine, which may influence findings. This causes them to have low ecological validity. EEG, in particular portable EEG, may be the way to improve on this.

EEG equipment has become increasingly portable as technological advancements enable components to become smaller and more robust. These developments have allowed EEG to potentially be used in a wider variety of 'real world' environments, including within the workplace, with increasing ease. Further benefits of portable EEG systems include a fast set up, use of dry electrodes (therefore causing less disruption to routine), wireless connectivity and

overall simplicity of usage. These characteristics have led to an increased market for consumer EEG systems.

Consumer systems, such as the Muse™ headband, began to appear on the market in the early 2000s, and many were originally sold as an aid to relaxation and meditation or as part of a game (Grush, 2016). However, the utility of these easily portable and relatively cheap EEG systems for use in clinical settings was initially uncertain. Ratti et al. (2017) compared two medical grade and two consumer EEG systems and found that although consumer systems were more prone to artefacts, due to eye blinks and muscle movement in the frontal region, 3 of the 4 systems tested showed similar power spectra. The consumer bands provided 'fairly good quality data' however there were some differences in the power increase and shape of the alpha peak at 8-13 Hz. Test/retest reliability was also lower in consumer systems. They concluded that whilst medical grade EEG systems offer clear advantages in the data quality and amount, consumer devices, such as Muse headbands, did offer benefits in terms of set up time (due to dry electrodes) and low cost (Ratti et al., 2017). Further validation of the Muse headband for use in event related brain potential (ERP) research by Krigolson et al. (2017) found that it was possible to observe and quantify ERP components in two cognitive tasks, supporting the use of portable EEG systems in research (Krigolson, Williams, Norton, Hassall, & Colino, 2017). Whilst there are still caveats to these portable systems being used in scientific research, the advantages over full cap EEG for work-related preliminary research is clear.

Single channel EEG headsets have also been used to detect drowsiness. Ogino and Mitsukura (2018) used two tasks – one intended to evoke drowsiness (counting from 1-300) and one to promote attentiveness and wakefulness (Wisconsin Card Sorting Task, WCST) (Ogino & Mitsukura, 2018). They found significant differences in drowsiness probabilities during the two tasks, with the counting task producing a higher average estimate of drowsiness level than the WCST. Rohit et al. (2017) further assessed the use of EEG bands as a real time drowsiness detection tool, which would be of particular use to shift workers working in an attention critical environment e.g. drivers, machine handlers, doctors. Using 23 subjects, in both drowsy and non-drowsy states, they established that Muse headbands were able to classify drowsy states with a high accuracy (Rohit et al., 2017). Based on the data described, it is reasonable to suggest that commercial EEG headbands are viable for use in an occupational research context.

Eyes open/eyes closed protocols (also known as resting state EEG) are often used within the field of EEG when initial baseline testing is required, due to their relative simplicity and non-invasive method (Anderson & Perone, 2018). These conditions involve different levels of visual stimulation and as a result have shown significant differences in EEG activity (Anderson & Perone, 2018; Barry, Clarke, Johnstone, Magee, & Rushby, 2007; Li, 2010). Barry et al. (2007) examined eyes

open and eyes closed resting conditions across scalp regions in 28 healthy students. They found higher states of arousal in the eyes open resting condition as well as alpha topography that was likely present due to engagement of the visual systems. Barry et al. recommended that eyes closed protocols are used as a baseline measure of arousal, compared to eyes open being used as a baseline measure of activation.

In the present study, we aimed to assess the physiological impact of shift work in an occupationally relevant setting, without the confound of work-related fatigue using commercially available EEG headsets.

7.2 Specific aims

1. To assess whether shift work has a persistent physiological effect on the brain in the absence of post-work fatigue
2. To determine if there are differences at baseline at the beginning of a day shift compared to a night shift
3. To evaluate the practicalities of consumer EEG equipment for research use in the occupational context

7.3 Method

All research presented in this chapter has received ethical approval following review by The Open University's Human Research Ethics Committee (HREC/2669/Breese). This study also adheres to all BPS ethics standards (The British Psychological Society, 2018).

A full information sheet, briefing and debrief were provided and each participant was required to provide informed consent before being enrolled. Participants were informed of their right to withdraw at any point (prior to data anonymisation and aggregation) and given the opportunity to ask any questions prior to signing consent. Contact details of the research team were provided at the beginning and end of testing, should participants wish to ask any further questions.

7.3.1 Recruitment approach

Contact was made through previous participant groups and advertised around a university department. The data presented in this chapter are derived from the successful recruitment of a group of security personnel, campus maintenance staff and academic staff based at a UK Higher Education Institution.

7.3.2 Exclusion criteria

Eight shift workers and fifteen non-shift workers were excluded from the study due to incomplete data and poor signal quality. One shift working participant's data were partially excluded, however one channel was deemed usable. One shift worker only completed one testing session. This left a total of eight shift workers and nine non-shift workers included in AF7 analysis and seven shift workers and nine non-shift workers included in AF8 analysis. One participant in the control group had previously worked shifts, however as this was over 10 years ago this was not deemed as exclusion worthy from the control.

7.3.3 Questionnaire instruments

All participants were required to complete multiple questionnaires over the course of these studies. As described in Chapter Two these included:

- A full MEQ questionnaire – a 19 item questionnaire aimed at classifying an individual as either a 'morning type', 'neutral' or 'evening type'.
- Basic demographic questions including age, sex and handedness
- Shift specific questions including shift schedule, years worked shifts and shift history
- Caffeine and sugar intake questions

7.3.4 Muse headband

The Muse headband (InteraXon, Toronto, ON, Canada) has seven EEG electrodes, consisting of four channels (two left frontal and two right frontal) and three references, therefore enabling

hemispheric asymmetry analysis (Figure 59). In this study, channels AF7 and AF8 were extracted for analysis (Figure 60). The frequency thresholds for the recordings are defined in Table 100. These frequency thresholds are widely used in the existing EEG literature (Read & Innis, 2017).

Table 100 Frequency thresholds extracted from Muse headband

Frequency band	Frequency threshold (Hz)	Associated with
Delta	2-4	Stages of sleep (Amzica & Steriade, 1998) and fatigue (Lal & Craig, 2002).
Theta	4-8	Drowsiness (James A. Horne & Baulk, 2004; Kaida et al., 2006; Ogino & Mitsukura, 2018).
Alpha	8-12	Attention and inhibitory control (most prominent during relaxation) (Read & Innis, 2017)
AlphaL	8-10	
AlphaH	10-12	
SMR (sensorimotor rhythm)	12-15	State of relaxed alertness (Kober, Witte, Ninaus, Neuper, & Wood, 2013)
Beta	15-29	Active thinking, alertness, sensorimotor functions, working memory and decision making (Dustman, Boswell, & Porter, 1962; Spitzer & Haegens, 2017)
Beta2	13-21	

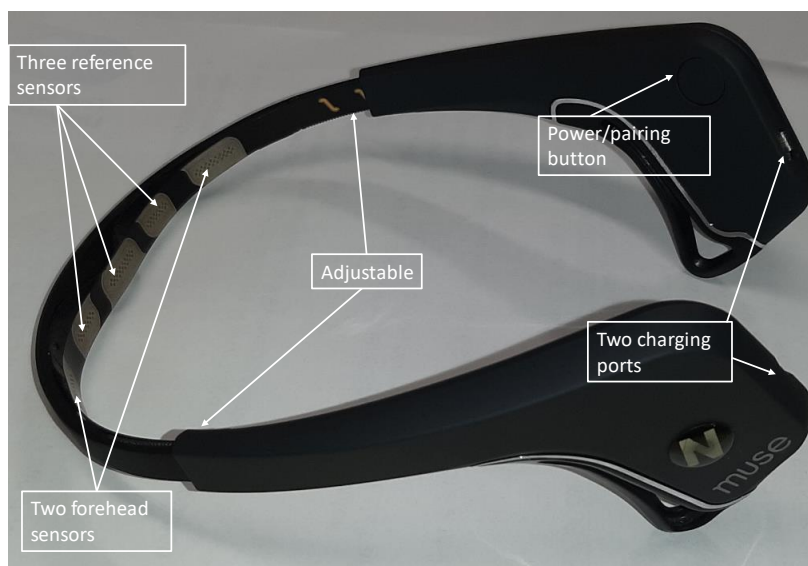


Figure 58 Muse™ headband

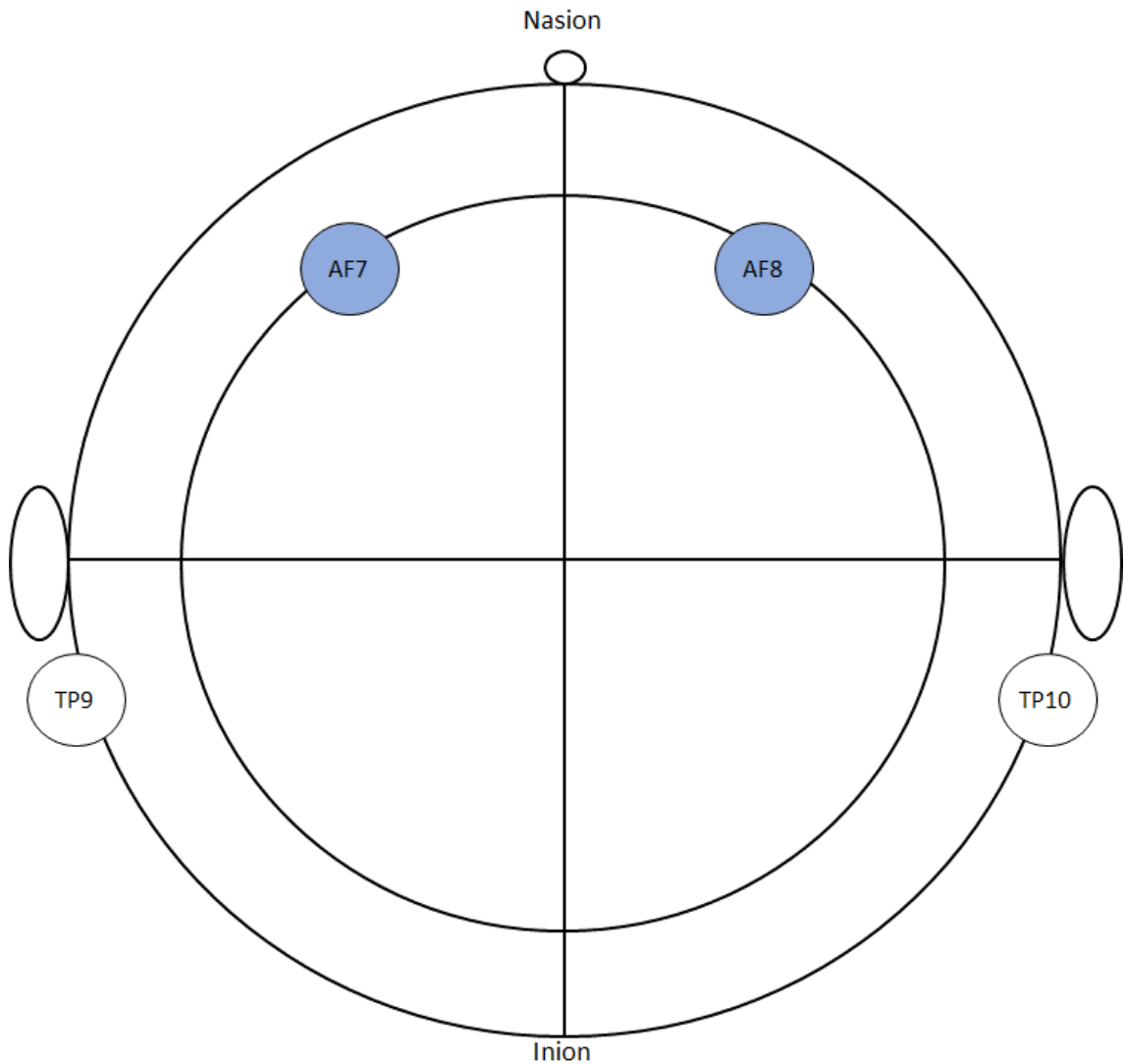


Figure 59 Muse headband electrode locations

7.3.5 Design

Participants were tested twice in total, always at the beginning of a working shift in order to minimise the potential effects of fatigue. Shift working individuals were tested on the third night shift and the third day shift in a rotation of four. This shift was chosen to ensure workers were following their normal shift working routine as it is plausible there would be more variability in terms of sleepiness on the first or last day of a new shift type. Non-shift workers were tested on two consecutive Wednesdays as, given this sample worked Monday to Friday, this was deemed most similar to the third shift of SW group.

7.3.6 Testing procedure

Once the study was explained to each participant, informed consent had been obtained, and any remaining questions addressed, each individual was given the full questionnaire battery to complete and the date of the second testing session was confirmed. Before the second testing session only the caffeine and sugar intake questionnaire was given.

Following completion of the questionnaire, participants were asked to sit in a chair in a comfortable upright position at a table in a quiet well-lit room. The Muse headband was placed on the participant's head by the researcher and positioned just above the eyebrows. A signal check was then run to ensure a clear signal was being recorded from each of the four electrodes and the band was repositioned if necessary. Recordings were taken with custom software provided by Tony Steffert (Muse Sonify, written in house) on an HP Model 11-aa051sa laptop.

An eyes open/eyes closed protocol was used in this study. When the participant confirmed they were ready, they were asked to close their eyes for five minutes. Immediately after, the eyes open trial was completed with individuals asked to stare at one point directly in front of them and avoid looking around the room.

There are alternative protocols often used in EEG assessment. These include the Karolinska Drowsiness test, where participants sit focusing on a point on a wall for 5 minutes, then sit for 2 minutes with closed eyes. However, following consultation with an EEG expert (Tony Steffert) and considering the use of a relatively new technology, the more basic 'eyes open eyes closed' protocol was used. Future repetitions of this study would utilise a sleep related protocol such as the Karolinska Drowsiness Test.

Once testing had finished participants were thanked for their time, and the following testing session details were again confirmed. Following the final testing session, participants received a debrief and were compensated for their time (£5 Amazon voucher). While individual performance data was not shared with any participant, each person was asked if they would like to receive a copy of the aggregated data set and analysis report.

7.3.7 Output variables

The output variables for this study were the power calculated for each of the eight frequency bands in each of the eye conditions (eyes open and eyes closed).

7.3.8 Statistical analysis

Paper questionnaire data were inputted and prepared for statistical analysis using Microsoft Excel 2013 (Microsoft, 2013). Descriptive statistics (mean, standard deviation and range) were generated for demographic data, including age, sex, years working shifts & sleep disorder frequency using GraphPad Prism version 8.2.1 (GraphPad Software, La Jolla California USA, n.d.).

Extraction of data was conducted with Brainstorm (Tadel et al., 2011), which is documented and freely available for download online under the GNU general public license (<http://neuroimage.usc.edu/brainstorm>). Initial quality control of the raw signal data was conducted through visual inspection by an EEG specialist (Dr Tony Steffert, The Open University)

to ensure appropriate signal characteristics, prior to further automated processing. Recordings that passed quality control were fed into a customised analysis pipeline prepared using Brainstorm. The settings of this pipeline were: removal of DC offset, 50Hz notch filter, Band-pass 0.5Hz – 40Hz, threshold detection over 20uV, power spectrum density (Welch).

EEG data were analysed using JASP (www.jasp-stats.org, version 0.11.1) and GraphPad Prism version 8.2.1 (GraphPad Software, La Jolla California USA, n.d.). To address multiple comparisons, Tukey post hoc analyses were performed as appropriate. Significance was given by a p-value of less than 0.05.

7.4 Results

7.4.1 Demographics

The cohort consisted of 16 males and 1 female participant so meaningful sex difference analysis was not possible. Cohort characteristics are shown in Table 101. All participants were right-handed though handedness was not an exclusion criterion in this study. No participant declared a head injury or disclosed a diagnosed sleep disorder.

There was no significant difference in the age of participants ($t(15)=1.867$, $p=0.082$).

Table 101 Demographic characteristics of cohort

Testing group	Mean age \pm SD	Sex ratio (M:F)	Average years worked shifts
Shift workers	52.125 \pm 14.035	8:1	15.27
Non shift workers	39.22 \pm 14.386	8:0	N/A

7.4.2 Morningness-Eveningness Questionnaire

The 19 self-rated questions of the Morningness-Eveningness questionnaires were combined to create one global score. This score was then used to sort individuals into one of five categories: Definite evening, Moderate evening, Intermediate, Moderate morning or Definite morning (J. A. Horne & Östberg, 1976; Terman et al., 2008) (Table 102). Neither testing group had any ‘definite evening’ or ‘moderate evening’ individuals.

Table 102 MEQ categorisations

MEQ score range	MEQ category
16-30	Definite evening
31-41	Moderate evening
42-58	Intermediate
59-69	Moderate morning
70-86	Definite morning

The proportion of individuals within each MEQ category as a function of worker status is presented in Table 103.

Table 103 MEQ Scores for shift workers and controls

MEQ Category	Shift workers	Non-shift workers
Definite evening	0%	0%
Moderate evening	0%	0%
Intermediate	62.5%	44.44%
Moderate morning	37.5%	33.33%
Definite morning	0%	22.22%

7.4.3 EEG data

7.4.3.1 Comparison of eyes open and eyes closed conditions reveal some evidence of changes in EEG

As an initial characterisation, comparisons between the EEG power (the amount of activity in certain frequency bands of the signal (Nunez & Srinivasan, 2005)) in each frequency band under ‘eyes open’ and ‘eyes closed’ conditions were performed for both AF7 and AF8.

Significant differences were observed in all AF7 frequency bands except Beta2 and SMR (Figure 61 a-h). Significant differences were also observed in all AF8 frequency bands except Beta, Beta2 and SMR (Figure 62 a-h).

All t-test comparison scores are displayed in Table 104.

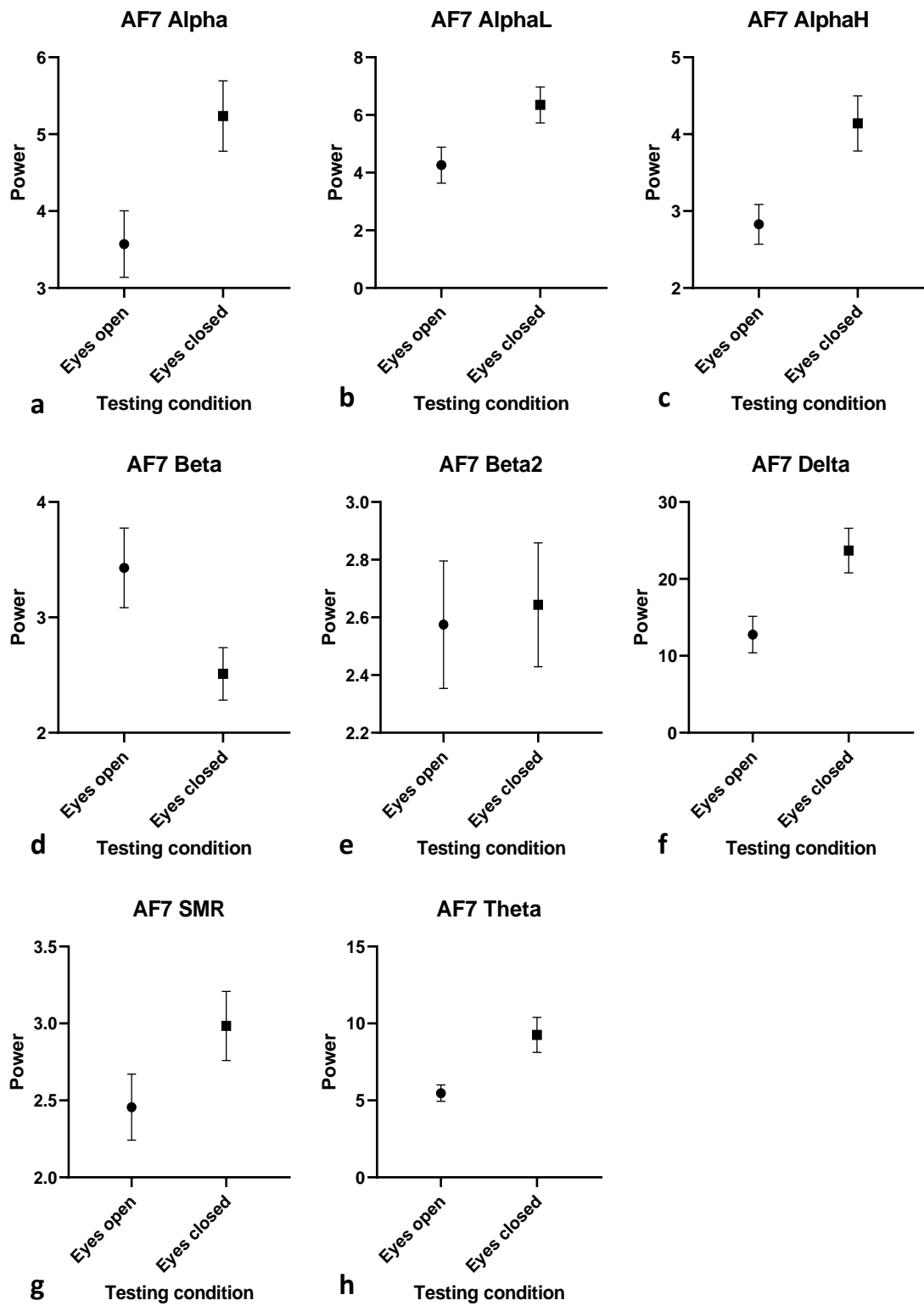


Figure 60 Comparison of mean power recorded in eyes open and eyes closed conditions (AF7) (a) Alpha frequency range (b) Alpha L frequency range (c) Alpha H frequency range (d) Beta frequency

range (e) Beta2 frequency range (f) Delta frequency range (g) SMR and (h) Theta frequency range. Error bars indicate SEM.

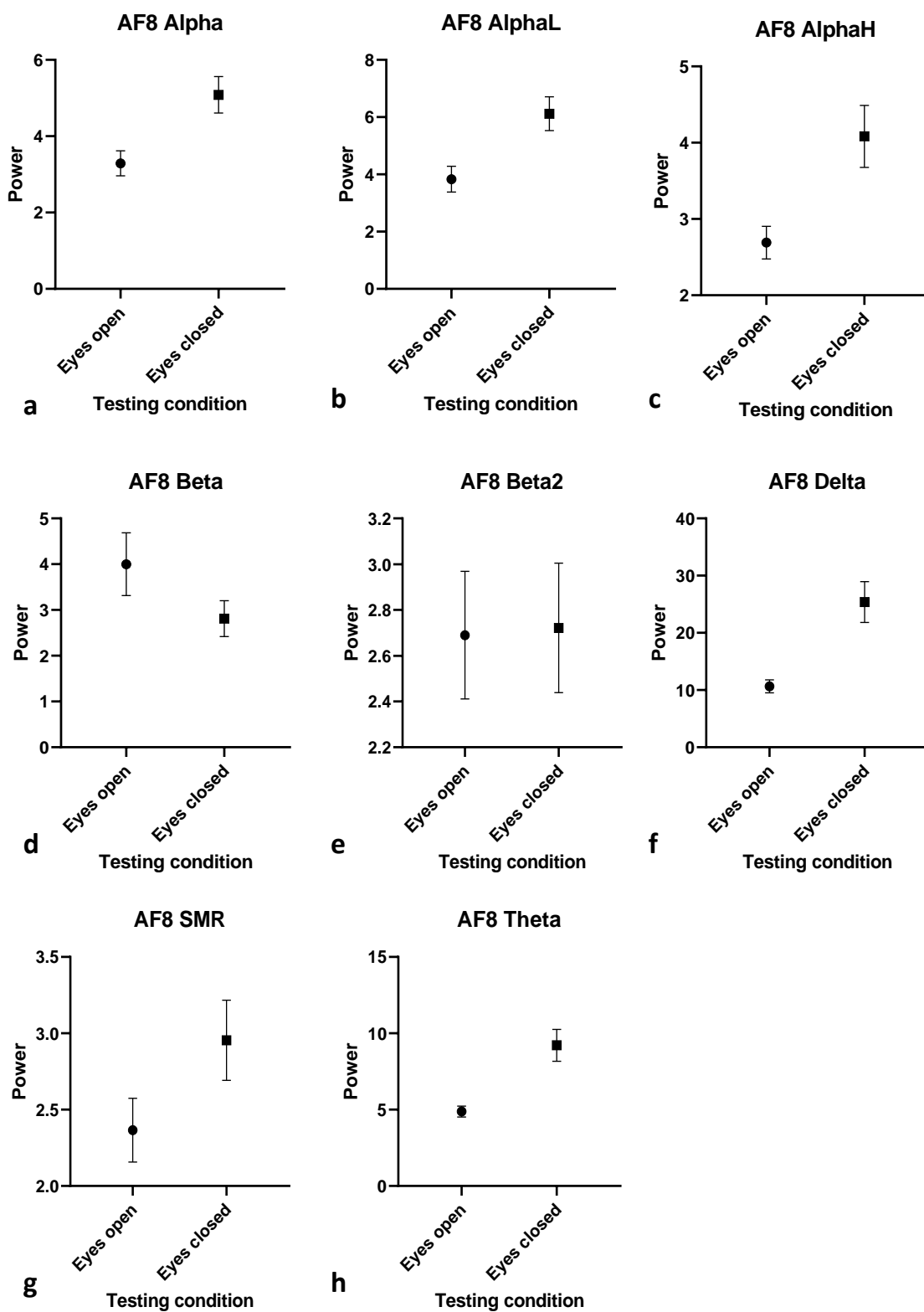


Figure 61 Comparison of mean power recorded in eyes open and eyes closed conditions (AF8) (a) Alpha frequency range (b) Alpha L frequency range (c) Alpha H frequency range (d) Beta frequency

range (e) Beta2 frequency range (f) Delta frequency range (g) SMR and (h) Theta frequency range. Error bars indicate SEM.

Table 104 Eyes open VS Eyes closed channel comparisons ^aindicates Welch's transformation used
*indicates significance

Channel	Frequency band	t value	p value	Cohen's d
AF7	Alpha	t(64)=2.648	0.01*	0.652
	Alpha L	t(64)=2.366	0.021*	0.583
	Alpha H	t(64)=2.967	0.004*	0.731
	Beta ^a	t(55.369)=-2.227	0.03*	-0.548
	Beta2	t(64)=0.223	0.824	0.055
	Delta	t(64)=2.913	0.005*	0.717
	SMR	t(64)=1.7	0.094	0.419
	Theta	t(64)=3.006	0.004*	0.740
AF8	Alpha	t(60)=3.014	0.003*	0.788
	Alpha L	t(60)=3.073	0.003*	0.78
	Alpha H ^a	t(45.459)=3.041	0.004*	0.772
	Beta	t(60)=-1.510	0.136	-0.383
	Beta2	t(60)=0.08	0.937	0.02
	Delta ^a	t(36.007)=3.947	<0.001*	1.003
	SMR	t(60)=1.753	0.085	0.445
	Theta ^a	t(37.011)=3.930	<0.001*	0.998

7.4.3.2 Comparison of shift worker and control participants reveals EEG changes, restricted to eyes open condition

All testing time points were grouped based on participant group. Table 105 shows all t-test comparison scores.

AF7 analysis revealed no significant differences were found in eyes closed testing in any frequency band. Significant differences were found between shift workers and non-shift workers in frequency bands Beta (t(22.42)=-2.74, p=0.01), Beta2 (t(31)=-2.67, p=0.01) and SMR (t(21.11)=-2.25, p=0.04) in the eyes open condition, with the SW group showing higher power than the control group (Figure 63).

AF8 analysis showed no significant differences in the eyes closed testing in any frequency band. Significant difference were found between shift workers and non-shift workers in frequency

bands Beta ($t(13.405)=-2.321$, $p=0.037$), Beta2 ($t(14.987)=-3.112$, $p=0.007$) and SMR ($t(15.402)=-2.599$, $p=0.02$) in the eyes open condition, with SW group showing higher power than the control group (Figure 64).

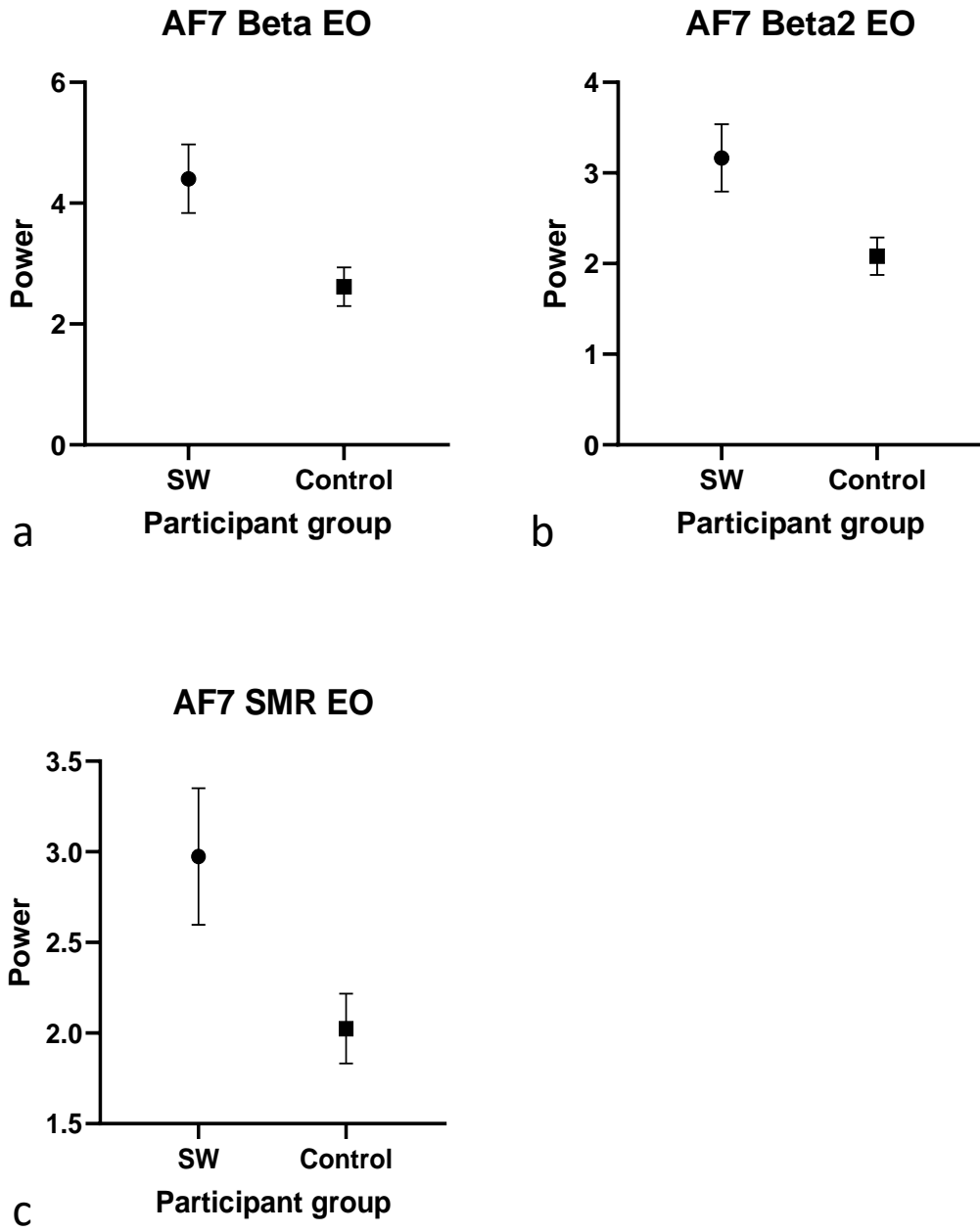


Figure 62 Frequency bands showing significant difference (a) AF7 Beta frequency band eyes open condition (b) AF7 Beta2 frequency band, eyes open condition (c) AF7 SMR frequency band, eyes open condition. Error bars indicate SEM.

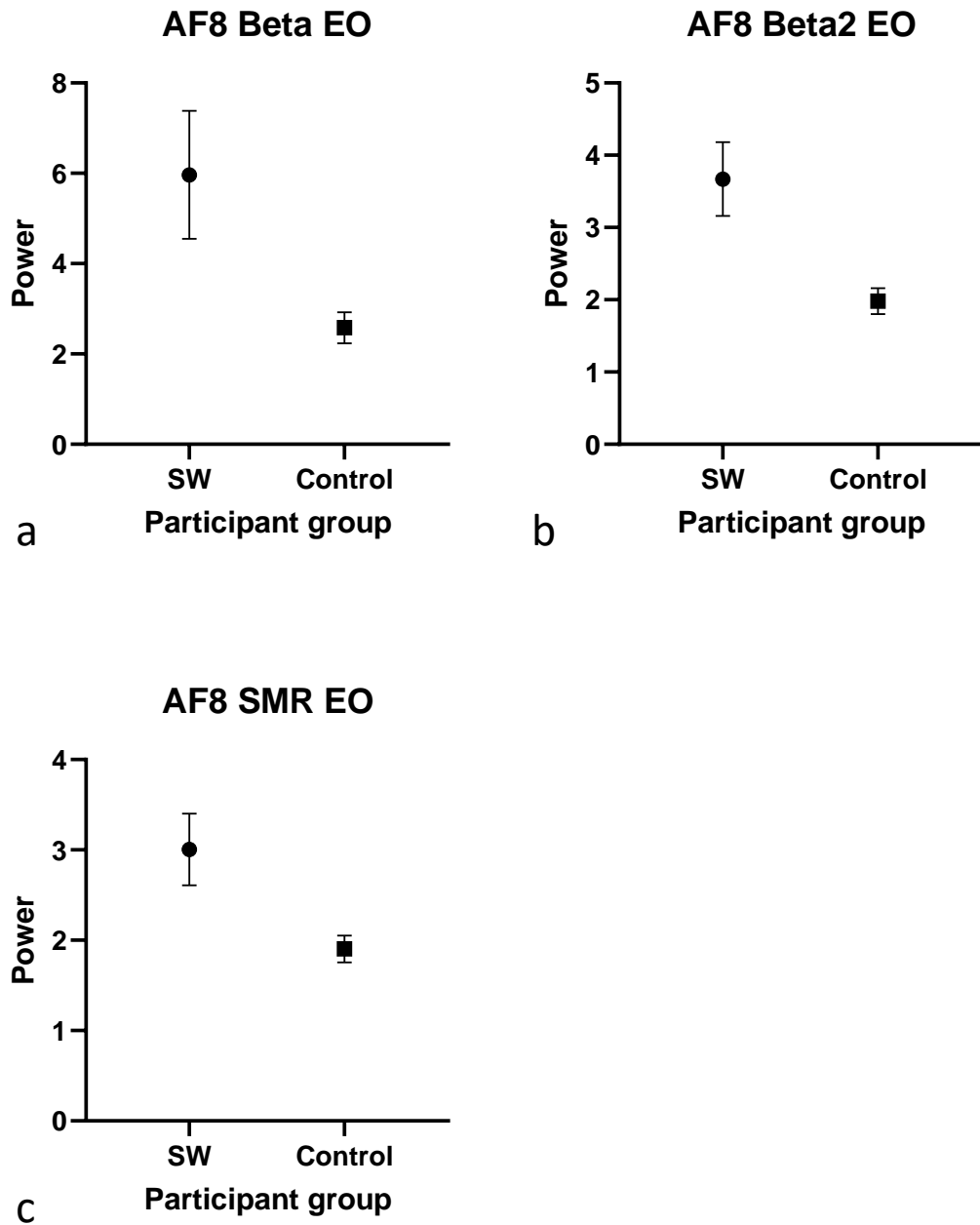


Figure 63 Frequency bands showing significant difference a) AF8 Beta frequency band eyes open condition (b) AF8 Beta2 frequency band, eyes open condition (c) AF8 SMR frequency band, eyes open condition. Error bars indicate SEM.

Table 105 Shift worker VS control comparisons ^aindicates Welch's transformation used ^{*}indicates significance

Channel	Testing condition	Frequency band	t value	p value	Cohen's d
AF7	Eyes closed	Alpha ^a	t(22.011)=-1.238	0.229	-0.442
		Alpha L ^a	t(21.812)=-1.248	0.225	-0.466
		Alpha H	t(31)=-1.131	0.267	-0.396
		Beta	t(31)=-0.188	0.852	-0.066
		Beta2	t(31)=-0.309	0.759	-0.108
		Delta	t(31)=-1.353	0.186	-0.473
		SMR	t(31)=-0.883	0.384	-0.309
		Theta	t(31)=-1.432	0.162	-0.501
	Eyes open	Alpha	t(31)=-0.747	0.461	-0.261
		AlphaL	t(31)=-0.389	0.7	-0.136
		AlphaH ^a	t(19.388)=-1.675	0.110	-0.602
		Beta ^a	t(22.415)=-2.738	0.012*	-0.976
		Beta2	t(31)=-2.667	0.012*	-0.932
		Delta ^a	t(14.533)=-1.972	0.068	-0.719
		SMR ^a	t(21.106)=-2.246	0.036*	-0.803
Theta		t(31)=-1.289	0.207	-0.451	
AF8	Eyes closed	Alpha	t(29)=0.853	0.4	0.311
		Alpha L	t(29)=0.977	0.336	0.356
		Alpha H	t(29)=0.557	0.582	0.203
		Beta	t(29)=-0.475	0.638	-0.173
		Beta2	t(29)=0.073	0.942	0.027
		Delta	t(29)=0.674	0.506	0.245
		SMR	t(29)=0.121	0.905	0.044
		Theta	t(29)=0.829	0.414	0.302
	Eyes open	Alpha	t(29)=-0.594	0.557	-0.216
		AlphaL	t(29)=0.005	0.996	0.002
		AlphaH ^a	t(16.307)=-1.7	0.108	-0.648
		Beta ^a	t(13.405)=-2.321	0.037*	-0.901
		Beta2 ^a	t(14.987)=-3.112	0.007*	-1.196
		Delta ^a	t(14.093)=-1.163	0.264	-0.449
		SMR ^a	t(15.402)=-2.599	0.02*	-0.996
Theta		t(29)=-0.382	0.705	-0.139	

7.4.3.3 Time of shift comparisons

Shift workers were separated into the time of testing, either at the start of a day shift or the start of a night shift and compared to control tested at the start of the day. A summary of ANOVAs run for each frequency band is presented in Table 106 (post hoc = mean \pm SD).

AF7 analysis revealed no significant differences were found in eyes closed testing in any frequency band. Significant differences were observed in the eyes open condition. Specifically, differences were seen in frequency bands Beta ($F(2,30)=4.702$, $p=0.017$), with Day SW group showing higher power than the control group, Beta2 ($F(2,30)=3.574$, $p=0.041$), with no further interactions, and Delta ($F(2,30)=3.429$, $p=0.046$), with Night SW group showing higher power than control group (Figure 65).

AF8 analysis showed no significant differences in the eyes closed testing in any frequency band. In the eyes open condition, significant difference were found between shift workers and non-shift workers in frequency bands Beta ($F(2,28)=4.789$, $p=0.016$), Beta2 ($F(2,28)=7.555$, $p=0.002$) and SMR ($F(2,28)=4.718$, $p=0.017$) in the eyes open condition with Day SW group showing higher power than the control group (Figure 66).

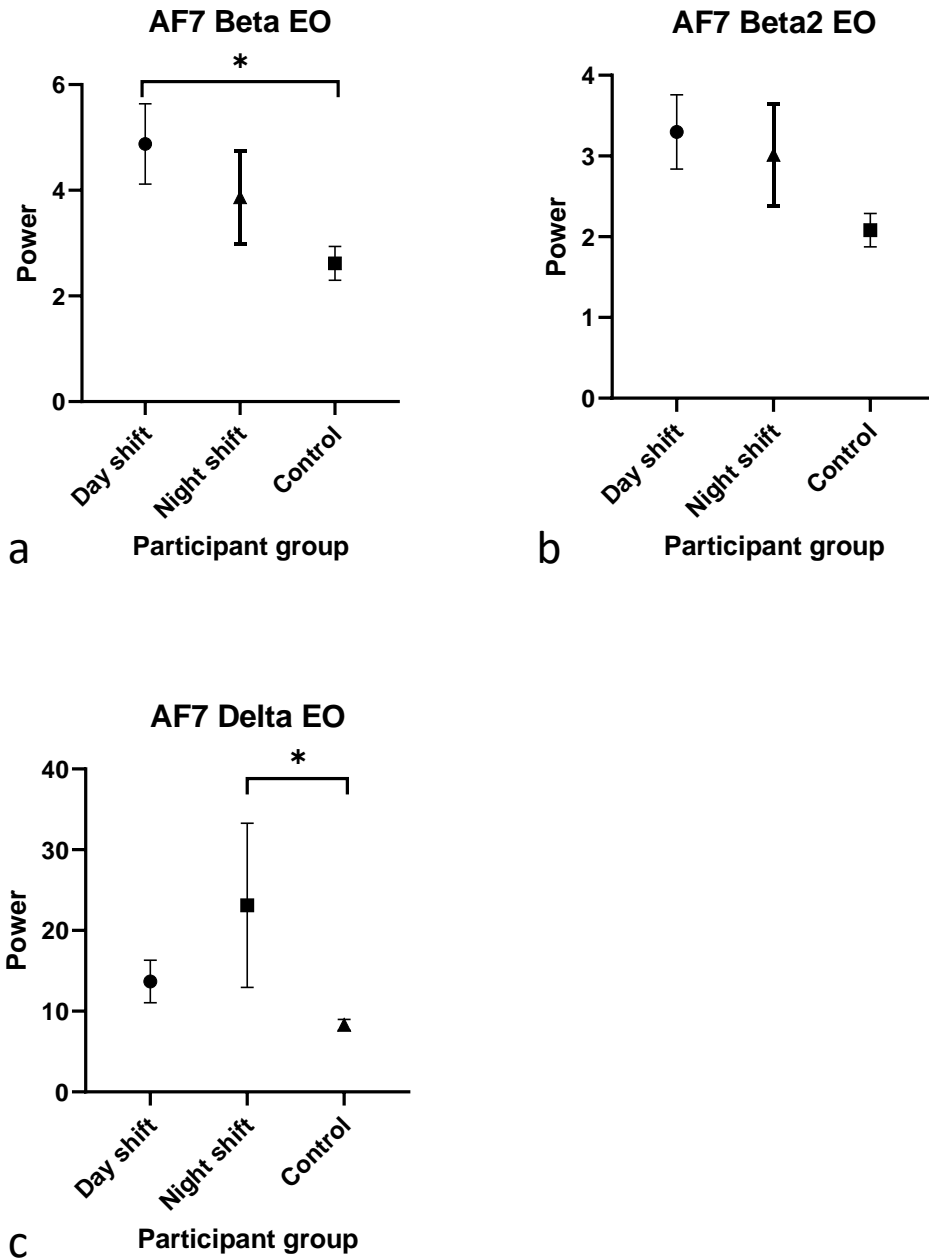


Figure 64 Frequency bands showing significant difference (a) AF7 Beta frequency band, eyes open condition (b) AF7 Beta2 frequency band, eyes open condition (c) AF7 Delta frequency band, eyes open condition. Error bars indicate SEM.

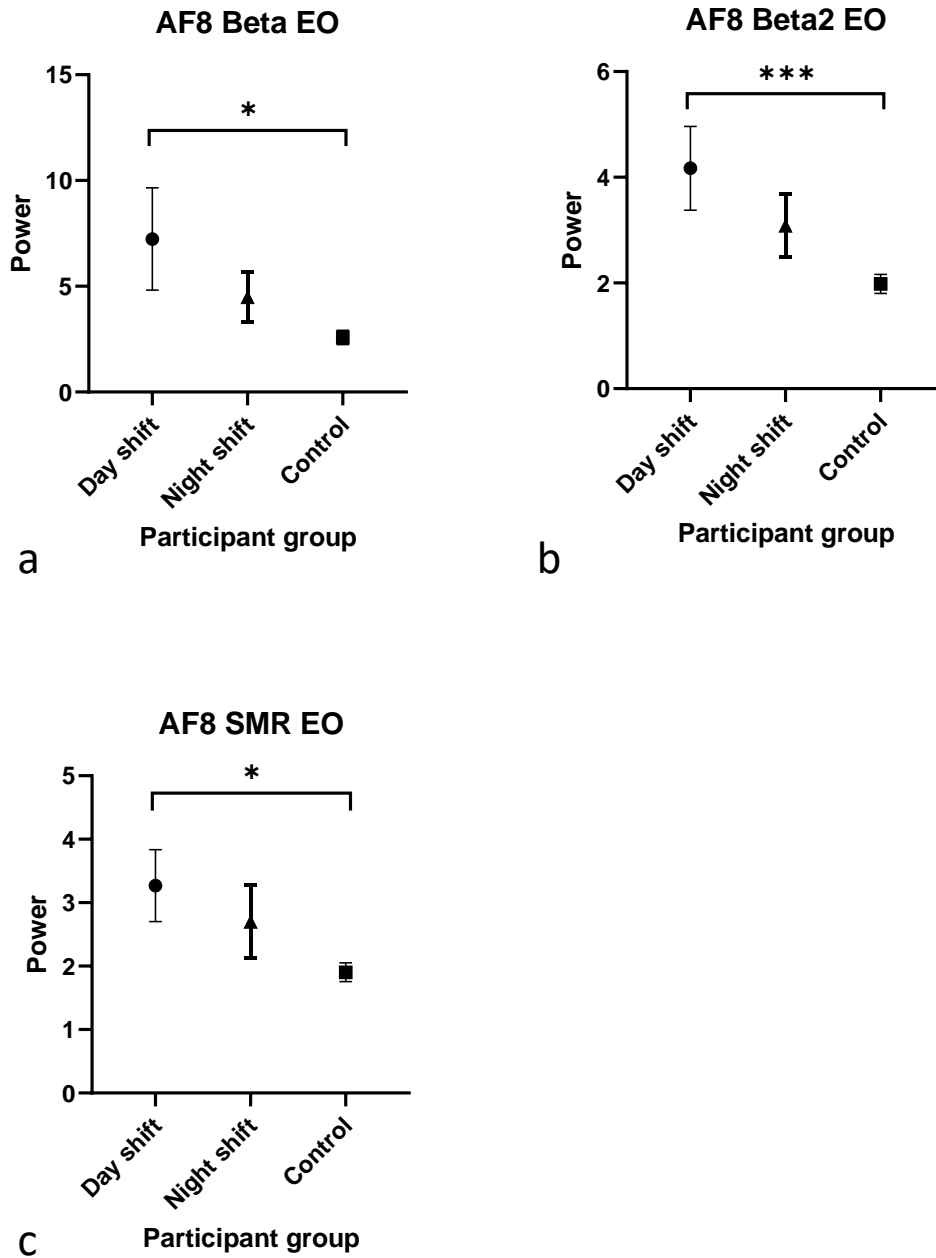


Figure 65 Frequency bands showing significant difference (a) AF8 Beta frequency band, eyes open condition (b) AF8 Beta2 frequency band, eyes open condition (c) AF8 SMR frequency band, eyes open condition. Error bars indicate SEM.

Table 106 Time of day comparisons (day shift VS night shift VS control) *indicates significance

Channel	Testing condition	Frequency band	F value	p value	η^2	Tukey post hoc test
AF7	Eyes closed	Alpha	F(2,30)= 1.9	0.167	0.112	
		Alpha L	F(2,30)= 2.212	0.127	0.129	
		Alpha H	F(2,30)= 1.092	0.349	0.068	
		Beta	F(2,30)= 0.039	0.961	0.003	
		Beta2	F(2,30)= 0.091	0.914	0.006	
		Delta	F(2,30)= 1.729	0.195	0.103	
		SMR	F(2,30)= 0.582	0.565	0.037	
		Theta	F(2,30)= 2.878	0.072	0.161	
	Eyes open	Alpha	F(2,30)= 0.554	0.581	0.036	
		Alpha L	F(2,30)= 0.329	0.722	0.021	
		Alpha H	F(2,30)= 1.735	0.194	0.104	
		Beta	F(2,30)= 4.702	0.017*	0.239	Control EO=2.617 ± 1.358, Day SW EO=4.876 ± 2.15, p=0.015
		Beta2	F(2,30)= 3.574	0.041*	0.192	No further interactions
		Delta	F(2,30)= 3.429	0.046*	0.186	Control EO=8.322 ± 2.872 Night EO=23.126 ± 26.902, p=0.036
		SMR	F(2,30)= 2.693	0.084	0.152	
Theta		F(2,30)= 1.974	0.157	0.116		
AF8	Eyes closed	Alpha	F(2,28)= 0.398	0.676	0.028	
		Alpha L	F(2,28)= 0.506	0.609	0.035	
		Alpha H	F(2,28)= 0.212	0.81	0.015	
		Beta	F(2,28)= 0.649	0.530	0.044	
		Beta2	F(2,28)= 0.249	0.782	0.017	
		Delta	F(2,28)= 0.225	0.8	0.016	
		SMR	F(2,28)= 0.082	0.921	0.006	

		Theta	F(2,28)= 0.334	0.719	0.023	
	Eyes open	Alpha	F(2,28)= 0.171	0.843	0.012	
		Alpha L	F(2,28)= 0.022	0.978	0.002	
		Alpha H	F(2,28)= 1.878	0.172	0.118	
		Beta	F(2,28)= 4.789	0.016*	0.255	Control EO=2.581 ± 1.450 Day SW EO=7.236 ± 6.410 p=0.013
		Beta2	F(2,28)= 7.555	0.002*	0.351	Control EO=1.982 ± 0.763 Day SW EO=4.171 ± 2.094 p=0.002
		Delta	F(2,28)= 2.944	0.069	0.174	
		SMR	F(2,28)= 4.718	0.017*	0.252	Control EO=1.904 ± 0.632 Day SW EO=3.269 ± 1.501 p=0.017
		Theta	F(2,28)= 0.364	0.698	0.025	

7.5 Discussion

The data presented here represents initial efforts to establish if any physiological effects of shift work remain in the absence of post-work fatigue. Further, it aims to examine if these effects are different at the beginning of a day shift, compared to a night shift. To maximise ecological validity, a strength that is missing from much of the current literature, portable EEG devices were used within the workplace. This helped minimise disruption to the workers, improving retention rates as well as the validity of findings. Overall, data suggests that some physiological differences are present in shift workers compared to non-shift workers. Significant shift dependant effects were observed in frontal beta and SMR, frequency bands that are associated with active thinking and relaxed alertness. Further, time of shift/time of testing dependant differences were also observed, with some evidence of interhemispheric variation.

Understanding the relationship between shift work and the brain is a topic of increasing interest. As described above, a number of studies have shown that sleep deprivation not only causes cognitive impairment, it can also lead to changes to brain physiology. Shift workers experience a form of circadian misalignment, reporting increased fatigue/tiredness as well as exhibiting cognitive impairment. This would suggest that shift workers are also experiencing changes in brain physiology. There is some research that indicates these cognitive impairments may be still exhibited for up to five years after shift work has stopped and are therefore not influenced completely by work-related fatigue/sleep (Titova et al., 2016). Any physiological changes that had

occurred during shift work may also still be present when an individual is not fatigued, indicating the possible existence of a 'shift worker brain'.

The eyes open/eyes closed condition comparison was conducted as an initial baseline study, given that it is not yet known whether any physiological changes exist in shift workers in the absence of work-related fatigue. These conditions involve different levels of visual stimulation and have been shown to have substantial differences in EEG activity (Anderson & Perone, 2018; Barry et al., 2007; L. Li, 2010). Barry et al. (2007) found the eyes open condition was linked to a higher state of arousal as well as alpha topography that was likely present due to engagement of the visual systems (Barry et al., 2007). Therefore, for this study it was pertinent to screen both conditions.

Comparison of eyes open and eyes closed conditions revealed significant differences in alpha, alphaL, alphaH, beta, delta and theta frequency bands in AF7. Beta2 and SMR did not show differences. In AF8, all bands except beta, beta2 and SMR showed significant differences. In all AF7 frequency bands, except beta, eyes closed condition showed more power however this relationship was reversed in beta. This was replicated in AF8. Similar findings have been found in Barry et al. (2007). They assessed EEG activity from university students using eyes open/eyes closed conditions. Reductions in across scalp mean in alpha, beta, delta and theta, were observed from the eyes closed condition to the eyes open condition. There were also topographic differences in all bands except for alpha, with reduced lateral frontal delta and increased frontal beta in the eyes open condition (Barry et al., 2007).

Based on the literature regarding these experiment conditions we would have expected to see a significant difference between eyes open/eyes closed in all frequency bands. However, beta and SMR did not follow this trend. Given that it is a mixed sample, indeed one where significant differences were found within condition in these frequency bands, it is possible that increased variation between groups led to a lack of significance in these bands.

In the current study, data was collected from two channels, AF7 and AF8, meaning it was possible to look for potential interhemispheric differences. Hemispheric differences have previously been seen in the literature, in particular regarding alpha. Trivedi and Bhargava (2017) found the right hemisphere displayed higher alpha waves during an eyes open condition than the left (Trivedi & Bhargava, 2017). Alpha has shown further hemispheric differences in cognitive testing, with peak alpha frequency increasing in the left hemisphere during arithmetic tasks compared to the opposite seen during visuospatial tasks (Osaka, 1984). In the present study, changes in alpha were not expected, given their link with cognition. However, what hemispheric differences mean in the context of the other channels remains unclear.

Comparison of shift workers and control participants revealed EEG changes in three frequency bands (beta, beta2 and SMR), however only in the eyes open condition. These significant differences were seen in the same frequency bands in both channels (showing no interhemispheric differences) and displayed the same directional relationship, with shift workers having more power than controls.

Beta waves have been linked with active thinking, alertness, sensorimotor functions, working memory and decision making (Dustman et al., 1962; Spitzer & Haegens, 2017). It has also been shown as a carrier for attentional control (Gola, Magnuski, Szumska, & Wróbel, 2013). Here we found shift workers had higher beta power than controls. Given that all participants were given the same instructions regarding movement and thinking, it is unlikely this beta difference is linked to preparation/execution of voluntary movement or due to conscious active thinking. Instead, it may suggest that shift workers were more alert during the eyes open condition. Nguyen et al. (2017) found low beta signals in the frontal cortex were observed when individuals were in a drowsy, low alert state, further lending support to this conclusion (Nguyen et al., 2017).

There has been evidence to suggest a frontal beta-theta network present in the frontal regions during REM sleep (Vijayan, Lepage, Kopell, & Cash, 2017). Specifically, increased presence of both theta and beta activity were seen in the anterior cingulate cortex and the dorsolateral prefrontal cortex, suggesting these areas may play an important role in REM sleep. However, no changes were seen in theta activity in the study reported here. This may be due to the fact Vijayan et al. (2017) took recordings whilst participants were in REM sleep, compared to the present study where participants were awake. Therefore, the lack of a theta-beta signature suggests that participants were not in a state approaching sleep, even in eyes closed condition, again supporting the use of this testing design to minimise any potential confound of work-related fatigue.

SMR is associated with a state of relaxed alertness (Kober, Witte, Ninaus, Neuper, & Wood, 2013) and typically decreases during activation of sensory and motor areas (Reichert, Kober, Neuper, & Wood, 2015). Here, higher SMR power was seen in the shift workers compared to controls. This suggests that whilst these individuals may be more alert (due to their higher beta power), they could be slower to react and deliver a behavioural response (because of their higher SMR power). This was seen in Boulay et al. (2011) who found increased SMR rhythms were associated with longer reaction times in a Go Nogo task (Boulay, Sarnacki, Wolpaw, & McFarland, 2011). This change in SMR potentially impacting responses could provide explanation for changes in reaction time seen within shift working literature. For example, Narciso et al. (2016) found shift workers had increased reaction times following a twelve hour shift (Narciso et al., 2016).

The lack of any changes in delta, found during sleep, suggests that shift working individuals were no sleepier during testing than controls. Delta power has been shown to correlate with stages of sleep (Amzica & Steriade, 1998) as well as fatigue (Lal & Craig, 2002). This would suggest that the design used here, in which participants were tested at the beginning of a shift, has minimised the potential confound of fatigue associated with completing a work shift prior to being assessed.

Once time of testing was considered, further differences were observed. Again, no differences were observed in the eyes closed condition in either electrode.

In the eyes open condition, significant differences were detected in beta and beta2, in both AF7 and AF8. Further post hoc analysis revealed the changes in beta were due to a significantly higher power seen in day shift workers relative to controls. As described above, a high beta power has been associated with active thinking. It appears that fundamental differences in beta frequencies, between shift workers and controls, only exist at the beginning of a day shift, however the precise explanation for this is unclear.

A different relationship was observed in delta frequency range. Changes in delta were being driven by a significant difference in power between night shift workers and control. This would suggest, counter to the SW/control analysis seen previously, night shift workers were exhibiting an EEG pattern more consistent with a sleep like state.

However, the changes in SMR observed in the previous analysis persisted. The relationship observed, in which SMR was higher in day SWs than controls, may again be a manifestation of a potentially delayed motor programme. As this was only detected in one hemisphere the functional significance remains unclear.

The significant differences between the day shift workers and controls are of particular note given that both these groups were tested at a time that would not interfere with a normal circadian rhythm. It also controls for the level of light, which is known to influence circadian rhythm. The lack of significant difference between night shift workers and controls (with the exception of delta in AF7) suggests something occurs at the beginning of a night shift that dampens the usual brain activity present at the beginning of the day shift. It is possible that compensatory mechanisms are employed by shift workers who are presently working against their circadian rhythm and as such display an EEG signature more similar to that of a control.

The absence of any significant differences across channels in frequency bands alpha and theta bands are of particular interest due to these bands being known to correlate with drowsiness (Horne & Baulk, 2004; Kaida et al., 2006; Ogino & Mitsukura, 2018). Kaida et al. (2006) found that, during an eyes open condition, the Karolinska Sleepiness Scale was correlated with alpha and theta activity. This would suggest that, despite increased drowsiness being associated with shift

work, the physiological signature was not present at the beginning of a shift in the participants assessed in the present study. A global increase of theta activity has been observed following prolonged wakefulness (Hung et al., 2013). As participants in the present study were tested at the beginning of a shift, it is unlikely they had experienced prolonged wakefulness, therefore were unlikely to exhibit heightened theta activity. This is also support for the testing design used in this study. Screening at the beginning of a shift appears to ensure there are no markers typically associated with tiredness/fatigue. Further, this suggests the differences seen here are due to the participants being shift workers, rather than due to participants being tired because they happen to be shift workers.

7.5.1 Limitations and future directions

One demographic limitation of this study is the small participant population and the homogeneity of occupation within the shift working group. The issue with much of the current literature is that it only looks at a very small work group, often in a medical or military profession (Kim & Kim, 2016; Park et al., 2019b). These occupations have been associated with irregular shift times, high stress environments and unpredictable work (Adriaenssens, De Gucht, & Maes, 2015; Caplan, 1994; Firth, 1986). Therefore, it is very difficult to generalise the findings to the rest of the shift working population who are in lower stress environments, often conducting repetitive work. Although this shift working sample is also from a singular occupation, it adds to the growing literature regarding physiological changes in shift workers and presents data from a non-medical/first responder occupation group. Future work should look to broadening this further by assessing larger, more occupationally varied groups.

The lack of a range of morningness-eveningness types also limits the generalisability of findings. However, this may reflect the global spread. Paine et al. (2006) found that within the 30-49 age range, using the Horne and Ostberg classification, 49.8% of the population were classed as morning type, compared to just 5.6% evening types (Paine, Gander, & Travier, 2006). However, they also suggest that this criteria is no longer relevant for grouping in a middle-aged population. Instead, they suggest using score cut-offs developed by Taillard et al. (2004) who argue the Horne and Ostberg MEQ has not been adapted for a non-student population (Taillard, Philip, Chastang, & Bioulac, 2004). Further, Paine et al. (2006) conclude that night shift workers were more likely to be definite evening types. In the present study no definite evening types were observed, irrespective of working group, despite similar age ranges (ages 39-52). However, if the cut-offs suggested by Taillard et al. (2004) are used, the shift worker group contains 25% definite evening types and 37.5% moderate evening types. In comparison, the control group contains 33% definite evening and 0% moderate evening. This would suggest the sample is more representative of the shift working population than previously stated, and thus the findings are more generalisable.

Further, this highlights the need for appropriate categorisations of samples when using questionnaire tools such as MEQ.

Sex has also been found to be linked with morningness, with morningness found to be significantly higher in males than females (Von Schantz et al., 2015). Given the current sample is predominantly male, the lack of evening types may be a manifestation of this sex difference.

Finally, despite detecting no evidence of EEG markers typically associated with sleep states or drowsiness, the inability to control time of waking in this study and the lack of a fatigue questionnaire complicates the interpretation of findings with respect to fatigue status. As with all field experiments, variability in participants' behaviour prior to testing needs to be considered. Future work should include a fatigue questionnaire such as the 10 item Fatigue Assessment Scale (Michielsen, De Vries, & Van Heck, 2003) as well as attempt to get a clearer view of sleep and wakefulness prior to testing.

7.5.2 Conclusions

Consumer EEG devices offer promise for occupational studies due to their inexpensiveness, simplicity in set up/running and use of dry electrodes. Data presented here supports this, showing these devices are viable for use in research and can produce meaningful results.

Significant shift work dependant effects in frontal beta and SMR were observed, suggesting that there may be some changes in brain physiology present in shift workers. In particular, these changes can be seen in frequency bands associated with deep sleep and active thinking. However there do appear to be differences dependant on type of shift/time of testing, with some evidence of interhemispheric variation. Based on the lack of a shift worker effect in alpha, delta and theta frequencies, it appears that this assessment approach (testing before a shift begins) minimises any potential fatigue/tiredness confound.

These observations highlight the need for further examination of these complex relationships.

8.1 Current research landscape

Sleep is a vital process required by humans to maintain healthy physical, mental and cognitive functioning (Ferrara & De Gennaro, 2001; Hor & Tafti, 2009; Lo, Groeger, Cheng, Dijk, & Chee, 2016; Miller et al., 2014; Sejnowski & Destexhe, 2000). Indeed, the link between sleep and cognition has been well established through laboratory-based SD studies (Mantua & Simonelli, 2019). However, it is increasingly recognised that such studies, which often involve long periods of SD may not be as informative as they could be because such designs lack ecological validity and may overestimate the magnitude of any impact. For example, in general, humans do not have to endure extended periods of forced wakefulness where they are retained in a novel laboratory environment, and therefore extrapolating findings based on this approach, is not particularly accurate or useful.

There are lots of different varieties of sleep disturbance in contemporary society. Two populations who experience real-world sleep-related disruption and/or circadian misalignment on a regular basis are shift workers and new parents. Both experience distinct profiles of sleep disruption. In shift workers this is primarily characterised by circadian misalignment, whereas in new parents it is associated with highly unpredictable sleep interruptions. It is vital to examine whether sleep disruption impacts these groups through direct assessment (as opposed to a laboratory based simulation), since the potential consequences can be serious. A new parent has a responsibility to look after a newborn whilst caring for themselves and interacting safely with the outside world. Cognitive impairment while, for instance, driving a car, could be disastrous. Similarly, within the context of shift working, a decline in cognitive function, depending on the occupation, could lead to injury or even death.

Through extensive literature review, presented in Chapter One, it is clear that there are many issues with cognitive assessment of shift workers and new parents, aside from the inappropriate extrapolation of findings from laboratory SD studies. These include selective sampling and a lack of consideration of the potential impact of acute fatigue.

8.2 Research approach

This thesis aimed to address the many inconsistencies and lacunae in previous work by assessing four cognitive domains across shift workers and new parents, using an online assessment platform and a battery of well-established cognitive tasks. The cognitive domains were chosen due to their role in underpinning key behaviours in both the occupational and parenting contexts,

as well as their suspected vulnerability to SD. The online platform was selected to enhance ecological validity, by facilitating direct and rapid access to large samples of these hard to reach groups (relative to simulating the associated profiles of circadian misalignment or sleep disruption), to eliminate the need to disrupt daily routines through requiring laboratory visits and to enable assessment to be completed in a familiar context.

To address the issue of selective sampling observed in existing shift worker studies, three samples of occupationally diverse shift workers were tested across the four cognitive domains (the SW1, SW2 and SW3 cohorts). As reported in Chapters Three, Four, Five and Six, little to no cognitive impairment was observed. This was unexpected given the findings from published sleep deprivation and limited shift working studies. It was suspected that this may have been an effect of the occupational heterogeneity of the cohorts assessed here, relative to the more occupationally restricted cohorts typically reported in the literature. Therefore, a fourth group of shift workers was used to examine one domain (attention) further. Unlike the previous shift working cohorts, the Po cohort consisted of a more occupationally homogenous group of individuals working for the UK police force, and as such aligned more with existing literature. To address the selective sampling issue within existing new parent studies, a sample of new parents containing both mothers and fathers was collected. This was specifically to improve upon the potential bias of exclusively female focused studies.

To minimise the role of acute fatigue, assessment here was conducted on a day off from work (shift workers) and as close to waking as possible (new parents). Through assessing on a day off from work, any cognitive impairment found could be more strongly attributed to the chronic effects of a shift working lifestyle, as opposed to acute fatigue. Similarly, with the new parent cohort, by testing as close to waking as possible, the assessments would likely capture a state of cognition that was not directly influenced by acute mental fatigue.

Overall, it is believed that the measures taken in the research reported in this thesis have successfully addressed these issues, which likely contributed to the marked variability and inconsistent conclusions reported in the existing literature in this area. As such, this thesis sheds new light on the cognitive profile of shift workers and new parents.

8.3 Key outcomes

Previous research indicated that chronic periods of SD led to impairments in the four cognitive domains assessed in this thesis. However, the previous literature focusing on cognitive assessment of shift workers and new parents is relatively small and often variable. This variability may suggest that the magnitude of cognitive impairment is small or that differences in study design lead to differential outcomes.

8.3.1 Shift workers

To examine the precise differences in sleep problems, the BSWSQ was used in the SW1, SW2, SW3 and Po cohorts. No significant differences between self-reported shift types (night, rotating and day) were seen in the SW1 and Po cohorts. This suggests that, when self-reporting retrospectively, the participants in these group show no differences in sleep issues, irrespective of the type of shifts they work. In contrast, the SW2 and SW3 cohort showed a significant difference when responding regarding evening shifts, with rotating participants reporting more sleep issues than day participants. The effect sizes of the significant differences seen were small (0.05) and medium (0.15) respectively. Whilst this finding is in line with much of the current literature regarding shift work, in that the shift workers are experiencing worse sleep than the non- shift workers, the magnitude of the relationship appears weak. Further, it is important to note that no other significant differences were seen in the other work categories. This would suggest that there were no differences between self-reported night shift workers and rotating shift workers when reporting on night shifts and no difference between night, rotating and day shift workers when reporting on rest days.

Despite the outcomes of this questionnaire, it is possible that sleep issue differences do exist between the shift types in all four cohorts. Indeed, without extensive actigraphy and EEG monitoring, it is impossible to draw a firm conclusion. However this outcome suggests that while the sleep problems may exist in shift workers, they are not always noticed, indeed they may have even been overcome in the first few months of experiencing shift work so that they no longer have a conscious impact on these workers. This resilience may explain why some people appear to thrive whilst doing shift work, whilst others are completely debilitated by it. The results reported here indicate that the precise relationship between shift work and retrospectively self-reported sleep issues is more complex than previous work indicates.

Previous work reports evidence of impairment in the domains of attention, response inhibition and visuomotor coordination (Kaliyaperumal, Elango, Alagesan, & Santhanakrishanan, 2017; Titova et al., 2016; Wilson et al., 2019). Working memory, on the other hand, appears more resilient to the circadian misalignment associated with shift work (Kazemi et al., 2018). As detailed in Chapters One, Three – Six, there is debate surrounding the magnitude and indeed presence of these impairments.

Overall, the experiments described in this thesis indicate that shift work appears to have little to no cognitive impact on individuals in conditions where fatigue is minimised. Fatigue is a gradual and cumulative process, associated with disinclination towards effort, that ultimately results in reduced performance efficiency (Grandjean, 1979). However, fatigue can be resolved after a period of rest (Philip et al., 2005).

As described in Chapter Three, no attentional impairments were observed in two groups of occupationally heterogeneous shift workers (the SW1 and SW2 cohorts), nor in a more occupationally homogenous cohort of UK police force staff (Po cohort). Further Bayesian analysis revealed moderate to anecdotal evidence in support of the null hypothesis. This suggests that any attentional decline reported in the literature as a result of shift work can be recovered by a single period of sleep. Due to the disparity between the finding found here and those found in the literature further categorisations and analysis were conducted on the basis of BSWSQ score. Again few significant differences were found, suggesting that when based on sleep issues measured by the BSWSQ, there were no significant differences in attentional performance between shift workers and non-shift workers in these cohorts. This lack of significant difference was not due to the influence of demographic variables, which were also examined.

Similarly, response inhibition appeared to be resistant to the effects of the shift working lifestyle, when fatigue is minimised. This was established through the use of two response inhibition tasks, across a range of shift workers. As presented in Chapter Four, the GNG was used to examine response inhibition in two cohorts of shift workers (the SW1 and SW2 cohorts). Given the inconsistency between findings reported here and that of the existing literature, it was deemed necessary to examine this domain with an alternative task. As discussed in Chapter Four, cognitive tasks such as the GNG and Eriksen flanker are not construct pure, in that they assess different components of response inhibition. The GNG task assesses task-relevant response inhibition, processing speed and sustained attention (Bender et al., 2016; Donders, 1969). The Eriksen flanker task is used to assess information processing, response inhibition and selective attention (Eriksen & Eriksen, 1974). As discussed previously, cognitive tasks are rarely construct pure and different tasks can be used to examine different combinations of components. Whilst the majority of outcome variables showed no significant differences, Bayesian analysis revealed anecdotal evidence in support of the alternative hypothesis in the SW2 cohort in overall correct performance in the GNG task. As discussed above, due to the frequentist statistic being close to significance it is plausible that in a larger sample a difference may have been seen. Although this finding does suggest more cautious conclusions need to be drawn regarding the impact of shift work on response inhibition there was further lack of significant difference seen when participants were regrouped on the basis of BSWSQ score and no correlations seen between outcome variables and BSWSQ score. Taken together, the large lack of significant differences seen across two different tasks and the lack of significant differences when regrouped it is likely these findings are robust and that a shift working lifestyle does not directly lead to an impairment in response inhibition. One explanation for the disparity between the result shown here and much of the literature may be the impact of demographic variables. When examined further, there were some interactions between demographic variables, such as sex and time awake, and

cognitive variables in the GNG task in the SW2 cohort. However, when the factors were controlled for there was no main effect of BSWSQ group. This suggests that while the expected relationships between broad demographics (e.g. age) and task performance were present in the data, the BSWSQ score itself did not have any significant effect on performance. This may provide explanation for the significant differences seen in the literature when samples are extremely occupationally homogeneous. If samples contain a wider variety of job types and shift lengths, as with the presented cohorts, it is possible that the impact of shift work is dampened.

Working memory showed conflicting results with regards to shift work related impairment. Whilst one heterogeneous group of shift workers showed no WM impairment (the SW1 cohort) across any of the assessed parameters, significant differences in overall correct performance were observed in the second group of shift workers (the SW2 cohort). However, these were relatively small in magnitude, given that post hoc analysis was unable to ascertain the direction of this relationship. Similar differences were found in a second variable - reaction times of correct responses - though here post hoc analysis indicated that rotating shift workers were slower than night shift workers and day workers in the SW2 cohort.

The disparity between the two groups of shift workers may indicate that any WM impairment present is extremely small, and as such may only be detectable in larger, and therefore more powerful, samples. Alternatively, this could highlight the inherent variability within two samples of shift workers. Given that these two samples were collected from the same recruitment platform, it is expected that variables such as job type and demographic parameters such as age are likely to be represented fairly equally across the cohorts. Therefore, the divergent results are unexpected, and could indicate that the shift working population as a whole is extremely difficult to study consistently. This supports the argument that findings from studies conducted within a specific group, such as the medical professionals often assessed in the published literature, should not be generalised to the wider shift working population. The disparity between groups is also unlikely to be due to a task insensitivity to impairments caused by sleep disturbances, given that impairments have been seen using this task in sleep deprived individuals (Terán-pérez et al., 2012). However sensitivity analysis did show a lack of correlation between age and overall correct performance. Further, comparisons with the depression literature found accuracy scores were higher in the online version of the task, indicating a possible ceiling effect. Whilst it is important to view these findings in light of the potential lack of sensitivity it is impossible to ignore the significant findings that were found, suggesting that task sensitivity cannot be the sole reason for a lack of findings in most cohorts.

Finally, data collected using the TMT suggests there may be unique visuomotor coordination differences dependant on the type of shift worked that persist even after recovery sleep has

occurred. This impairment is again subtle, given that the findings were not replicated in both shift working cohorts, and were only present in one variable of the TMTA portion of the task (SW2 TMTA completion time). Whilst this disparity may have been due to some of the same reasons noted for working memory, differences in study design between the cohorts may also have contributed here. As explained in Chapter Six, the SW2 cohort received a TMT with clearer instructions and a demonstration video due to the lack of understanding of the task apparent in a large proportion of the SW1 cohort. To examine the robustness of this effect, a replication study is needed, using the SW2 cohort study parameters. In addition, should a replication of the effect be detected, larger groups of each shift type should be collected to allow for more specific categorisations to be assessed. For example, assessing the impact of a forward rotating shift pattern, compared to a backward rotating shift pattern.

It is also important to highlight the additional analysis conducted using BSWSQ score. No significant differences between groups were found in TMTA or TMTB completion time, nor a correlation between BSWSQ score and completion time. Whilst some demographic variables were found to significantly interact with TMTA and TMTB completion time, there was effect of BSWSQ group when these were controlled for. Overall this additional exploration of the data further supports the nuance needed when drawing firm conclusions regarding these sample populations and visuomotor coordination.

Given the frontal dependence of many of the cognitive domains explored here, an effort was made to establish if any meaningful frontal physiological differences were present in shift workers, through the use of frontal EEG (Chapter Seven). Using a basic eyes open/eyes closed protocol, no shift work dependant effects were observed in alpha, delta and theta frequencies, but changes in power were detected in frontal beta and SMR. This is of interest given the association of beta and SMR with deep sleep and active thinking. Here, beta power was higher in shift workers compared to controls, which may suggest that the shift workers were more alert than the controls. Low frontal beta signals have been observed in individuals who are in a drowsy, low alert state (Nguyen et al., 2017), further lending support to this conclusion. Higher SMR power was also seen in the shift workers compared to controls. This suggests that whilst these shift workers may be more alert (due to their higher beta power), they could be slower to react and deliver a behavioural response (because of their higher SMR power).

More broadly, these EEG data imply that there are persistent neural changes, despite the suggestion that cognition/behavioural outputs appear to be maintained in shift workers. This may be evidence of neural level compensation in the brain which enables it to maintain cognitive performance, despite the impact of a shift working lifestyle. However, it is important to caveat this conclusion, since the shift workers who were examined with EEG here did not complete any

of the cognitive assessments. Likewise, those who completed the cognitive assessments reported in Chapters Three – Six did not participate in the EEG study. The combination of both EEG testing and cognitive assessment would provide a clearer picture of any potential physiological changes as a result of the shift working lifestyle. Such simultaneous EEG/cognitive assessment is highly feasible, given that these data were generated using EEG headbands which are considerably easier to work with than full EEG caps and as such could be used easily outside of laboratory settings.

8.3.2 New parents

Existing studies in new parents suggest the presence of attentional impairment in this group (Insana et al., 2013). Unlike shift workers, working memory capacity appears to also be negatively affected (Janes et al, 1999). Response inhibition appears to be resilient to the impacts of new parenthood-related sleep disruption, and visuomotor performance, to the best of our knowledge, remains minimally explored in this group. However, as with the shift working literature, there are significant conflicting findings amongst the existing studies of new parents, as detailed in Chapters One, Three – Six.

The studies presented in this thesis suggest that new parenthood appears to have minimal cognitive impact in conditions of minimal fatigue. For example, no attentional impairments were observed in new parents with moderate and anecdotal Bayesian evidence supporting these findings. This suggests that any attentional decline described in the literature as occurring in new parenthood can be recovered by a single period of sleep. Similarly, response inhibition appeared to be preserved in new parents when fatigue was minimised. Unlike the shift working samples, in the new parent study only one task was used to assess response inhibition. Therefore, it is entirely plausible that impairment would be seen with a different task, for example the Eriksen flanker, given that it assesses response inhibition differently. This again highlights the need for assessments using an extensive cognitive battery that makes use of overlapping tasks that assess different aspects of the same overall cognitive domain. Working memory also showed no impairment in the NP cohort when examined using frequentist statistics. However there was moderate support for the alternative hypothesis in overall correct performance, indicating that with a larger sample a significant difference may have been seen. As discussed in Chapter 5, this highlights the complexity of the relationship between new parenthood and working memory and warrants further exploration. Finally, data from the TMTA showed no significant differences in visuomotor coordination in new parents. Whilst TMTB did reveal significant differences, post hoc analysis was unable to ascertain the direction of this relationship. This suggests that, whilst there may be an impairment in visuomotor coordination due to the varied sleep schedule associated with new parenthood, it is not very large. Though, given the minimisation of fatigue in this

sample, this mild impairment in visuospatial coordination may indicate this effect is persistent, even with recovery sleep.

These minimal findings are consistent with Workman et al (2011) who conducted a review of the current research examining cognition across pregnancy and the postpartum period. They suggested that whilst deficits in specific cognitive domains may exist during these periods, the effects are subtle and are likely influenced by multiple factors, including the type of memory system being utilised, how and where memory is tested, the sex of the foetus and the gravidae status of the women (Workman, Barha, & Galea, 2011).

As described previously, mothers lose more night-time sleep than fathers following the birth of a child (Gay, Lee, & Lee, 2004). Many of the cognitive domains tested here have previously shown a sex dependent effect. This includes visuospatial coordination, with males performing worse on a TMTA, though not on a TMTB (Munro et al., 2013), working memory, with higher accuracy and marginally slower reaction times observed in females, compared to males, when assessed using a verbal working memory task battery (Speck et al., 2000) and attention, with significantly slower reaction times reported in females than males, on a PVT task, independent of age (Blatter et al., 2006).

Given the profound hormonal, biological and physical changes experienced by females throughout pregnancy, birth and the postpartum period, it seems reasonable to expect that such sex differences would also be observed, and perhaps magnified, between new mothers and fathers. Yet, in all four cognitive domains, an apparent lack of any sex dependant effects was observed here. The lack of differences between mothers and fathers may represent a protective effect as a result of becoming a parent, in that, evolutionarily, after the birth of a child, both parents would work to keep their offspring from any danger in order to progress their genetic line and protect the considerable investment of time, energy and resources made during gestation and early life. In order to do this, normal cognitive functioning is required. As such, despite the increase in sleep disturbances associated with a newborn, it is possible that finite cognitive resources are allocated differently in order to maintain normal functioning in new parents. There is evidence from both human and non-human animal studies that suggests enhanced cognition in the post-natal period results in lasting cognitive advantage in areas that would promote maternal or foetal fitness, for example face and emotion processing (Anderson & Rutherford, 2012). Indeed, Anderson and Rutherford suggest that rather than being seen as cognitive deficit, any cognitive decline in a certain domain in new parents should be seen as 'cognitive reorganisation' – essentially the mother is prioritising cognitive functioning that aids the survival of her offspring. As the child gets older, a sleep pattern more similar to the parents' is formed, and as such, parents are able to return to their pre-child sleep and cognitive resource allocation. Further, with

increased age, comes an increase in independence of the child, meaning less parental protection is needed.

The lack of differences between control males and females observed here was somewhat unexpected, given the existing cognitive assessment/sex difference literature, though this could be due to the small sample size of control females. A small sample size is likely to provide low statistical power, meaning any differences present are unlikely to be detected. A large, more evenly sex balanced sample of new parents and controls would help address this issue.

8.4 Perspectives on research outcomes for shift workers and new parents

Given the findings described in this thesis, it appears that in the context of minimal fatigue shift workers do not have attentional or response inhibition impairments. The impact on working memory and visuomotor coordination requires more nuanced interpretation: there is evidence for a minimal impairment, albeit not replicated in both groups of shift workers tested. With regards to new parents, these individuals seem to be relatively resilient to cognitive impairment associated with disturbed sleep. This may have an evolutionary basis given that a failure in any one of these cognitive domains could result in the death of young offspring. A plausible interpretation of the present findings is that the impairments seen in the existing literature may be confounded by fatigue. Comparatively, in conditions where efforts have been made to minimise this variable (as applied in this thesis), little to no cognitive impairment is seen as a result of either circadian misalignment (shift workers) or disturbed sleep (new parents).

However, as with most cognitive tasks, none of the tests used here are construct pure, meaning no task isolates and measures just one area of cognition. Therefore, whilst conclusions have been drawn regarding four areas of cognition, the tests used may be representing other cognitive impairments/resilience. For example, whilst the GNG task was used here to examine response inhibition, it also examines processing speed and sustained attention. As no impairments in shift workers were seen using GNG, this supports the findings of no sustained attention impairment in shift workers, assessed using a PVT task. As a result of this, a conclusion that can be drawn from the findings is that not only are they robust, in that multiple domains of cognition have been assessed through the use of multiple cognitive tasks, but that a varied cognitive assessment battery, that makes use of distinct tasks with dependencies on overlapping cognitive elements, is key to exploring and unveiling cognitive impairments in any given population. Furthermore, if a large impairment in a cognitive element such as sustained attention was present it would be expected to be seen across multiple cognitive tasks. As this was not observed in any of the reported findings here, it is unlikely that any cognitive effects were present.

The lack of findings of an impairment in either shift workers or new parents is unlikely to be a result of a lack of task sensitivity. Multiple tasks which have been previously well-characterised and widely used in a variety of cohorts and conditions were used to assess a range of cognitive domains in these populations. Therefore, it is improbable that all five tasks have a lack of sensitivity. The tasks used here were also selected based on previous studies showing their sensitivity to the impact of sleep deprivation. Further, as described in the sensitivity sections in each chapter (Sections 3.4.5, 4.4.1.5, 4.4.2, 6.5.4.5 and 6.4.3) comparisons with the literature, analysis of key demographic variables known to correlate with cognitive outcome measures and within task analysis have shown these tasks to be sensitive enough to detect impairments.

8.5 Perspectives on the use of online cognitive testing

Shift workers proved to be a difficult to reach group of participants. Initial efforts at recruitment for this thesis made use of direct written and verbal communication to a number of UK based companies, however this proved unsuccessful. Further, due to the general assumption that shift work causes detrimental effects to health and cognition, few companies are willing to give access to their workers. In addition, unlike with disease related participant groups, there are few support groups that enable convenient access to large groups of shift workers outside the workplace context. With hindsight, such workplace based recruitment may have ultimately been a significant limitation, given the apparent high variability within the shift working populations, such that if assessment has occurred in just one company, and therefore one occupation, this would have limited the generalisability of results.

With regards to new parents, this group also appeared to be difficult to reach. Recruitment adverts were delivered to multiple antenatal groups as well as contact made with the National Childbirth Trust, however again this was unsuccessful. The addition of a newborn to any family is a life changing event and requires significant resources, including mental, physical, financial and time. This therefore impacts parents' willingness to commit to a study. Further difficulties arose as a result of the study design, requiring testing to occur as close to waking as possible, which may have made a face-to-face laboratory assessment visit particularly unpalatable.

Here, efforts to minimise fatigue through testing on a day off from work and as close to waking as possible meant that in-person testing would have most likely had to be conducted in the participant's home. This proved to be another barrier to in-person testing. Therefore, given the initial considerable difficulty experienced in reaching the target populations assessed in this thesis, online cognitive testing was deemed to be the most appropriate form of assessment.

This thesis adds to the growing body of literature using online cognitive testing, particularly in otherwise hard to access populations. This approach is likely to become increasingly common,

with the continuing expansion of online connectivity across the globe. Its utility has been further highlighted in the current COVID-19 pandemic, with in person testing no longer as feasible. While this approach is proving to be effective in many respects, online cognitive testing has a unique set of advantages and disadvantages compared to more traditional laboratory based testing, many of which have been observed directly during the completion of this thesis.

Firstly, using recruitment platforms such as Prolific enables the collection of data from a large, geographically diverse population, something which can be difficult if traditional routes of contact and recruitment are used. In the case of this thesis, significant, but unsuccessful, efforts were made to recruit shift workers directly through the place of work and conduct in person assessment on a day off. Similarly unsuccessful attempts were made to recruit new parents through antenatal centres.

By using online recruitment and cognitive testing, a more representative sample of both shift workers and new parents was collected. It was possible to capture a range of job types, ages and experiences, and therefore results are more generalisable. If testing and recruitment had occurred through a small number of workplaces or antenatal centres this sample would potentially have been a lot more demographically homogenous. A related advantage of using a recruitment pool such as Prolific is that general demographics of all currently active (within the last 3 months) individuals are calculated. At the time of writing (July 2020), Prolific stated that 33.2% of their sample consisted of individuals with an undergraduate degree and just 0.86% with no formal qualifications. Further, 42.93% were in full time employment compared to 16.95% unemployed. This arguably suggests that this sample is predominantly biased toward high socioeconomic status (SES). This needs to be taken into account when discussing the global applicability of findings. Although, it is important to caveat this assumption with the fact that no questionnaire was given to participants to directly ascertain their SES in this thesis. Whilst education level, computer accessibility and employment can be indicators of high SES, there are multiple reasons why this may be deceptive. For example, whilst computer access is needed to complete these online cognitive assessments, libraries often offer free access, therefore not requiring an individual to be in ownership of a computer. Further, whilst employment is associated with earning an income (which improves SES), many individuals receive less than a living wage (in 2019, 16.2% of jobs were low paid, with 425,000 paid below the national minimum wage and national living wage, in the UK) (Office for National Statistics, 2019). Nevertheless, the reporting of this data enables informed decisions to be made regarding whether the platform is suitable for particular research projects. For example, if a range of SES was a major requirement for a study, Prolific may not be the most appropriate platform to use.

This method of recruitment also allowed for an extremely fast rate of recruitment. Data for the SW1, SW2, SW3 and NP cohorts was collected in a matter of days (predominantly in less than 24 hours). This enabled sample size targets to be met with ease. In comparison, the recruitment technique used for the Po sample resulted in recruitment efforts extended over 3 months with a yield of only 62 participants, 16 of whom had to be excluded. Whilst it is believed that a larger Po sample could have been collected if more time was available, the speed of data collection available through recruitment platforms such as Prolific has a clear advantage over more traditional methods.

An advantage of using a computerised task platform such as Gorilla is that it provides simple online consent collection, secure data collection/storage and automated collection of performance metrics. Specifically relating to Gorilla, whilst researchers have to pay to perform studies online, it is possible to create and share studies for free. Sharing tasks with others facilitates open scientific practices. As more researchers use a common task platform, it becomes standardised, making it easier to harmonise protocols and compare data. The ability to directly compare data derived from independent groups would be of particular value in the shift work and new parent cognitive assessment areas, given the wide variety of study designs, tasks and outcome measures reported in the existing literature. Further, Gorilla does not require any coding knowledge to build complex computerised cognitive tasks. This, alongside its extensive technical support, makes the platform accessible to a wide range of researchers across disciplines. Finally, it is important to note that Gorilla can be used in person as well as online. This diversity in terms of testing application makes the platform even more valuable for use in cognitive assessment.

Despite the clear advantages of this method of testing, there are important criticisms to take into account. Most important is the lack of control. With laboratory testing there is often an examiner present who ensures that the task is delivered in the same conditions regardless of participant. This includes maintaining a quiet testing environment, removing any distractions (particularly vital for attention based tasks) and ensuring participants complete the experiment in its entirety. Consistency is also maintained in respect of the assessment device used (important for visual acuity), response apparatus (important for latency measures) and positioning in relation to the testing set-up.

However, online cognitive testing takes place outside of this controlled environment, often, but not always, in the participants own home, without the presence of a researcher. Strategies that can be employed to help maximise consistency between participants include clear instructions as to when testing should occur, in this case on a day off/as close to waking as possible. Though it was not possible in this thesis to fully assess participants' compliance with instructions, attempts were made to minimise falsified activity by checking questionnaire responses for inconsistent

answers that may have indicated that a person was not on a day off. This included a question within the demographic questionnaire asking 'Is today your first day off?' as well as questions asking about their current shift rotation (see appendix for full list of questions asked).

As described above, an issue with online cognitive testing is the variety of assessment devices, physical position of the participant relative to the assessment device and screen sizes used. Gorilla allows restrictions to be put in place regarding the type of device (computer, phone and tablet) used and all testing presented in this thesis was restricted to a computer. However, computer screen sizes and display resolutions can differ drastically, and this could not be controlled for here. Gorilla is currently beta testing screen calibration in order to overcome this (Gorilla, 2020). This function asks participants to hold up a credit card to the screen and then resize an onscreen credit card to match. It also asks participants to input their distance from the screen. This allows stimuli to be consistently presented across devices. Whilst this is currently in beta testing, these efforts to increasingly standardise remote testing are encouraging.

Further, it is possible, as with all online testing through a recruitment platform, that because participants were working unobserved for a monetary reward they were trying to maximise their efficiency by working through assessments as fast as possible, and therefore were not properly engaging. To mitigate this, and detect participants using this strategy, attention checks were employed throughout the questionnaires, and participants were forced to answer all questions before being allowed to continue, following data collection from the first cohort (SW1). This included the addition of questions that required specific answers e.g. 'It is important we know you are paying attention. Please answer never for this question'. Evidence of the efficacy of these mitigations was derived from comparison of completion rates between SW1 and the other cohorts. Improvements in participant retention and completion were seen in SW2, SW3 and NP, compared to SW1. Beyond these measures, as described in the data chapters, strict exclusion criteria were put in place. For high event rate tasks, signal detection theory was used, where participants were removed if their response profile indicated that they were responding to every trial, regardless of the stimulus presented, or were letting the task run without any engagement.

After data collection from the SW1 cohort, instructions were also made clearer for the GNG, N-back and TMT tasks (as described in Chapters Four-Six), and an instructional task demonstration video was added to the TMT. Further instructions were also given concerning the time at which participants should be completing the study (on a day off from work/close to waking). Whilst these changes did result in an improvement in uptake and retention, due to the online study design, it is not possible to completely rule out any potential effects from this lack of control. These effects may have included participants engaging on a working day or, for new parents, engaging at a more convenient time than immediately after waking, therefore increasing the

potential contribution of acute fatigue to performance, slow responding due to participants' distance from testing apparatus, or erratic response profiles if participants did not remain focused throughout the study.

Finally, the use of the online recruitment platform Prolific contributed to a lack of control regarding cohort demographics. Whilst it is possible to recruit based on a range of exclusion criteria inputted into the Prolific platform, these criteria are generic as Prolific serves many different research areas. As such, factors that might be key to particular studies (i.e. occupation type in the SW study here) cannot always be specified. As noted previously, job role has been shown to impact cognition, with machine-based workers performing faster but with more errors on a TMT than those working non-machine-based roles (Proctor et al., 1996). Unfortunately, there were no suitable exclusion criteria regarding job role available in Prolific at the time the studies reported here were completed. Following data collection from the SW1 cohort, a question regarding participant occupation was added to all subsequent cohorts. Due to the size of these samples, meaningful categorisation of this variable was not possible, however in a larger sample this could be isolated as a potential influencing factor.

The Po sample, consisting of those working within the UK police force, was an attempt to address this occupation heterogeneity, given that many shift worker studies reported in the literature evaluate highly occupationally restricted cohorts. However, no marked attentional impairments were observed in this cohort. This may indicate that, specifically concerning attention measured with a PVT, occupation may not play as important a role in the effects of shift work on cognition as previously assumed. Though, the generalisability of this finding comes with its own restrictions in that only attention was assessed in this cohort. Therefore, no assumptions can be made regarding other cognitive domains. Further, whilst this cohort was undoubtedly more occupationally homogenous than previous cohorts (SW1, SW2 and SW3), it still contained a variety of job roles, including but not limited to, police officers, emergency handlers and IT staff. It is possible that even this level of occupational variety is too much to unmask any clear cognitive impairment in shift working cohorts.

Overall, online remote cognitive assessment appears to be becoming increasingly common. Whilst this has clear advantages, there remains the need for further comparison of the results of online and in-person cognitive assessment in a range of populations. This is to ensure that factors such as the relatively greater lack of control in the online approach are not negatively impacting findings, leading potentially to incorrect conclusions being drawn.

8.6 Limitations and Future directions

While the data collected for this thesis provides some useful insights, it is imperative, as with all studies, to consider some of the limitations, outstanding questions and future directions.

Building on the earlier discussion of the issues associated with remote online assessment, it is important to consider the influence of external factors when examining the conclusions drawn here. There are several demographic variables which have been shown to impact cognition, which were not controlled for in these studies. For example, there is debate around the influence of sex on cognitive functioning. Attention has been suggested to be vulnerable to sex effects with females responding significantly more slowly than males on a PVT (Blatter et al., 2006). Response inhibition has also shown sex dependant impairment with males suggested to be more vulnerable to impairment in inhibitory control and have higher levels of impulsivity (Li et al., 2006; Petry et al., 2002). Further sex related differences have been seen in visuospatial coordination, however only within the context of 67-89 year olds. Munro et al (2013) found women performed better than men on TMTA, with no differences between men and women in TMTB (Munro et al., 2013).

Whilst this was not a factor controlled for in the shift working populations, this information was gathered. However, due to cohort size and uncontrolled data collection resulting in different sex balances across tasks and cohort, no useful sex analysis was possible. On the other hand, the new parent cohort was split on the basis of sex. No clear sex effects were present in any of the four cognitive domains tested. However, the rationale for categorising on the basis of sex within the new parent sample was based upon the hormonal and physical differences in new mothers compared to new fathers. This arguably suggests that the findings cannot be applied to females not undergoing these changes. Further, whilst a control group consisting of both male and female individuals who did not have a newborn child was used in this cohort, and also appeared to show no effect of sex, the control female sample size was extremely small and as such likely to provide low statistical power.

Another factor known to influence cognition is age. Sustained attention is known to be less stable in children compared to adults (Tao et al., 2017). However, there is a lack of empirical evidence regarding the length of sustained attention across a range of adult ages (Wilson & Korn, 2007). A large majority of the tasks given to the cohorts required at least 5-10 minutes of sustained attention, and therefore, if this construct is vulnerable to increasing age, this is likely to have impacted results. Visuospatial coordination has also shown age related differences with TMT performance decreasing with increasing age (Davies, 1968). Similarly, assessments of memory, and specifically working memory, have shown a decline in performance with increasing age (Salthouse, 2015; Salthouse & Babcock, 1991). In particular, Dobbs and Rule (1989) found significant working memory declines between the ages of 60-69 and 70+ (Dobbs & Rule, 1989).

The shift working age range in the data presented here was appropriate given the average working age is 18-65. However, no categorisations within the shift working groups were made to account for any confounding impact of age-related cognitive decline. With regards to the new parents, as discussed above, most declines in performance relating to age appear to be present in non-child bearing years (i.e. 50+). Given that the average age of menopause in women in the UK is 51 (NHS, 2018) and therefore pregnancy is no longer viable, in this population, age is unlikely to be a confounding factor.

Socioeconomic status (SES) has also been linked to impaired cognition. SES is 'the social standing or class of an individual or group. It is often measured as a combination of education, income and occupation' (American Psychological Association, n.d.). Tombaugh (2004) observed that participant education influenced TMT performance, with lower levels of education associated with poorer TMT performance (Tombaugh, 2004). On the other hand, working memory in children aged 6-7 years old appears to be impervious to differences in socioeconomic background, with no differences found between a group of low SES and a group of higher SES (Engel, Santos, & Gathercole, 2008). The data presented in this thesis was predominantly collected online, meaning participants had to have access to a computer with internet access. This will have undoubtedly narrowed the SES of the samples. However, as information was not gathered regarding education levels and income, it is not possible to determine how narrow the samples were. As mentioned previously, Prolific does provide information regarding the demographic profile of all active users in the last three months. Whilst this can provide some indication as to the SES profile of the samples, this is based on all current users, and as such it is possible the cohorts collected for this thesis over the last several years do not match the current active user profile.

In order to address these demographic related limitations, future efforts should be made to collect a large data set from a wide range of ages and SES and both sexes and fully isolate each of these factors to determine their precise influence on cognition within these populations.

Time of testing was a key contributor to the novelty of this project, in that testing occurred at a time when fatigue was minimal (on a day off/immediately after waking). As described previously, fatigue is linked to impairments in cognition (Boksem et al., 2005; Guo et al., 2018; Jain & Nataraja, 2019; Kato et al., 2009). In order to minimise levels of fatigue, sleep and rest are necessary. One form of sleep that has shown to be beneficial in those experiencing sleep disruption is napping. Whilst the impact of napping was not examined in this thesis there is evidence to suggest napping could be a 'powerful public health tool' when used to counteract negative consequences of sleep debt (Faraut, Andrillon, Vecchierini, & Leger, 2017). Specifically, naps have been shown to benefit cognitive performance, stress and immune systems as well as improve mood and mental states (Faraut et al., 2017; Kaida, Takahashi, & Otsuka, 2007; Luo &

Inoué, 2000). Further, Milner and Cote (2009) found short sleep periods of approximately 10-15 minutes can restore cognitive impairments that have developed over a longer period of wakefulness (typically more than 16 hours) (Milner & Cote, 2009). Napping benefits have also been seen within the shift working population, with Zion and Shochat (2019) examining the benefit of scheduled naps in 109 female nurses. Tested over four night shifts (two with a scheduled nap, two without), they found lower levels of sleepiness and modestly improved cognitive performance (assessed using a digit symbol substitution task and a letter cancellation task) in the nap condition, compared to the no nap condition (Zion & Shochat, 2019). Future studies should be conducted using a protocol which allows participants to nap to help further assess its benefit and practicality for use within these specific populations.

Yet, the question remains what the precise levels of fatigue within the individuals assessed in this thesis were. Future projects should aim to utilise a fatigue questionnaire to directly confirm the minimisation of fatigue. Further, it is unknown if the protective/restorative effect of sleep persists throughout the day. For example, if participants did complete the task when asked, it is unknown if cognition was captured before fatigue set in. If testing had occurred a few hours later would the protective properties of sleep have worn off and cognitive impairment be present. By testing participants over the course of multiple days a full cognitive profile could be established, shedding light on this outstanding question. Relating specifically to shift workers, including testing sessions before and after a shift, as well as following recovery sleep, would further contribute to this field.

Finally, future studies should be conducted on groups of highly occupationally restricted populations, both online and in person to examine how consistent the data produced is. Furthermore, this would help address the question as to whether studies exploring the impact of shift work need to be occupationally homogenous or if the findings can be generalised.

Power analysis is an important part of the planning process of any cognitive assessment in order to ascertain the exact sample size needed however this was not done for the experiments reported in this study. This was due to a lack of appropriate literature featuring a low fatigue context on which to base power analysis. It is not recommended for power analysis to be completed post hoc (Zhang et al., 2019), therefore it remains unknown whether the cohorts used here were large enough to detect a significant difference. Future work should utilise power calculations before data collection to avoid this limitation. However efforts were made in the present study to examine the impact of the findings and to establish if the null findings found using frequentist statistics were due to a lack of power. Bayesian analysis allows for further examination of the findings based on the probability. Indeed, the data presented here was largely supported by Bayesian analysis with anecdotal to strong support for the null hypothesis in the large majority of cognitive outcomes. Effects sizes can also be a useful indicator for the magnitude

of a relationship. A large effect size on a non-significant result may indicate the sample is not large enough to say it is significant. However small effect sizes were seen in a large majority of the null findings, suggesting that in these cohorts, tested using online methodologies, there were limited effects of shift work and new parenthood, in the context of minimal fatigue.

In conclusion, there appear to be minimal effects of shift work across four widely assessed domains of cognition, in the context of minimised fatigue, even when grouped based on BSWSQ score. EEG analysis revealed apparent physiological changes in shift workers that may be representative of compensatory mechanisms being engaged to maintain cognitive performance. Similarly, there appear to be no cognitive impairments resulting from the sleep disruption associated with new parenthood, in the context of minimised fatigue. There are also no sex differences apparent between new parents in these conditions. Taken together, this suggests that the cognitive impairments observed previously in these groups may be primarily driven by acute fatigue which can be alleviated, at least transiently, by a single period of sleep. However, further analysis using Bayesian approaches has suggested the presence of some effects in these populations. These observations warrant further exploration in future studies.

This appendix contains:

- A.1 Recruitment adverts
- A.2 Information sheets
- A.3 Consent forms
- A.4 Debrief forms
- A.5 Bergen Shift Work Questionnaire
- A.6 MEQ and rMEQ
- A.7 Pittsburgh Sleep Quality Index and scoring guide
- A.8 Demographic questionnaire
- A.9 Caffeine questionnaire
- A.10 Task Instructions

A.1 Recruitment adverts

Detailed in this section are:

- Figure 66 SW1 recruitment advert
- Figure 67 SW2 recruitment advert for shift workers
- Figure 68 SW2 recruitment advert for non-shift workers
- Figure 69 SW3 recruitment advert for night shift workers
- Figure 70 SW3 recruitment advert for rotating shift workers
- Figure 71 SW3 recruitment advert for non-shift workers
- Figure 72 NP recruitment advert
- Figure 73 Po recruitment advert
- Figure 74 EEG control advert

Are you a shift worker?

Hosted by *Emily Breese*

£2.50 • 30 minutes • £5.00/hr • 200 places remaining



This study should be completed by individuals who are currently working shifts that are outside a 9-5 work schedule.

The study should be completed on a day off from work.

In this study you will be asked to complete two cognitive tasks (similar to computer games) and a short survey of recent shift activity and sleep patterns.

This study should take no longer than half an hour to complete.

When you first click the link you will be asked to enter a 'Public ID'. This can be anything you choose (e.g. name of pet, date of birth, street name) except for your full name.

Please note this should be completed on a computer (laptop or desktop) NOT a mobile device as these tests will not work effectively.

If you have any questions please contact emily.breese@open.ac.uk

Research approved by The Open University Human Research Ethics Committee – approval number HREC/2017/2549/Breese/1, HREC/2017/2535/Breese/1, HREC/2016/2444/Breese/2

[Open study link in a new window](#)

Figure 66 SW1 Recruitment advert

Cognitive impact of shift work

Hosted by *Emily Breese*

£2.50 • 30 minutes • £5.00/hr • 198 places remaining



This study should be completed by individuals who are currently working shifts that are outside a 9-5 work schedule. Please note we are only looking for those working **rotating or night shifts**. Rotating shifts should include at least one shift during night hours. Please note that individuals working day shifts exclusively will **not be paid**.

The study should be completed on a day off from work. Please note you will **not be paid if you are not currently on a day off from work**.

In this study you will be asked to complete two cognitive tasks (similar to computer games) and a short survey of recent shift activity and sleep patterns.

This study should take no longer than half an hour to complete.

When you first click the link you will be asked to enter a 'Public ID'. Please enter your Prolific unique ID code.

Please note that this study should be completed on a computer (laptop or desktop) and NOT a mobile device to ensure the cognitive tests are presented in a consistent format.

If you have any questions please contact emily.breese@open.ac.uk

Research approved by The Open University Human Research Ethics Committee – approval number HREC/2017/2549/Breese/1, HREC/2017/2535/Breese/1, HREC/2016/2444/Breese/2

Figure 67 SW2 shift workers recruitment advert

Cognitive impact of work

Hosted by *Emily Breese*

£2.50 • 30 minutes • £5.00/hr • 95 places remaining



This study should be completed by individuals who are currently working a 9-5 work schedule. Please note we are only looking for those working **days**. Please note that individuals not working days exclusively will **not be paid**.

The study should be completed on a day off from work. Please note you will **not be paid if you are not currently on a day off from work**.

In this study you will be asked to complete two cognitive tasks (similar to computer games) and a short survey of recent shift activity and sleep patterns.

This study should take no longer than half an hour to complete.

When you first click the link you will be asked to enter a 'Public ID'. Please enter your Prolific unique ID code.

Please note that this study should be completed on a computer (laptop or desktop) and **NOT** a mobile device to ensure the cognitive tests are presented in a consistent format.

If you have any questions please contact emily.breese@open.ac.uk

Research approved by The Open University Human Research Ethics Committee – approval number HREC/2017/2549/Breese/1, HREC/2017/2535/Breese/1, HREC/2016/2444/Breese/2

Figure 68 SW2 non-shift workers recruitment advert

The cognitive impact of night shift work.

Hosted by *Emily Breese*

£3.93 • 47 minutes • £5.01/hr • 8 places remaining



This study should be completed by individuals who are **currently** working **NIGHT** shifts (shifts beginning after 8pm and ending after midnight). Please note we are only looking for those working exclusively **night shifts**. Please note that individuals working day shifts exclusively or rotating shifts will **not be paid**.

The study should be completed on a day off from work. Please note you will **not be paid if you are not currently on a day off from work**.

In this study you will be asked to complete two cognitive tasks (similar to computer games) and a short survey of recent shift activity and sleep patterns.

This study should take no longer than 47 minutes to complete.

When you first click the link you will be asked to enter a 'Public ID'. Please enter your Prolific unique ID code.

Please note that this study should be completed on a computer (laptop or desktop) and NOT a mobile device to ensure the cognitive tests are presented in a consistent format.

If you have any questions please contact emily.breese@open.ac.uk

Research approved by The Open University Human Research Ethics Committee – approval number HREC/2017/2549/Breese/1, HREC/2017/2535/Breese/1, HREC/2016/2444/Breese/2

Figure 69 SW3 Night shift workers recruitment advert

The cognitive impact of rotating shift work.

Hosted by *Emily Breese*

£3.93 • 47 minutes • £5.01/hr • 35 places remaining



This study should be completed by individuals who are **currently** working **ROTATING** shifts (shifts rotating through at least two shift times). Rotating shifts should include at least one shift during night hours. Please note that individuals working day shifts or night shifts exclusively will **not be paid**.

The study should be completed on a day off from work. Please note you will **not be paid if you are not currently on a day off from work**.

In this study you will be asked to complete two cognitive tasks (similar to computer games) and a short survey of recent shift activity and sleep patterns.

This study should take no longer than 47 minutes to complete.

When you first click the link you will be asked to enter a 'Public ID'. Please enter your Prolific unique ID code.

Please note that this study should be completed on a computer (laptop or desktop) and NOT a mobile device to ensure the cognitive tests are presented in a consistent format.

If you have any questions please contact emily.breese@open.ac.uk

Research approved by The Open University Human Research Ethics Committee – approval number HREC/2017/2549/Breese/1, HREC/2017/2535/Breese/1, HREC/2016/2444/Breese/2

Figure 70 SW3 Rotating shift workers recruitment advert

Cognitive impact of work

Hosted by *Emily Breese*

£3.34 • 40 minutes • £5.01/hr • 83 places remaining



This study should be completed by individuals who are **currently** working a 9-5 work schedule. Please note we are only looking for those working **days**. Please note that individuals not working days exclusively will **not be paid**.

The study should be completed on a day off from work. Please note you will **not be paid if you are not currently on a day off from work**.

In this study you will be asked to complete two cognitive tasks (similar to computer games) and a short survey of recent shift activity and sleep patterns.

This study should take no longer than 40 minutes to complete.

When you first click the link you will be asked to enter a 'Public ID'. Please enter your Prolific unique ID code.

Please note that this study should be completed on a computer (laptop or desktop) and **NOT** a mobile device to ensure the cognitive tests are presented in a consistent format.

If you have any questions please contact emily.breese@open.ac.uk

Research approved by The Open University Human Research Ethics Committee – approval number HREC/2017/2549/Breese/1, HREC/2017/2535/Breese/1, HREC/2016/2444/Breese/2

Figure 71 SW3 Non-shift workers recruitment advert

Impact on cognition of being a new parent

Hosted by *Emily Breese*

£2.50 • 30 minutes • £5.00/hr • 198 places remaining



This study should be completed by individuals with at least one child/children who is/are aged 12 months or less.

Please note individuals whose children are all older than 12 months will **not be paid**.

In this study you will be asked to complete two cognitive tasks (similar to computer games) and a short survey of recent activity and sleep patterns.

This study should take no longer than half an hour to complete.

When you first click the link you will be asked to enter your Prolific ID.

Please note that this study should be completed on a computer (laptop or desktop) and **NOT** on a mobile device to ensure that the cognitive tests are presented in a consistent format.

You must be **18 years old or over** to participate.

If you have any questions please contact emily.breese@open.ac.uk

Research approved by The Open University Human Research Ethics Committee – approval number HREC/2017/2549/Breese/1, HREC/2017/2535/Breese/1, HREC/2016/2444/Breese/2

Figure 72 NP recruitment advert



Workers wanted to participate in a psychology study

- The Open University is currently running a research study into how shift working can affect the brain
- We are looking for:
 - Shift workers
 - Non-Shift workers
 - Men and women
 - 18+
 - All ranks and job roles
- Volunteers will be asked to complete a brief computer game and a short survey of recent work and sleep patterns on a day off from work
- Participation should take no longer than half an hour
- If you are interested in this study please follow this link <https://research.sc/participant/login/dynamic/3125C455-EAD8-4DA8-BFB4-075E3A171FDA> or contact emily.breese@open.ac.uk
- When you first click the link, you will be asked to enter a "Public ID". This can be anything you choose except your full name and should be memorable to you (e.g. name of a pet or a street name). If your chosen ID has already been entered by someone else, please select another.
- This study should be completed on a computer NOT a mobile device
- Participants have the option to be entered into a prize draw for one of ten £30 Amazon vouchers

For more information contact: emily.breese@open.ac.uk

Research approved by The Open University Human Research Ethics Committee – approval number HREC/2017/2549/Breese/1, HREC/2017/2535/Breese/1, HREC/2016/2444/Breese/2

Figure 73 Po recruitment advert



Male non-shift workers wanted to participate in an EEG study



- The Open University and Sheffield Hallam University are currently running a research study into how shift working can affect the brain
- We are currently recruiting for a control group
- We are looking for:
 - Male non-shift workers
 - 18+
- Volunteers will be asked to complete a short survey of recent working and sleep patterns and sit for 10 minutes wearing a Muse headband
- Testing will occur on two Wednesdays, within the first hour of your working day
- Participation should take no longer than half an hour for each testing session
- Participants will be reimbursed for their time with a £5 Amazon voucher
- If you are interested in this study please contact emily.breese@open.ac.uk

For more information contact: emily.breese@open.ac.uk

Research approved by The Open University Human Research Ethics Committee – approval number HREC/2669/Breese



Figure 74 EEG Control recruitment advert

A.2 Information sheets

Detailed in this section are:

- Figure 75 SW1 Information sheet
- Figure 76 Information sheet used for the SW2 and SW3 cohorts
- Figure 77 NP Information sheet
- Figure 78 Po Information sheet
- Figure 79 EEG Information sheet for shift workers
- Figure 80 EEG Information sheet for non-shift workers

Please enter your Prolific ID here

Information Sheet

Quantifying the effects of circadian rhythm disruption on cognition

Circadian rhythm is a natural mechanism that regulates sleepiness and wakefulness in a 24 hour cycle. This rhythm causes a series of daily fluctuations in a variety of physical and mental processes that are tightly regulated by the predictable changes in natural light levels. Regular sleeping habits (i.e. sleeping and waking at similar times each day) that closely match natural light changes (i.e. sleeping during the hours of darkness and waking during the early hours of daylight) are important for an optimal circadian rhythm. Therefore, common activities such as staying up later at the weekend or flying across different time zones (causing jet lag) which desynchronise the relationship between light levels and sleep/wake timings can have effects on this system. Shift working, in which people are often required to be awake during the hours of darkness and asleep in the hours of daylight for a number of consecutive days, can also have effects on this mechanism.

Aim of the project

It has been suggested that prolonged shift work patterns can have effects on cognition due to their impact on the circadian rhythm. The way this occurs and the areas of cognition that are affected are poorly understood. This project intends to explore a number of areas of cognition believed to be affected by shift work to determine how impairing any changes in performance are.

The type of data to be collected and method

We will be collecting data regarding several aspects of cognition through a series of computerised cognitive assessments administered via a website accessed using a computer. You will be required to view a series of stimuli that will be presented on the screen and respond to them using a typical computer input gesture such as a button press, mouse/track pad click or touchscreen press. Stimuli have been selected that will not provoke fear, anxiety or stress. The pace of the assessments will be controlled by you and each is of short duration such that participation should not have any major impact on the timings of your work routine. Each assessment will begin with a series of written instructions which you should read before initiating the evaluation. Data on your performance will be collected by the computer and saved for analysis by the research team. The research team will also collect basic information regarding your recent sleep and shift patterns. This will be done via a small number of simple multiple choice questions. Please note that as this study requires you to view a computer screen you should not take part if you have photosensitive epilepsy or are unable to view a computer screen for a sustained period of time due to eye strain or other visual impairments.

Confidentiality

Your participation will be treated in strict confidence in accordance with the Data Protection Act. All data will be stored on an OU server within the OU network for security for 5 years and securely disposed of after this period. The data will be anonymous and can only be identified using the unique ID code generated by you at the beginning of the session. If you wish to withdraw from the study you may do so at any time up until the point of data analysis without any adverse effect. You do not have to provide an explanation for your decision.

Contact Details

Principal Investigator: Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; emily.breese@open.ac.uk Researcher's primary supervisor: Dr Christopher Heath, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; christopher.heath@open.ac.uk

If you wish to receive a copy of the summary project report detailing the outcomes of this work and did not provide your email address on the previous page, please contact the Principal Investigator.

Figure 75 SW1 Information sheet

Please enter your Prolific ID here

Information Sheet

Quantifying the effects of circadian rhythm disruption on cognition

Circadian rhythm is a natural mechanism that regulates sleepiness and wakefulness in a 24 hour cycle. This rhythm causes a series of daily fluctuations in a variety of physical and mental processes that are tightly regulated by the predictable changes in natural light levels. Regular sleeping habits (i.e. sleeping and waking at similar times each day) that closely match natural light changes (i.e. sleeping during the hours of darkness and waking during the early hours of daylight) are important for an optimal circadian rhythm. Therefore, common activities such as staying up later at the weekend or flying across different time zones (causing jet lag) which desynchronise the relationship between light levels and sleep/wake timings can have effects on this system. Shift working, in which people are often required to be awake during the hours of darkness and asleep in the hours of daylight for a number of consecutive days, can also have effects on this mechanism.

Aim of the project

It has been suggested that prolonged shift work patterns can have effects on cognition due to their impact on the circadian rhythm. The way this occurs and the areas of cognition that are affected are poorly understood. This project intends to explore a number of areas of cognition believed to be affected by shift work to determine how impairing any changes in performance are.

The type of data to be collected and method

We will be collecting data regarding several aspects of cognition through a series of computerised cognitive assessments administered via a website accessed using a computer. You will be required to view a series of stimuli that will be presented on the screen and respond to them using a typical computer input gesture such as a button press, mouse/track pad click or touchscreen press. Stimuli have been selected that will not provoke fear, anxiety or stress. The pace of the assessments will be controlled by you and each is of short duration such that participation should not have any major impact on the timings of your work routine. Each assessment will begin with a series of written instructions which you should read before initiating the evaluation. Data on your performance will be collected by the computer and saved for analysis by the research team. The research team will also collect basic information regarding your recent sleep and shift patterns. This will be done via a small number of simple multiple choice questions. Please note that as this study requires you to view a computer screen you should not take part if you have photosensitive epilepsy or are unable to view a computer screen for a sustained period of time due to eye strain or other visual impairments.

Confidentiality

Your participation will be treated in strict confidence in accordance with the General Data Protection Regulation (GDPR). All data will be stored on an OU server within the OU network for security for 5 years and securely disposed of after this period. The data will be anonymous and can only be identified using the unique ID code generated by you at the beginning of the session. If you wish to withdraw from the study you may do so at any time up until the point of data analysis without any adverse effect. You do not have to provide an explanation for your decision.

Contact Details

Principal Investigator: Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; emily.breese@open.ac.uk Researcher's primary supervisor: Dr Christopher Heath, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; christopher.heath@open.ac.uk

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Figure 76 Information sheet used for the SW2 and SW3 cohorts

Please enter your Prolific ID here

Information Sheet

Quantifying the effects of circadian rhythm disruption on cognition

Circadian rhythm is a natural mechanism that regulates sleepiness and wakefulness in a 24 hour cycle. This rhythm causes a series of daily fluctuations in a variety of physical and mental processes that are tightly regulated by the predictable changes in natural light levels. Regular sleeping habits (i.e. sleeping and waking at similar times each day) that closely match natural light changes (i.e. sleeping during the hours of darkness and waking during the early hours of daylight) are important for an optimal circadian rhythm. Therefore, common activities such as staying up later at the weekend or flying across different time zones (causing jet lag) which desynchronise the relationship between light levels and sleep/wake timings can have effects on this system. Regular waking and disturbed sleep, as often experienced by parents of young children, can also have effects on this mechanism.

Aim of the project

It has been suggested that prolonged sleep deprivation can have effects on cognition due to its impact on the circadian rhythm. The way this occurs and the areas of cognition that are affected are poorly understood. This project intends to explore a number of areas of cognition believed to be affected by the unique sleep deprivation experienced by parents to determine how impairing any changes in performance are.

The type of data to be collected and method

We will be collecting data regarding several aspects of cognition through a series of computerised cognitive assessments administered using an electronic device connected to the internet. You will be required to view a series of stimuli that will be presented on the screen and respond to them using a typical computer input gesture such as a button press, mouse/track pad click or touchscreen press. Stimuli have been selected that will not provoke fear, anxiety or stress. The pace of the assessments will be controlled by you and each is of short duration such that participation should not have any major impact on the timings of your everyday routine. Each assessment will begin with a series of written instructions which you should read before initiating the evaluation. Data on your performance will be collected by the electronic device being used, transferred to a secure server and saved for analysis by the research team. The research team will also collect basic information regarding your recent sleep, work and activity patterns. This will be done via a small number of simple multiple choice questions. Please note that as this study requires you to view an electronic screen you should not take part if you have photosensitive epilepsy or are unable to view an electronic screen for a sustained period of time due to eye strain or other visual impairments.

Confidentiality

Your participation will be treated in strict confidence in accordance with the General Data Protection Regulation (GDPR). All data will be stored on an OU server within the OU network for security for 5 years and securely disposed of after this period. The data will be anonymous and can only be identified using the unique ID code generated by you at the beginning of the session. If you wish to withdraw from the study you may do so at any time up until the point of data analysis without any adverse effect. You do not have to provide an explanation for your decision.

Contact Details

Principal Investigator: Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; emily.breese@open.ac.uk Researcher's primary supervisor: Dr Christopher Heath, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; christopher.heath@open.ac.uk

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Figure 77 NP Information sheet

Please enter the unique identifier you signed in with here

Information Sheet

Quantifying the effects of circadian rhythm disruption on cognition

Circadian rhythm is a natural mechanism that regulates sleepiness and wakefulness in a 24 hour cycle. This rhythm causes a series of daily fluctuations in a variety of physical and mental processes that are tightly regulated by the predictable changes in natural light levels. Regular sleeping habits (i.e. sleeping and waking at similar times each day) that closely match natural light changes (i.e. sleeping during the hours of darkness and waking during the early hours of daylight) are important for an optimal circadian rhythm. Therefore, common activities such as staying up later at the weekend or flying across different time zones (causing jet lag) which desynchronise the relationship between light levels and sleep/wake timings can have effects on this system. Shift working, in which people are often required to be awake during the hours of darkness and asleep in the hours of daylight for a number of consecutive days, can also have effects on this mechanism.

Aim of the project

It has been suggested that prolonged shift work patterns can have effects on cognition due to their impact on the circadian rhythm. The way this occurs and the areas of cognition that are affected are poorly understood. This project intends to explore a number of areas of cognition believed to be affected by shift work to determine how impairing any changes in performance are.

The type of data to be collected and method

We will be collecting data regarding cognition through a computerised cognitive assessment administered via a website accessed using a computer. You will be required to view a series of stimuli that will be presented on the screen and respond to them using a typical computer input gesture such as a button press, mouse/track pad click or touchscreen press. Stimuli have been selected that will not provoke fear, anxiety or stress. The pace of the assessments will be controlled by you and each is of short duration such that participation should not have any major impact on the timings of your daily routine. Each assessment will begin with a series of written instructions which you should read before initiating the evaluation. Data on your performance will be collected by the computer and saved for analysis by the research team. The research team will also collect basic information regarding your recent sleep and work patterns. This will be done via a small number of simple multiple choice questions. Please note that as this study requires you to view a computer screen you should not take part if you have photosensitive epilepsy or are unable to view a computer screen for a sustained period of time due to eye strain or other visual impairments.

Confidentiality

Your participation will be treated in strict confidence in accordance with the General Data Protection Regulation (GDPR). All data will be stored on an OU server within the OU network for security for 5 years and securely disposed of after this period. The data will be anonymous and can only be identified using the unique ID code generated by you at the beginning of the session. If you wish to withdraw from the study you may do so at any time up until the point of data analysis without any adverse effect. You do not have to provide an explanation for your decision.

Contact Details

Principal Investigator: Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; emily.breese@open.ac.uk Researcher's primary supervisor: Dr Christopher Heath, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; christopher.heath@open.ac.uk

If you wish to receive a copy of the summary project report detailing the outcomes of this work and did not provide your email address on the previous page, please contact the Principal Investigator.

Figure 78 Po Information sheet

School of Life, Health and Chemical Sciences

Information Sheet for persons participating in the research project: Examining the relationship between circadian rhythm, disruption to sleep, exercise, and brain activity levels.

Circadian rhythm is a natural mechanism that regulates sleepiness and wakefulness in a 24 hour cycle. This rhythm causes a series of daily fluctuations in a variety of physical and mental processes that are tightly regulated by the predictable changes in natural light levels. Regular sleeping habits (i.e. sleeping and waking at similar times each day) that closely match natural light changes (i.e. sleeping during the hours of darkness and waking during the early hours of daylight) are important for an optimal circadian rhythm. Therefore, common activities such as staying up later at the weekend or flying across different time zones (causing jet lag) which desynchronise the relationship between light levels and sleep/wake timings can have effects on this system. Shift working, in which people are often required to be awake during the hours of darkness and asleep in the hours of daylight for a number of consecutive days, can also have effects on this mechanism.

Aim of the project:

It has been suggested that prolonged shift work patterns may have effects on cognition due to their impact on the circadian rhythm. Physical activity (exercise) has also been suggested to impact cognition. The way this occurs and the areas that are affected are poorly understood. This project intends to explore a number of areas of cognition believed to be affected by shift work to characterise any changes in performance and to determine if physical activity can influence them.

The type of data to be collected and method:

We will be collecting data regarding brain activity and exercise.

For the testing session a small EEG headband will be placed across your forehead. This will monitor your brain activity for the testing period. You will be asked to sit for 5 minutes in a relaxed position with your eyes closed, and then a further 5 minutes with your eyes open. Data from this device will be collected and saved by the research team for analysis.

We will also be collecting data regarding your exercise and sleep quality through the use of an activity monitor placed on your wrist 24 hours before assessment. This data will also be saved for further analysis by the research team.

Finally, the research team will also collect basic information about you and about your recent sleep and shift patterns. This will be done via a series of short questionnaires.

This whole testing should take no longer than 20 minutes.

We will be completing testing at the beginning of a day shift and at the beginning of a night shift, preferably the third in rotation.

Participants will be reimbursed for their time with a £5 amazon voucher.

Confidentiality:

Your participation will be treated in strict confidence in accordance with the General data protection regulation. All data will be stored on an OU server within the OU network for security for 5 years and securely disposed of after this period. The data will be anonymous and can only be identified using an ID code unique to you. If you wish to withdraw from the study you may do so at any time up until the point of data analysis without any adverse effect. You do not have to provide an explanation for your decision.

Contact Details:

Principal Investigator: Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; emily.breese@open.ac.uk

Researcher's primary supervisor: Dr Christopher Heath, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; christopher.heath@open.ac.uk

If you wish to receive a copy of the summary report of the research findings please indicate this on your consent form.

Figure 79 EEG information sheet for shift workers

School of Life, Health and Chemical Sciences

Information Sheet for persons participating in the research project: Examining the relationship between circadian rhythm, disruption to sleep, exercise, and brain activity levels.

Circadian rhythm is a natural mechanism that regulates sleepiness and wakefulness in a 24 hour cycle. This rhythm causes a series of daily fluctuations in a variety of physical and mental processes that are tightly regulated by the predictable changes in natural light levels. Regular sleeping habits (i.e. sleeping and waking at similar times each day) that closely match natural light changes (i.e. sleeping during the hours of darkness and waking during the early hours of daylight) are important for an optimal circadian rhythm. Therefore, common activities such as staying up later at the weekend or flying across different time zones (causing jet lag) which desynchronise the relationship between light levels and sleep/wake timings can have effects on this system. Shift working, in which people are often required to be awake during the hours of darkness and asleep in the hours of daylight for a number of consecutive days, can also have effects on this mechanism.

Aim of the project:

It has been suggested that prolonged shift work patterns may have effects on cognition due to their impact on the circadian rhythm. Physical activity (exercise) has also been suggested to impact cognition. The way this occurs and the areas that are affected are poorly understood. This project intends to explore a number of areas of cognition believed to be affected by shift work to characterise any changes in performance and to determine if physical activity can influence them.

The type of data to be collected and method:

We will be collecting data regarding brain activity and exercise.

For the testing session a small EEG headband will be placed across your forehead. This will monitor your brain activity for the testing period. You will be asked to sit for 5 minutes in a relaxed position with your eyes closed, and then a further 5 minutes with your eyes open. Data from this device will be collected and saved by the research team for analysis.

Finally, the research team will also collect basic information about you and about your recent sleep and work patterns. This will be done via a series of short questionnaires.

This whole testing should take no longer than 20 minutes.

We will be completing testing twice, both times on a Wednesday as this is the middle of your working week. Testing will be done within the first hour of your work day.

Participants will be reimbursed for their time with a £5 amazon voucher.

Confidentiality:

Your participation will be treated in strict confidence in accordance with the General data protection regulation. All data will be stored on an OU server within the OU network for security for 5 years and securely disposed of after this period. The data will be anonymous and can only be identified using an ID code unique to you. If you wish to withdraw from the study you may do so at any time up until the point of data analysis without any adverse effect. You do not have to provide an explanation for your decision.

Contact Details:

Principal Investigator: Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; emily.breese@open.ac.uk

Researcher's primary supervisor: Dr Christopher Heath, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; christopher.heath@open.ac.uk

If you wish to receive a copy of the summary report of the research findings please indicate this on your consent form.

Figure 80 EEG Information sheet for non-shift workers

A.3 Consent forms

Detailed in this section are:

Figure 81 Consent form for SW1, SW2 and SW3 cohorts

Figure 82 NP Consent form

Figure 83 Po Consent form

Figure 84 EEG Consent form

One difference between the consent forms given to the SW1, SW2 and SW3 cohorts was the date of data aggregation: for the SW2 cohort this was 01/12/18, for the SW3 cohort this was 21/09/19.

Consent Form

1. I consent to participate in this project, the details of which have been explained to me through written statements in plain language which I have been able to retain by saving, printing or taking screen shots of.
2. I understand that my participation will involve:
 - Provision of basic demographic information such as my age and gender
 - Completion of a brief survey of my recent shift and sleep patterns
 - Answering questions regarding my consumption of caffeine and other factors that could have affected my ability to sleep or my wakefulness
 - Completion of a series of cognitive tasks

and I agree that the researcher may use the results as described in the plain language statement.

3. I acknowledge that:

- a. the possible effects of participating in this research have been explained to my satisfaction;
- b. I have been informed that I am free to withdraw from the project without explanation or prejudice and to request the destruction of any data that has been gathered from me until it is analysed and group-level aggregate values calculated. I understand that data analysis will occur on 01/11/18 and that after this point my data will have been processed and it will not be possible to withdraw it;
- c. the project is for the purpose of research;
- d. I have been informed that the confidentiality of the information I provide will be safeguarded subject to any legal requirements;
- e. I have been informed that with my consent the data generated will be stored on an OU server and will be securely disposed of after five years;
- f. If necessary any data from me will be referred to by a pseudonym in any publications arising from the research;
- g. I have been informed that a summary copy of the research findings will be forwarded to me, should I request this.

Do you agree with all of the above points?

Next

Figure 81 Consent form SW1, SW2 and SW3 cohorts

Consent Form

1. I consent to participate in this project, the details of which have been explained to me through written statements in plain language which I have been able to retain by saving, printing or taking screen shots of.

2. I understand that my participation will involve:

- Provision of basic demographic information such as my age and gender
- Completion of a brief survey of my recent sleep and activity patterns
- Answering questions regarding my consumption of caffeine and other factors that could have affected my ability to sleep or my wakefulness
- Completion of a series of cognitive tasks

and I agree that the researcher may use the results as described in the plain language statement.

3. I acknowledge that:

a. the possible effects of participating in this research have been explained to my satisfaction;

b. I have been informed that I am free to withdraw from the project without explanation or prejudice and to request the destruction of any data that has been gathered from me until it is analysed and group-level aggregate values calculated. I understand that data analysis will occur on 01/04/19 and that after this point my data will have been processed and it will not be possible to withdraw it;

c. the project is for the purpose of research;

d. I have been informed that the confidentiality of the information I provide will be safeguarded subject to any legal requirements;

e. I have been informed that with my consent the data generated will be stored on an OU server and will be securely disposed of after five years;

f. If necessary any data from me will be referred to by a pseudonym in any publications arising from the research;

g. I have been informed that a summary copy of the research findings will be forwarded to me, should I request this.

Do you agree with all of the above points?

Next

Figure 82 NP Consent form

Consent Form

1. I consent to participate in this project, the details of which have been explained to me through written statements in plain language which I have been able to retain by saving, printing or taking screen shots of.

2. I understand that my participation will involve:

- Provision of basic demographic information such as my age and gender
- Completion of a brief survey of my recent work and sleep patterns
- Answering questions regarding my consumption of caffeine and other factors that could have affected my ability to sleep or my wakefulness
- Completion of a cognitive task

and I agree that the researcher may use the results as described in the plain language statement.

3. I acknowledge that:

a. the possible effects of participating in this research have been explained to my satisfaction;

b. I have been informed that I am free to withdraw from the project without explanation or prejudice and to request the destruction of any data that has been gathered from me until it is analysed and group-level aggregate values calculated. I understand that data analysis will occur on 31/10/19 and that after this point my data will have been processed and it will not be possible to withdraw it;

c. the project is for the purpose of research;

d. I have been informed that the confidentiality of the information I provide will be safeguarded subject to any legal requirements;

e. I have been informed that with my consent the data generated will be stored on an OU server and will be securely disposed of after five years;

f. If necessary any data from me will be referred to by a pseudonym in any publications arising from the research;

g. I have been informed that a summary copy of the research findings will be forwarded to me, should I request this.

Do you agree with all of the above points?

Next

Figure 83 Po Consent form

School of Life, Health and Chemical Sciences
Consent form for persons participating in the research
project:

Examining the relationship between circadian rhythm, sleep disruption, cognition, and activity levels
Name of participant: _____

Name of principal investigator(s): Emily Breese

1. I consent to participate in this project, the details of which have been explained to me, and I have been provided with a written statement in plain language to keep.
2. I understand that my participation will involve:
 - Provision of basic demographic information such as my age and gender
 - Completion of a survey of my recent shift and sleep patterns
 - Answering questions regarding my consumption of caffeine and other factors that could have affected my ability to sleep or my wakefulness
 - Wearing an activity monitor / EEG headband for a specified period of time

and I agree that the researcher may use the results as described in the plain language statement.
3. I acknowledge that:
 - a. the possible effects of participating in this research have been explained to my satisfaction;
 - b. I have been informed that I am free to withdraw from the project at any time and that I do not need to provide any explanation or justification for my decision;
 - c. I have been informed that I may request the destruction of any data that has been gathered from me until it is analyzed and group-level aggregate values calculated. I understand that data analysis will occur on 10/03/19 and that after this point my data will have been processed and it will not be possible to withdraw it;
 - d. the project is for the purpose of research;
 - e. I have been informed that the confidentiality of the information I provide will be safeguarded subject to any legal requirements;
 - f. I have been informed that with my consent the data generated will be stored on an OU server and will be securely disposed of after five years;
 - g. If necessary any data from me will be referred to by a pseudonym in any publications arising from the research;
 - h. I have been informed that a summary copy of the research findings will be forwarded to me, should I request this.

Participant signature: _____

Date: _____

PI = Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA
emily.breese@open.ac.uk

Primary supervisor = Dr Christopher Heath, Venables Building, The Open University, Walton Hall,
Milton Keynes, MK7 6AA christopher.heath@open.ac.uk

Figure 84 EEG Consent form

A.4 Debrief forms

Detailed in this section are:

Figure 85 Debrief form used for the SW1 cohort and SW2 shift workers

Figure 86 Debrief form for SW2 non-shift workers

Figure 87 SW3 debrief form for shift workers

Figure 88 SW3 debrief form for non-shift workers

Figure 89 NP debrief form

Figure 90 Po debrief form

Figure 91 EEG debrief form for shift workers

Figure 92 Debrief form for non-shift workers

Text varied between the SW1 cohort and the SW2 and SW3 with regards to confidentiality. In SW1 this was in accordance with the Data Protection Act. In the other cohorts this was in line with the General Data Protection Regulation.

Debrief Statement

Thank you for taking part in this study. Your time is greatly appreciated and the data you have provided will be very helpful in understanding the relationship between shift work and cognition. Below is some information regarding the study and how the data collected will be used.

Background

Circadian rhythm is a natural mechanism that regulates sleepiness and wakefulness in a 24 hour cycle. This rhythm causes a series of daily fluctuations in a variety of physical and mental processes that are tightly regulated by the predictable changes in natural light levels. Regular sleeping habits (i.e. sleeping and waking at similar times each day) that closely match natural light changes (i.e. sleeping during the hours of darkness and waking during the early hours of daylight) are important for an optimal circadian rhythm. Therefore, common activities such as staying up later at the weekend or flying across different time zones (causing jet lag) which desynchronise the relationship between light levels and sleep/wake timings can have effects on this system. Shift working, in which people are often required to be awake during the hours of darkness and asleep in the hours of daylight for a number of consecutive days, can also have effects on this mechanism.

Aim of the project

It has been suggested that prolonged shift work patterns can have effects on cognition due to their impact on the circadian rhythm. The way this occurs and the areas of cognition that are affected are poorly understood. This project intends to explore a number of areas of cognition believed to be affected by shift work to determine how impairing any changes in performance are.

How data will be used

The data that has been collected from you anonymously will be added to data given by others to produce a large database. This will then be analysed to assess any trends that may be present among shift workers. The findings from this group-level analysis will be written up as part of the PhD thesis authored by the principal researcher. No results will be linked back to any particular individual who has taken part in the study.

Confidentiality

Your participation will be treated in strict confidence in accordance with the Data Protection Act. All data will be stored on an OU server within the OU network for security for 5 years and securely disposed of after this period. The data will be anonymous and can only be identified using the unique ID code generated by you at the beginning of the session. If you wish to withdraw from the study you may do so at any time up until the point of data analysis without any adverse effect. You do not have to provide an explanation for your decision.

The Tests

As part of the participation in this study you completed 2 tests. These were measuring different parts of the way in which you think. Attention, response inhibition (stopping yourself responding), working memory (a type of short term memory) and hand eye coordination were all assessed through the 2 tests.

If you have any concerns regarding this study please do contact the principal investigator.

Contact Details

Principal Investigator: Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; emily.breese@open.ac.uk Researcher's primary supervisor: Dr Christopher Heath, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; christopher.heath@open.ac.uk If you wish to receive a summary of the findings of this project please contact the Principal Investigator.

I have read and understood the above information

Once you have completed this page follow the following link to prove you have completed this study (you may need to copy and paste this into a new tab):

www.prolific.ac/submissions/complete?cc=9R0YO7WV

Figure 85 Debrief form used for SW1, SW2 shift workers

Debrief Statement

Thank you for taking part in this study. Your time is greatly appreciated and the data you have provided will be very helpful in understanding the relationship between shift work and cognition. Below is some information regarding the study and how the data collected will be used.

Background

Circadian rhythm is a natural mechanism that regulates sleepiness and wakefulness in a 24 hour cycle. This rhythm causes a series of daily fluctuations in a variety of physical and mental processes that are tightly regulated by the predictable changes in natural light levels. Regular sleeping habits (i.e. sleeping and waking at similar times each day) that closely match natural light changes (i.e. sleeping during the hours of darkness and waking during the early hours of daylight) are important for an optimal circadian rhythm. Therefore, common activities such as staying up later at the weekend or flying across different time zones (causing jet lag) which desynchronise the relationship between light levels and sleep/wake timings can have effects on this system. Shift working, in which people are often required to be awake during the hours of darkness and asleep in the hours of daylight for a number of consecutive days, can also have effects on this mechanism.

Aim of the project

It has been suggested that prolonged shift work patterns can have effects on cognition due to their impact on the circadian rhythm. The way this occurs and the areas of cognition that are affected are poorly understood. This project intends to explore a number of areas of cognition believed to be affected by shift work to determine how impairing any changes in performance are.

How data will be used

The data that has been collected from you anonymously will be added to data given by others to produce a large database. This will then be analysed and compared to a database of shift workers to assess any differences that may be present. The findings from this group-level analysis will be written up as part of the PhD thesis authored by the principal researcher. No results will be linked back to any particular individual who has taken part in the study.

Confidentiality

Your participation will be treated in strict confidence in accordance with the General Data Protection Regulation (GDPR). All data will be stored on an OU server within the OU network for security for 5 years and securely disposed of after this period. The data will be anonymous and can only be identified using the unique ID code generated by you at the beginning of the session. If you wish to withdraw from the study you may do so at any time up until the point of data analysis without any adverse effect. You do not have to provide an explanation for your decision.

The Tests

As part of the participation in this study you completed 2 tests. These were measuring different parts of the way in which you think. Attention, response inhibition (stopping yourself responding), working memory (a type of short term memory) and hand eye coordination were assessed in this study.

If you have any concerns regarding this study please do contact the principal investigator.

Contact Details

Principal Investigator: Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; emily.breese@open.ac.uk Researcher's primary supervisor: Dr Christopher Heath, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; christopher.heath@open.ac.uk If you wish to receive a summary of the findings of this project please contact the Principal Investigator.

I have read and understood the above information

Once you have completed this page follow the following link to prove you have completed this study (you may need to copy and paste this into a new tab):
<https://app.prolific.ac/submissions/complete?cc=59F7TEWV>

Figure 86 SW2 Debrief form for non-shift workers

Debrief Statement

Thank you for taking part in this study. Your time is greatly appreciated and the data you have provided will be very helpful in understanding the relationship between shift work and cognition. Below is some information regarding the study and how the data collected will be used.

Background

Circadian rhythm is a natural mechanism that regulates sleepiness and wakefulness in a 24 hour cycle. This rhythm causes a series of daily fluctuations in a variety of physical and mental processes that are tightly regulated by the predictable changes in natural light levels. Regular sleeping habits (i.e. sleeping and waking at similar times each day) that closely match natural light changes (i.e. sleeping during the hours of darkness and waking during the early hours of daylight) are important for an optimal circadian rhythm. Therefore, common activities such as staying up later at the weekend or flying across different time zones (causing jet lag) which desynchronise the relationship between light levels and sleep/wake timings can have effects on this system. Shift working, in which people are often required to be awake during the hours of darkness and asleep in the hours of daylight for a number of consecutive days, can also have effects on this mechanism.

Aim of the project

It has been suggested that prolonged shift work patterns can have effects on cognition due to their impact on the circadian rhythm. The way this occurs and the areas of cognition that are affected are poorly understood. This project intends to explore a number of areas of cognition believed to be affected by shift work to determine how impairing any changes in performance are.

How data will be used

The data that has been collected from you anonymously will be added to data given by others to produce a large database. This will then be analysed to assess any trends that may be present among shift workers. The findings from this group-level analysis will be written up as part of the PhD thesis authored by the principal researcher. No results will be linked back to any particular individual who has taken part in the study.

Confidentiality

Your participation will be treated in strict confidence in accordance with the General Data Protection Regulation (GDPR). All data will be stored on an OU server within the OU network for security for 5 years and securely disposed of after this period. The data will be anonymous and can only be identified using the unique ID code generated by you at the beginning of the session. If you wish to withdraw from the study you may do so at any time up until the point of data analysis without any adverse effect. You do not have to provide an explanation for your decision.

The Tests

As part of the participation in this study you completed 2 tests. These were measuring different parts of the way in which you think. Attention, response inhibition (stopping yourself responding) and working memory (a type of short term memory) were all assessed through the 2 tests.

If you have any concerns regarding this study please do contact the principal investigator.

Contact Details

Principal Investigator: Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; emily.breese@open.ac.uk Researcher's primary supervisor: Dr Christopher Heath, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; christopher.heath@open.ac.uk If you wish to receive a summary of the findings of this project please contact the Principal Investigator.

I have read and understood the above information

Once you have completed this page follow the link to prove you have completed this study

Figure 87 SW3 Debrief form for shift workers

Debrief Statement

Thank you for taking part in this study. Your time is greatly appreciated and the data you have provided will be very helpful in understanding the relationship between shift work and cognition. Below is some information regarding the study and how the data collected will be used.

Background

Circadian rhythm is a natural mechanism that regulates sleepiness and wakefulness in a 24 hour cycle. This rhythm causes a series of daily fluctuations in a variety of physical and mental processes that are tightly regulated by the predictable changes in natural light levels. Regular sleeping habits (i.e. sleeping and waking at similar times each day) that closely match natural light changes (i.e. sleeping during the hours of darkness and waking during the early hours of daylight) are important for an optimal circadian rhythm. Therefore, common activities such as staying up later at the weekend or flying across different time zones (causing jet lag) which desynchronise the relationship between light levels and sleep/wake timings can have effects on this system. Shift working, in which people are often required to be awake during the hours of darkness and asleep in the hours of daylight for a number of consecutive days, can also have effects on this mechanism.

Aim of the project

It has been suggested that prolonged shift work patterns can have effects on cognition due to their impact on the circadian rhythm. The way this occurs and the areas of cognition that are affected are poorly understood. This project intends to explore a number of areas of cognition believed to be affected by shift work to determine how impairing any changes in performance are.

How data will be used

The data that has been collected from you anonymously will be added to data given by others to produce a large database. This will then be analysed and compared to a database of shift workers to assess any differences that may be present. The findings from this group-level analysis will be written up as part of the PhD thesis authored by the principal researcher. No results will be linked back to any particular individual who has taken part in the study.

Confidentiality

Your participation will be treated in strict confidence in accordance with the General Data Protection Regulation (GDPR). All data will be stored on an OU server within the OU network for security for 5 years and securely disposed of after this period. The data will be anonymous and can only be identified using the unique ID code generated by you at the beginning of the session. If you wish to withdraw from the study you may do so at any time up until the point of data analysis without any adverse effect. You do not have to provide an explanation for your decision.

The Tests

As part of the participation in this study you completed 2 tests. These were measuring different parts of the way in which you think. Attention, response inhibition (stopping yourself responding), working memory (a type of short term memory) and hand eye coordination were assessed in this study.

If you have any concerns regarding this study please do contact the principal investigator.

Contact Details

Principal Investigator: Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; emily.breese@open.ac.uk Researcher's primary supervisor: Dr Christopher Heath, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; christopher.heath@open.ac.uk If you wish to receive a summary of the findings of this project please contact the Principal Investigator.

I have read and understood the above information

Once you have completed this page follow the link to prove you have completed this study

Figure 88 SW3 Debrief form for non-shift workers

Debrief Statement

Thank you for taking part in this study. Your time is greatly appreciated and the data you have provided will be very helpful in understanding the relationship between sleep deprivation and cognition. Below is some information regarding the study and how the data collected will be used.

Background

Circadian rhythm is a natural mechanism that regulates sleepiness and wakefulness in a 24 hour cycle. This rhythm causes a series of daily fluctuations in a variety of physical and mental processes that are tightly regulated by the predictable changes in natural light levels. Regular sleeping habits (i.e. sleeping and waking at similar times each day) that closely match natural light changes (i.e. sleeping during the hours of darkness and waking during the early hours of daylight) are important for an optimal circadian rhythm. Therefore, common activities such as staying up later at the weekend or flying across different time zones (causing jet lag) which desynchronise the relationship between light levels and sleep/wake timings can have effects on this system. Regular waking and disturbed sleep, as often experienced by parents of young children, can also have effects on this mechanism.

Aim of the project

It has been suggested that prolonged sleep deprivation can have effects on cognition due to its impact on the circadian rhythm. The way this occurs and the areas of cognition that are affected are poorly understood. This project intends to explore a number of areas of cognition believed to be affected by the unique sleep deprivation experienced by parents to determine how impairing any changes in performance are.

How data will be used

The data that has been collected from you anonymously will be added to data given by others to produce a large database. This will then be analysed to assess any trends that may be present among new parents. The findings from this group-level analysis will be written up as part of the PhD thesis authored by the principal researcher. No results will be linked back to any particular individual who has taken part in the study.

Confidentiality

Your participation will be treated in strict confidence in accordance with the General Data Protection Regulation (GDPR). All data will be stored on an OU server within the OU network for security for 5 years and securely disposed of after this period. The data will be anonymous and can only be identified using the unique ID code generated by you at the beginning of the session. If you wish to withdraw from the study you may do so at any time up until the point of data analysis without any adverse effect. You do not have to provide an explanation for your decision.

The Tests

As part of the participation in this study you completed 2 tests. These were measuring different parts of the way in which you think. Attention, response inhibition (stopping yourself responding), working memory (a type of short term memory) and hand eye coordination were all assessed through the tests.

If you have any concerns regarding this study please do contact the principal investigator.

Contact Details

Principal Investigator: Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; emily.breese@open.ac.uk Researcher's primary supervisor: Dr Christopher Heath, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; christopher.heath@open.ac.uk If you wish to receive a summary of the findings of this project please contact the Principal Investigator.

I have read and understood the above information

Once you have completed this page follow the following link to prove you have completed this study (you may need to copy and paste this into a new tab):
<https://app.prolific.ac/submissions/complete?cc=UMJBWDVP>

Figure 89 NP debrief form

Debrief Statement

Thank you for taking part in this study. Your time is greatly appreciated and the data you have provided will be very helpful in understanding the relationship between shift work and cognition. Below is some information regarding the study and how the data collected will be used.

Background

Circadian rhythm is a natural mechanism that regulates sleepiness and wakefulness in a 24 hour cycle. This rhythm causes a series of daily fluctuations in a variety of physical and mental processes that are tightly regulated by the predictable changes in natural light levels. Regular sleeping habits (i.e. sleeping and waking at similar times each day) that closely match natural light changes (i.e. sleeping during the hours of darkness and waking during the early hours of daylight) are important for an optimal circadian rhythm. Therefore, common activities such as staying up later at the weekend or flying across different time zones (causing jet lag) which desynchronise the relationship between light levels and sleep/wake timings can have effects on this system. Shift working, in which people are often required to be awake during the hours of darkness and asleep in the hours of daylight for a number of consecutive days, can also have effects on this mechanism.

Aim of the project

It has been suggested that prolonged shift work patterns can have effects on cognition due to their impact on the circadian rhythm. The way this occurs and the areas of cognition that are affected are poorly understood. This project intends to explore a number of areas of cognition believed to be affected by shift work to determine how impairing any changes in performance are.

How data will be used

The data that has been collected from you anonymously will be added to data given by others to produce a large database. This will then be analysed to assess any trends that may be present among shift workers and non shift workers. The findings from this group-level analysis will be written up as part of the PhD thesis authored by the principal researcher. No results will be linked back to any particular individual who has taken part in the study.

Confidentiality

Your participation will be treated in strict confidence in accordance with the General Data Protection Regulation (GDPR). All data will be stored on an OU server within the OU network for security for 5 years and securely disposed of after this period. The data will be anonymous and can only be identified using the unique ID code generated by you at the beginning of the session. If you wish to withdraw from the study you may do so at any time up until the point of data analysis without any adverse effect. You do not have to provide an explanation for your decision.

The Test

As part of the participation in this study you completed a reaction time test. This was measuring your sustained attention.

If you have any concerns regarding this study please do contact the principal investigator.

Contact Details

Principal Investigator: Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; emily.breese@open.ac.uk Researcher's primary supervisor: Dr Christopher Heath, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; christopher.heath@open.ac.uk If you wish to receive a summary of the findings of this project please contact the Principal Investigator.

I have read and understood the above information

If you wish to be entered into the prize draw to win one of 10 £30 amazon vouchers please enter your email below:

Once you have completed this page please close your browser.

Figure 90 Po Debrief form

Debrief statement

School of Life, Health and Chemical Sciences

Debrief Sheet for persons participating in the research project:

Examining the relationship between circadian rhythm, disruption to sleep, exercise, and brain activity levels.

Thank you for taking part in this study. Your time is greatly appreciated and the data you have provided will be very helpful in understanding the relationship between shift work and brain activity levels.

Below is information regarding the study and information on how the data collected will be used.

Circadian rhythm is a natural mechanism that regulates sleepiness and wakefulness in a 24 hour cycle. This rhythm causes a series of daily fluctuations in a variety of physical and mental processes that are tightly regulated by the predictable changes in natural light levels. Regular sleeping habits (i.e. sleeping and waking at similar times each day) that closely match natural light changes (i.e. sleeping during the hours of darkness and waking during the early hours of daylight) are important for an optimal circadian rhythm. Therefore, common activities such as staying up later at the weekend or flying across different time zones (causing jet lag) which desynchronise the relationship between light levels and sleep/wake timings can have effects on this system. Shift working, in which people are often required to be awake during the hours of darkness and asleep in the hours of daylight for a number of consecutive days, can also have effects on this mechanism.

Aim of the project:

It has been suggested that prolonged shift work patterns may have effects on cognition due to their impact on the circadian rhythm. Physical activity (exercise) has also been suggested to impact cognition. The way this occurs and the areas that are affected are poorly understood. This project intends to explore a number of areas of cognition believed to be affected by shift work to characterise any changes in performance and to determine if physical activity can influence them.

How data will be used:

The data that has been collected from you anonymously will be added to data given by others to produce a large database. This will then be analysed to assess any trends that may be present among shift workers. The findings from this group-level analysis will be written up as part of the PhD thesis authored by the principal researcher. No results will be linked back to any particular individual who has taken part in the study.

Confidentiality:

Your participation will be treated in strict confidence in accordance with the General data protection regulation. All data will be stored on an OU server within the OU network for security for 5 years and securely disposed of after this period. The data will be anonymous and can only be identified using an ID code unique to you. If you wish to withdraw from the study you may do so at any time up until the point of data analysis without any adverse effect. You do not have to provide an explanation for your decision.

If you have any concerns regarding this study please do contact the principal investigator.

Contact Details:

Principal Investigator: Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; emily.breese@open.ac.uk

Researcher's primary supervisor: Dr Christopher Heath, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; christopher.heath@open.ac.uk

If you wish to receive a summary of the findings of this project please contact the Principal Investigator.

Figure 91 EEG debrief form for shift workers

Debrief statement

School of Life, Health and Chemical Sciences

Debrief Sheet for persons participating in the research project:

Examining the relationship between circadian rhythm, disruption to sleep, exercise, and brain activity levels.

Thank you for taking part in this study. Your time is greatly appreciated and the data you have provided will be very helpful in understanding the relationship between shift work and brain activity levels.

Below is information regarding the study and information on how the data collected will be used.

Circadian rhythm is a natural mechanism that regulates sleepiness and wakefulness in a 24 hour cycle. This rhythm causes a series of daily fluctuations in a variety of physical and mental processes that are tightly regulated by the predictable changes in natural light levels. Regular sleeping habits (i.e. sleeping and waking at similar times each day) that closely match natural light changes (i.e. sleeping during the hours of darkness and waking during the early hours of daylight) are important for an optimal circadian rhythm. Therefore, common activities such as staying up later at the weekend or flying across different time zones (causing jet lag) which desynchronise the relationship between light levels and sleep/wake timings can have effects on this system. Shift working, in which people are often required to be awake during the hours of darkness and asleep in the hours of daylight for a number of consecutive days, can also have effects on this mechanism.

Aim of the project:

It has been suggested that prolonged shift work patterns may have effects on cognition due to their impact on the circadian rhythm. Physical activity (exercise) has also been suggested to impact cognition. The way this occurs and the areas that are affected are poorly understood. This project intends to explore a number of areas of cognition believed to be affected by shift work to characterise any changes in performance and to determine if physical activity can influence them.

How data will be used:

The data that has been collected from you anonymously will be added to data given by others to produce a large database. This will then be analysed to assess any trends that may be present among shift workers that are not present in non-shift workers. The findings from this group-level analysis will be written up as part of the PhD thesis authored by the principal researcher. No results will be linked back to any particular individual who has taken part in the study.

Confidentiality:

Your participation will be treated in strict confidence in accordance with the General data protection regulation. All data will be stored on an OU server within the OU network for security for 5 years and securely disposed of after this period. The data will be anonymous and can only be identified using an ID code unique to you. If you wish to withdraw from the study you may do so at any time up until the point of data analysis without any adverse effect. You do not have to provide an explanation for your decision.

If you have any concerns regarding this study please do contact the principal investigator.

Contact Details:

Principal Investigator: Emily Breese, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; emily.breese@open.ac.uk

Researcher's primary supervisor: Dr Christopher Heath, Venables Building, The Open University, Walton Hall, Milton Keynes, MK7 6AA; christopher.heath@open.ac.uk

If you wish to receive a summary of the findings of this project please contact the Principal Investigator.

Figure 92 EEG debrief form for non-shift workers

A.5 Bergen Shift Work Questionnaire

Bergen Sleep Questionnaire

How often has it taken you more than 30 minutes to fall asleep after the light is switched off? (Tick one option for each question)

a) When you are working day shift/ordinary day work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

b) When you are working evening shift/evening work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

c) When you are working night shift/ night work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

d) When you are not working (rest days /vacations)?

Never	Rarely	Sometimes	Often	Always
-------	--------	-----------	-------	--------

How often are you awake for more than 30 minutes within your main sleep period? (Tick one option for each question)

a) When you are working day shift/ordinary day work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

b) When you are working evening shift/evening work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

c) When you are working night shift/ night work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

d) When you are not working (rest days /vacations)?

Never	Rarely	Sometimes	Often	Always
-------	--------	-----------	-------	--------

How often have you woken up more than 30 minutes earlier than you wished, without being able to fall asleep again? (Tick one option for each question)

a) When you are working day shift/ordinary day work?

Never	Rarely	Sometimes	Often	Always
-------	--------	-----------	-------	--------

b) When you are working evening shift/evening work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

c) When you are working night shift/ night work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

d) When you are not working (rest days /vacations)?

Never	Rarely	Sometimes	Often	Always
-------	--------	-----------	-------	--------

How often have you not felt adequately rested following sleep? (Tick one option for each question)

a) When you are working day shift/ordinary day work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

b) When you are working evening shift/evening work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

c) When you are working night shift/ night work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

d) When you are not working (rest days /vacations)?

Never	Rarely	Sometimes	Often	Always	
-------	--------	-----------	-------	--------	--

How often have you been tired/sleepy at work? (Tick one option for each question)

a) When you are working day shift/ordinary day work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

b) When you are working evening shift/evening work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

c) When you are working night shift/ night work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

d) It is important we know you are paying attention. Please answer never for this question.

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

How often have you been tired/sleepy on your free time (time out of work) on workdays? (Tick one option for each question)

a) When you are working day shift/ordinary day work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

b) When you are working evening shift/evening work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

c) When you are working night shift/ night work?

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

How often have you been tired/sleepy on rest days/on vacation? (Tick off one option for each question)

Never	Rarely	Sometimes	Often	Always	N/A
-------	--------	-----------	-------	--------	-----

Next

Figure 93 Bergen shift work questionnaire

A.6 MEQ and rMEQ

Detailed in this section are:

Figure 94 MEQ

Figure 95 rMEQ

MORNINGNESS-EVENINGNESS QUESTIONNAIRE

Self-Assessment Version (MEQ-SA)¹

For each question, please select the answer that best describes you by circling the point value that best indicates how you have felt in recent weeks.

1. *Approximately* what time would you get up if you were entirely free to plan your day?

[5] 5:00 AM–6:30 AM (05:00–06:30 h)

[4] 6:30 AM–7:45 AM (06:30–07:45 h)

[3] 7:45 AM–9:45 AM (07:45–09:45 h)

[2] 9:45 AM–11:00 AM (09:45–11:00 h)

[1] 11:00 AM–12 noon (11:00–12:00 h)

2. *Approximately* what time would you go to bed if you were entirely free to plan your evening?

[5] 8:00 PM–9:00 PM (20:00–21:00 h)

[4] 9:00 PM–10:15 PM (21:00–22:15 h)

[3] 10:15 PM–12:30 AM (22:15–00:30 h)

[2] 12:30 AM–1:45 AM (00:30–01:45 h)

[1] 1:45 AM–3:00 AM (01:45–03:00 h)

3. If you usually have to get up at a specific time in the morning, how much do you depend on an alarm clock?

[4] Not at all

[3] Slightly

[2] Somewhat

[1] Very much

4. How easy do you find it to get up in the morning (when you are not awakened unexpectedly)?

[1] Very difficult

[2] Somewhat difficult

[3] Fairly easy

[4] Very easy

5. How alert do you feel during the first half hour after you wake up in the morning?

[1] Not at all alert

[2] Slightly alert

[3] Fairly alert

[4] Very alert

6. How hungry do you feel during the first half hour after you wake up?

[1] Not at all hungry

[2] Slightly hungry

[3] Fairly hungry

[4] Very hungry

7. During the first half hour after you wake up in the morning, how do you feel?

[1] Very tired

[2] Fairly tired

[3] Fairly refreshed

[4] Very refreshed

8. If you had no commitments the next day, what time would you go to bed compared to your usual bedtime?

[4] Seldom or never later

[3] Less than 1 hour later

[2] 1-2 hours later

[1] More than 2 hours later

9. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week, and the best time for him is between 7-8 AM (07-08 h). Bearing in mind nothing but your own internal "clock," how do you think you would perform?

[4] Would be in good form

[3] Would be in reasonable form

[2] Would find it difficult

[1] Would find it very difficult

10. At *approximately* what time in the evening do you feel tired, and, as a result, in need of sleep?

[5] 8:00 PM–9:00 PM (20:00–21:00 h)

[4] 9:00 PM–10:15 PM (21:00–22:15 h)

[3] 10:15 PM–12:45 AM (22:15–00:45 h)

[2] 12:45 AM–2:00 AM (00:45–02:00 h)

[1] 2:00 AM–3:00 AM (02:00–03:00 h)

11. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last two hours. You are entirely free to plan your day. Considering only your "internal clock," which one of the four testing times would you choose?

[6] 8 AM–10 AM (08–10 h)

[4] 11 AM–1 PM (11–13 h)

[2] 3 PM–5 PM (15–17 h)

[0] 7 PM–9 PM (19–21 h)

12. If you got into bed at 11 PM (23 h), how tired would you be?

[0] Not at all tired

[2] A little tired

[3] Fairly tired

[5] Very tired

13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which one of the following are you most likely to do?

[4] Will wake up at usual time, but will not fall back asleep

[3] Will wake up at usual time and will doze thereafter

[2] Will wake up at usual time, but will fall asleep again

[1] Will not wake up until later than usual

14. One night you have to remain awake between 4-6 AM (04-06 h) in order to carry out a night watch. You have no time commitments the next day. Which one of the alternatives would suit you best?

[1] Would not go to bed until the watch is over

[2] Would take a nap before and sleep after

[3] Would take a good sleep before and nap after

[4] Would sleep only before the watch

15. You have two hours of hard physical work. You are entirely free to plan your day. Considering only your internal "clock," which of the following times would you choose?

[4] 8 AM–10 AM (08–10 h)

[3] 11 AM–1 PM (11–13 h)

[2] 3 PM–5 PM (15–17 h)

[1] 7 PM–9 PM (19–21 h)

16. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week. The best time for her is between 10-11 PM (22-23 h). Bearing in mind only your internal "clock," how well do you think you would perform?

- [1] Would be in good form
- [2] Would be in reasonable form
- [3] Would find it difficult
- [4] Would find it very difficult

17. Suppose you can choose your own work hours. Assume that you work a five-hour day (including breaks), your job is interesting, and you are paid based on your performance. At *approximately* what time would you choose to begin?

- [5] 5 hours starting between 4–8 AM (05–08 h)
- [4] 5 hours starting between 8–9 AM (08–09 h)
- [3] 5 hours starting between 9 AM–2 PM (09–14 h)
- [2] 5 hours starting between 2–5 PM (14–17 h)
- [1] 5 hours starting between 5 PM–4 AM (17–04 h)

18. At *approximately* what time of day do you usually feel your best?

- [5] 5–8 AM (05–08 h)
- [4] 8–10 AM (08–10 h)
- [3] 10 AM–5 PM (10–17 h)
- [2] 5–10 PM (17–22 h)
- [1] 10 PM–5 AM (22–05 h)

19. One hears about "morning types" and "evening types." Which one of these types do you consider yourself to be?

- [6] Definitely a morning type
- [4] Rather more a morning type than an evening type
- [2] Rather more an evening type than a morning type
- [1] Definitely an evening type

_____ **Total points for all 19 questions**

Figure 94 MEQ

Morning Eveningness Questionnaire

Approximately what time would you get up if you were entirely free to plan your day?

- 5:00–6:30 AM
- 6:30–7:45 AM
- 7:45–9:45 AM
- 9:45–11:00 AM
- 11:00–12 noon

During the first half hour after you wake up in the morning, how do you feel?

- Very-tired
- Fairly-tired
- Fairly-refreshed
- Very-refreshed

At approximately what time in the evening do you feel tired, and, as a result, in need of sleep?

- 8:00–9:00 PM
- 9:00–10:15 PM
- 10:15–12:45 AM
- 12:45–2:00 AM
- 2:00–3:00 AM

At approximately what time of day do you usually feel your best?

- 5–8 AM
- 8–10 AM
- 10 AM–5 PM
- 5–10 PM
- 10 PM–5 AM

One hears about “morning-types” and “evening-types.” Which one of these types do you consider yourself to be?

- Definitely a morning-type
- Rather more a morning-type than an evening-type
- Rather more an evening-type than a morning-type
- Definitely an evening-type

Figure 95 rMEQ

A.7 Pittsburgh Sleep Quality Index and scoring guide

Detailed in this section are:

Figure 96 Pittsburgh Sleep Quality Index

Figure 97 Pittsburgh scoring guide

Pittsburgh Sleep Quality Index (PSQI)

Instructions: The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. **Please answer all questions.**

1. During the past month, what time have you usually gone to bed at night? _____
2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night? _____
3. During the past month, what time have you usually gotten up in the morning? _____
4. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed.) _____

5. During the <u>past month</u> , how often have you had trouble sleeping because you...	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
a. Cannot get to sleep within 30 minutes				
b. Wake up in the middle of the night or early morning				
c. Have to get up to use the bathroom				
d. Cannot breathe comfortably				
e. Cough or snore loudly				
f. Feel too cold				
g. Feel too hot				
h. Have bad dreams				
i. Have pain				
j. Other reason(s), please describe:				
6. During the past month, how often have you taken medicine to help you sleep (prescribed or "over the counter")?				
7. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?				
	No problem at all	Only a very slight problem	Somewhat of a problem	A very big problem
8. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?				
	Very good	Fairly good	Fairly bad	Very bad
9. During the past month, how would you rate your sleep quality overall?				

	No bed partner or room mate	Partner/room mate in other room	Partner in same room but not same bed	Partner in same bed
10. Do you have a bed partner or room mate?				
	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
If you have a room mate or bed partner, ask him/her how often in the past month you have had:				
a. Loud snoring				
b. Long pauses between breaths while asleep				
c. Legs twitching or jerking while you sleep				
d. Episodes of disorientation or confusion during sleep				
e. Other restlessness while you sleep, please describe:				

Figure 96 Pittsburgh Sleep Quality Index

Scoring the PSQI

The order of the PSQI items has been modified from the original order in order to fit the first 9 items (which are the only items that contribute to the total score) on a single page. Item 10, which is the second page of the scale, does not contribute to the PSQI score.

In scoring the PSQI, seven component scores are derived, each scored 0 (no difficulty) to 3 (severe difficulty). The component scores are summed to produce a global score (range 0 to 21). Higher scores indicate worse sleep quality.

Component 1: Subjective sleep quality—question 9

Response to Q9	Component 1 score
Very good	0
Fairly good	1
Fairly bad	2
Very bad	3

Component 1 score: _____

Component 2: Sleep latency—questions 2 and 5a

Response to Q2	Component 2/Q2 subscore
< 15 minutes	0
16-30 minutes	1
31-60 minutes	2
> 60 minutes	3

Response to Q5a	Component 2/Q5a subscore
Not during past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

Sum of Q2 and Q5a subscores	Component 2 score
0	0
1-2	1
3-4	2
5-6	3

Component 2 score: _____

Component 3: Sleep duration—question 4

Response to Q4	Component 3 score
> 7 hours	0
6-7 hours	1
5-6 hours	2
< 5 hours	3

Component 3 score: _____

Component 4: Sleep efficiency—questions 1, 3, and 4

Sleep efficiency = (# hours slept/# hours in bed) X 100%

hours slept—question 4

hours in bed—calculated from responses to questions 1 and 3

Sleep efficiency	Component 4 score
> 85%	0
75-84%	1
65-74%	2
< 65%	3

Component 4 score: _____

Component 5: Sleep disturbance—questions 5b-5j

Questions 5b to 5j should be scored as follows:

Not during past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

Sum of 5b to 5j scores	Component 5 score
0	0
1-9	1
10-18	2
19-27	3

Component 5 score: _____

Component 6: Use of sleep medication—question 6

Response to Q6	Component 6 score
Not during past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

Component 6 score: _____

Component 7: Daytime dysfunction—questions 7 and 8

Response to Q7	Component 7/Q7 subscore
Not during past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

Response to Q8	Component 7/Q8 subscore
No problem at all	0
Only a very slight problem	1
Somewhat of a problem	2
A very big problem	3

Sum of Q7 and Q8 subscores	Component 7 score
0	0
1-2	1
3-4	2
5-6	3

Component 7 score: _____

Global PSQI Score: Sum of seven component scores: _____

Copyright notice: The Pittsburgh Sleep Quality Index (PSQI) is copyrighted by Daniel J. Buysse, M.D. Permission has been granted to reproduce the scale on this website for clinicians to use in their practice and for researchers to use in non-industry studies. For other uses of the scale, the owner of the copyright should be contacted.

Citation: Buysse, DJ, Reynolds CF, Monk TH, Berman SR, Kupfer DJ: The Pittsburgh Sleep Quality Index (PSQI): A new instrument for psychiatric research and practice. *Psychiatry Research* 28:193-213, 1989

Figure 97 PSQI Scoring guide

A.8 Demographic questionnaire

Detailed in this section are:

- Figure 98 SW1 demographic questionnaire
- Figure 99 SW2 demographic questionnaire for shift workers
- Figure 100 SW2 demographic questionnaire for non-shift workers
- Figure 101 SW3 demographic questionnaire for shift workers
- Figure 102 SW3 demographic questionnaire for non-shift workers
- Figure 103 NP demographic questionnaire
- Figure 104 Po demographic questionnaire
- Figure 105 EEG demographic questionnaire for shift workers
- Figure 106 EEG demographic questionnaire for non-shift workers

Questions about your shifts

How would you describe your job type?

- Desk based
- Light level of physical activity (up to a quarter of the shift)
- Moderate level of physical activity (up to half the shift)
- High level of physical activity (over half the shift)

How long have you worked shifts?

- 0-3 months
- 4-6 months
- 7-12 months
- 1-2 years
- 2-5 years
- 6-10 years
- 11-15 years
- 16-20 years
- 21-25 years
- 26-30 years
- 30 years+

What rotations have you worked previously (How many day shifts vs night shifts) e.g. 4 night shifts, 4 days off, 4 day shifts

Have these always alternated between night and day shifts?

- Yes
- No I have worked permanent nights previously

What shifts have you worked in the last month?

Is this your first day off? If not, how many days off have you had? (e.g. on second day off)

On your last day off, did you sleep 'normal' hours?

- Yes
- No
- Do not wish to say

What time did you wake up before completing this study?

What is your favourite shift type and why?

What shift rotation do you currently work? e.g. 4 nights, 4 days, 4 off

Figure 98 SW1 demographic questionnaire

Basic information about you

Which of the following best describes you

- Male
- Female
- Other
- Do not wish to say

How old are you?

17

17

100

Which hand would you predominantly use a computer mouse with?

- Left
- Right
- Ambidextrous

Have you had a head injury that required medical attention in the last 3 months?

- Yes
- No

In which country do you currently live?

In which country do you currently work?

Do you have any children? If so, please give age(s) of each child

Have you or your partner recently given birth? If so, how old is the child now?

Questions about your sleep

In your opinion, are you currently sleeping poorly?

- Yes
- No

Do you have a diagnosed sleep disorder?

- Yes
- No

If so, please give brief details

Is there anything in your life at the moment which may be affecting your sleep, for example a new baby or poor accommodation?

- Yes
- No

If so, please give brief details

Are you currently on any medication (prescribed or over the counter) which can have side effects of drowsiness or insomnia?

- Yes
- No

If yes, what medication?

Do you use any electronic equipment just before sleeping?

- Yes
- No

If so, please state what equipment (e.g. computer, mobile phone etc.) and how long you use it for before sleeping

Questions about your shifts

What is your current occupation? E.g. Factory worker, IT support, Nurse etc. Please provide your specific job title

Are you responsible for supervising/managing any other staff?

- Yes
 No

If yes, how many?

How would you describe your job?

- Desk based
 Light level of physical activity (up to a quarter of the shift)
 Moderate level of physical activity (up to half the shift)
 High level of physical activity (over half the shift)

How would you describe stress levels in your job?

- High stress
 Moderate stress
 Low stress

How long have you worked shifts?

- 0-3 months
 4-6 months
 7-12 months
 1-2 years
 2-5 years
 6-10 years
 11-15 years
 16-20 years
 21-25 years
 26-30 years
 30 years+

Which of the following applies to you:

- I have always worked permanent nights
 I have always worked rotating shifts
 I have always worked day shifts
 I have previously worked a combination of shifts

What shifts have you worked in the last month?

- Night shifts
 Rotating shifts
 Day shifts

Is today your first day off?

- Yes
 No it is my second day off
 No I have been off for more than 2 days
 No I am not on a day off

On your days off what is your sleep strategy?

- I went to sleep at the same time as when on shift
 I went to sleep at a time considered conventional by non-shift workers (after 8pm)
 Other (please specify)

What time did you go to sleep last time you slept? Please indicate AM/PM

What time did you wake up before completing this study? Please indicate AM/PM

What is your favourite shift type?

- Night shift
 Day shift
 Other (please specify)

What is the primary reason for this shift being your favourite shift?

- I get to see more of my family
 Work environment is better (quieter etc)
 It pays more
 I am more efficient
 I get more sleep
 I feel more 'normal'
 Other (please specify)

What shift rotation do you currently work?

Nights

Rotating

Days

Describe your shift pattern. For example ' I work 4 night shifts, then 4 day shifts then I have 4 days off'

Figure 99 SW2 demographic questionnaire for shift workers

Basic information about you

Which of the following best describes you

- Male
- Female
- Other
- Do not wish to say

How old are you?

17 100

Which hand would you predominantly use a computer mouse with?

- Left
- Right
- Ambidextrous

Have you had a head injury that required medical attention in the last 3 months?

- Yes
- No

In which country do you currently live?

In which country do you currently work?

Do you have any children? If so, please give age(s) of each child

Have you or your partner recently given birth? If so, how old is the child now?

Questions about your sleep

In your opinion, are you currently sleeping poorly?

- Yes
- No

Do you have a diagnosed sleep disorder?

- Yes
- No

If so, please give brief details

Is there anything in your life at the moment which may be affecting your sleep, for example a new baby or poor accommodation?

- Yes
- No

If so, please give brief details

Are you currently on any medication (prescribed or over the counter) which can have side effects of drowsiness or insomnia?

- Yes
- No

If yes, what medication?

Do you use any electronic equipment just before sleeping?

- Yes
- No

If so, please state what equipment (e.g. computer, mobile phone etc.) and how long you use it for before sleeping

Questions about your job

What is your current occupation? E.g. Factory worker, IT support, Nurse etc. Please provide your specific job title

Are you responsible for supervising/managing any other staff?

- Yes
 No

If yes, how many?

How would you describe your job?

- Desk based
 Light level of physical activity (up to a quarter of the shift)
 Moderate level of physical activity (up to half the shift)
 High level of physical activity (over half the shift)

How would you describe stress levels in your job?

- High stress
 Moderate stress
 Low stress

How long have you worked a 9-5 job?

- 0-3 months
 4-6 months
 7-12 months
 1-2 years
 2-5 years
 6-10 years
 11-15 years
 16-20 years
 21-25 years
 26-30 years
 30 years+

Which of the following applies to you:

- I have previously worked permanent nights
 I have previously worked rotating shifts
 I have always worked day shifts
 I have previously worked a combination of shifts

Is today your first day off?

- Yes
 No it is my second day off
 No I have been off for more than 2 days
 No I am not on a day off

If this is not a day off, please return this survey as you are not eligible.

On your days off what is your sleep strategy?

- I went to sleep at the same time as when working
 I went to sleep at a time considered conventional by non-shift workers (after 8pm)
 Other (please specify)

What time did you go to sleep last time you slept? Please indicate AM/PM

What time did you wake up before completing this study? Please indicate AM/PM

Describe your work pattern. For example 'I work 5 days a week, 9am-5pm'

Figure 100 SW2 demographic questionnaire for non-shift workers

Questions about your shifts

What is your current occupation? E.g. Factory worker, IT support, Nurse etc. Please provide your specific job title

Are you responsible for supervising/managing any other staff?

- Yes
 No

If yes, how many?

How would you describe your job?

- Desk based
 Light level of physical activity (up to a quarter of the shift)
 Moderate level of physical activity (up to half the shift)
 High level of physical activity (over half the shift)

How would you describe stress levels in your job?

- High stress
 Moderate stress
 Low stress

How long have you worked shifts?

- 0-3 months
 4-6 months
 7-12 months
 1-2 years
 2-5 years
 6-10 years
 11-15 years
 16-20 years
 21-25 years
 26-30 years
 30 years+

Which of the following applies to you:

- I have always worked permanent nights
 I have always worked rotating shifts
 I have always worked day shifts
 I have previously worked a combination of shifts

What shifts have you worked in the last month?

- Night shifts
 Rotating shifts
 Day shifts

Is today your first day off?

- Yes
 No it is my second day off
 No I have been off for more than 2 days
 No I am not on a day off

On your days off what is your sleep strategy?

- I went to sleep at the same time as when on shift
 I went to sleep at a time considered conventional by non-shift workers (after 8pm)
 Other (please specify)

What time did you go to sleep last time you slept? Please indicate AM/PM

What time did you wake up before completing this study? Please indicate AM/PM

What is your favourite shift type?

- Night shift
 Day shift
 Other (please specify)

What is the primary reason for this shift being your favourite shift?

- I get to see more of my family
- Work environment is better (quieter etc)
- It pays more
- I am more efficient
- I get more sleep
- I feel more 'normal'
- Other (please specify)

What shift rotation do you currently work?

- Nights
- Rotating
- Days

Describe your shift pattern. For example ' I work 4 night shifts, then 4 day shifts then I have 4 days off'

Figure 101 SW3 demographic questionnaire for shift workers

Questions about your job

What is your current occupation? E.g. Factory worker, IT support, Nurse etc. Please provide your specific job title

Are you responsible for supervising/managing any other staff?

- Yes
 No

If yes, how many?

How would you describe your job?

- Desk based
 Light level of physical activity (up to a quarter of the shift)
 Moderate level of physical activity (up to half the shift)
 High level of physical activity (over half the shift)

How would you describe stress levels in your job?

- High stress
 Moderate stress
 Low stress

How long have you worked a 9-5 job?

- 0-3 months
 4-6 months
 7-12 months
 1-2 years
 2-5 years
 6-10 years
 11-15 years
 16-20 years
 21-25 years
 26-30 years
 30 years+

Which of the following applies to you:

- I have previously worked permanent nights
 I have previously worked rotating shifts
 I have always worked day shifts
 I have previously worked a combination of shifts

Is today your first day off?

- Yes
 No it is my second day off
 No I have been off for more than 2 days
 No I am not on a day off

If this is not a day off, please return this survey as you are not eligible.

On your days off what is your sleep strategy?

- I went to sleep at the same time as when working
 I went to sleep at a time considered conventional by non-shift workers (after 8pm)
 Other (please specify)

What time did you go to sleep last time you slept? Please indicate AM/PM

What time did you wake up before completing this study? Please indicate AM/PM

Describe your work pattern. For example 'I work 5 days a week, 9am-5pm'

Figure 102 SW3 demographic questionnaire for non-shift workers

Basic information about you

Which of the following best describes you

- Male
- Female
- Other
- Do not wish to say

How old are you?

17 17 100

Which hand would you predominantly use a computer mouse with?

- Left
- Right
- Ambidextrous

Have you had a head injury that required medical attention in the last 3 months?

- Yes
- No

In which country do you currently live?

In which country do you currently work?

Questions about your sleep

In your opinion, are you currently sleeping poorly?

- Yes
- No

Do you have a diagnosed sleep disorder?

- Yes
- No

If so, please give brief details

Is there anything in your life at the moment which may be affecting your sleep, other than a new baby? E.g poor accommodation

- Yes
- No

If so, please give brief details

Are you currently on any medication (prescribed or over the counter) which can have side effects of drowsiness or insomnia?

- Yes
- No

If so, what medication?

Do you use any electronic equipment just before sleeping?

- Yes
- No

If so, please state what equipment (e.g. computer, mobile phone etc.) and how long you use it for before sleeping

What time did you go to sleep last night? Please specify AM/PM

What time did you wake up before completing this study? Please specify AM/PM

Questions about you and your baby

When was your baby born?

- Less than 1 month ago
- 1-2 months ago
- 2- 3 months ago
- 3-4 months ago
- 4-5 months ago
- 5-6 months ago
- 6-7 months ago
- 7-8 months ago
- 8-9 months ago
- 9-10 months ago
- 10-11 months ago
- 11-12 months ago

Is this your first child?

- Yes
- No

If not, how many children do you have?

If you do have more than one child, please give the age for each child

Do you live alone with your baby/children?

- Yes
- No I live with another adult
- Other (please specify)

If you live with another adult, how is childcare divided between you?

Did you take parental leave following the birth of your child/children?

- Yes currently on leave
- Yes but I have gone back to work
- No my partner is currently on leave
- No my partner took leave but is now back at work
- No parental leave was taken

How long was parental leave taken for? Please tick all that are appropriate.

- More than 6 months before birth
- 3-6 months before birth
- 1-3 months before birth
- 0-1 month before birth
- 0-1 month after birth
- 1-3 months after birth
- 3-6 months after birth
- 6-9 months after birth
- More than 9 months after birth

Have you returned to work since the birth of your child?

- Yes
- No

If so please indicate when.

What is your current occupation? E.g. Factory worker, IT support, Staff Nurse etc.
Please provide your specific job title

Do you supervise/manage any other staff?

- Yes
- No

If yes, how many?

Over the last month, has your child slept all the way through the night?

Yes

No

If not, please indicate on average how many times a night you get up and for how long

How are you feeding your baby currently?

Breast milk (directly from breast)

Breast milk (from a bottle)

Formula

Mixture of formula and breast milk

Other

Prefer not to say

Figure 103 NP demographic questionnaire

Questions about your job

What is your current occupation? E.g. Factory worker, IT support, Nurse etc. Please provide your specific job title

Are you responsible for supervising/managing any other staff?

- Yes
 No

If yes, how many?

How would you describe your job?

- Desk based
 Light level of physical activity (up to a quarter of the shift)
 Moderate level of physical activity (up to half the shift)
 High level of physical activity (over half the shift)

How would you describe stress levels in your job?

- High stress
 Moderate stress
 Low stress

If you are a shift worker, how long have you worked shifts?

- 0-3 months
 4-6 months
 7-12 months
 1-2 years
 2-5 years
 6-10 years
 11-15 years
 16-20 years
 21-25 years
 26-30 years
 30 years+

If you are not currently a shift worker, how long have you worked a 9-5 job?

- 0-3 months
 4-6 months
 7-12 months
 1-2 years
 2-5 years
 6-10 years
 11-15 years
 16-20 years
 21-25 years
 26-30 years
 30 years+

Which of the following applies to you:

- I have always worked permanent nights
 I have always worked rotating shifts
 I have always worked day shifts
 I have previously worked permanent nights
 I have previously worked rotating shifts
 I have previously worked a combination of shifts
 I am not a shift worker

What shifts have you worked in the last month?

- Night shifts
 Rotating shifts
 Day shifts
 I'm not a shift worker

Is today your first day off?

- Yes
 No it is my second day off
 No I have been off for more than 2 days
 No I am not on a day off

If this is not a day off, please close this survey as you are not eligible to take part in the study

On your days off what is your sleep strategy?

- I go to sleep at the same time as when I am working
- I go to sleep at a time considered conventional by non-shift workers (after 8pm)
- Other (please specify)

What time did you go to sleep last time you slept?

What time did you wake up before completing this study?

What is your favourite shift type?

- Night shift
- Day shift
- Not a shift worker
- Other (please specify)

What is the primary reason for this shift being your favourite shift?

- I get to see more of my family
- Work environment is better (quieter etc)
- It pays more
- I am more efficient
- I get more sleep
- I feel more 'normal'
- Not applicable
- Other (please specify)

Describe your shift pattern. For example 'In my shift rotation of 12 days I work 4 night shifts, 4 day shifts and have 4 days off' or 'In my shift rotation of 7 days I work 0 night shifts, 5 day shifts and have 2 days off'

In my shift rotation of:

I work:

and have:

My night shifts usually start at: (if you don't work night shifts leave these clocks set at 00:00)

and end at:

My day shifts usually start at: (if you don't work day shifts leave these clocks set at 00:00)

and end at:

If you wish to provide any extra information about your work pattern please do so here:

Figure 104 Po demographic questionnaire

Sleep questionnaire

Unique ID code:

1. Male or female or other?
2. How old are you?
3. Are you right handed?
4. Are you aware of/ experiencing any sleep disorders currently?
5. Is there anything in your life at the moment which may be affecting your sleep, for example a new baby? Poor accommodation?
6. Are you currently on any medication which can have side effects of drowsiness or insomnia?
7. Have you recently had a head injury that required medical attention in the last 3 months?
8. Do you have a diagnosed sleep disorder?

Shift specific questions:

1. What shifts have you worked in the last month?
2. When was your last day off, did you sleep 'normal hours' (Y/N)?
3. When did you wake up before coming to work for this shift?
4. What is your favourite shift and why?
5. How many cups of coffee/cans of energy drink have you consumed before this shift?
6. How long have you worked shifts?
7. Have these always alternated between night and day shifts?
8. Have you ever worked only nights?

Figure 105 Demographic questionnaire for shift workers

Sleep questionnaire

Unique ID code:

1. Male or female or other?
2. How old are you?
3. Are you right handed?
4. Are you aware of/ experiencing any sleep disorders currently?
5. Is there anything in your life at the moment which may be affecting your sleep, for example a new baby? Poor accommodation?
6. Are you currently on any medication which can have side effects of drowsiness or insomnia?
7. Have you had a head injury that required medical attention in the last 3 months?
8. Do you have a diagnosed sleep disorder?

Shift specific questions:

1. What hours do you normally work (in the last month)?
2. When was your last day off, did you sleep 'normal hours' (Y/N)?
3. When did you wake up before coming to work for this shift?
4. How many cups of coffee/cans of energy drink have you consumed before this shift?
5. How you ever worked shifts? If so, when and what sort.

Figure 106 Demographic questionnaire for non-shift workers

A.9 Caffeine questionnaire

The caffeine questionnaire given was the same for all cohorts

Have you had any caffeine recently?

Currently consuming
 Last 30 minutes
 Last hour
 Last two hours
 No

In what form was the caffeine consumed e.g. coffee, energy drink, caffeine tablet

On average how much caffeine do you usually consume a day?

Have you had any high sugar food recently?

Currently consuming
 Last 30 minutes
 Last hour
 Last two hours
 No

If so, what was this?

Has anything emotionally significant (e.g. performance appraisal with line manager, argument with a family member etc.) happened to you recently?

Yes
 No
 Not Sure
 Don't want to say

If yes, what was this?

Have you had any other stimulant (legal or illegal) which may be affecting you?

Figure 107 Caffeine questionnaire

A.10 Task Instructions

Along with illustrative diagrams the instructions for each task are outlined below.

Detailed in this section are:

A.10.1 PVT

A.10.2 GNG

A.10.2.1 Task instructions for SW1

A.10.2.2 Task instructions for all other cohorts

A.10.3 N-Back

A.10.3.1 Task instructions for SW1

A.10.3.2 Revised N-Back task instructions

A.10.4 TMT

A.10.4.1 TMTA Task instructions for SW1

A.10.4.2 TMTB Task instructions for SW1

A.10.4.3 TMTA Task instructions for all other cohorts

A.10.4.4 TMTB Task instructions for all other cohorts

A.10.5 Eriksen Flanker

A.10.1 PVT Instructions

Press the space bar **as fast as possible** when a blue circle appears. The task will take approximately 10 minutes. Press the **space bar** when you are ready to start!

A.10.2.1 SW1 GNG Instructions

Press space bar when a square is shown. Wait when a fixation cross is shown. Do not press when a triangle is shown. The task will take approximately 10 minutes. Press the **space bar** when you are ready to start!

A.10.2.2. All other cohorts GNG Instructions

For this task you are required to respond **as fast as possible** to three different shapes. These are a LARGE square, a LARGE triangle and a SMALL square. However you must avoid pressing when a SMALL triangle is shown. These shapes will not appear on the screen for very long. There will be a blank screen shown after each shape. A fixation point will appear before the next shape is shown. Do not press when the fixation point is displayed. This task will take approximately **10 minutes**. Press the **space bar** when you are ready to start.

A.10.3.1 N-Back Instructions

In this task you will view a sequence of single digit numbers. Press the **space bar** when the number shown on the screen is the same as the number shown 2 positions previously in the sequence. **For example** in the sequence '5 9 5 8' you would press the **space bar** when you saw the 2nd '5', as it is two positions after the 1st '5' in the sequences. This task will take approximately **10 minutes**. Press space bar when you are ready to start!

A.10.3.2 Revised N-back Instructions

In this task you will view a sequence of single letters. These can be either upper or lower case. You are required to memorise these letters and indicate if the letter you are looking at either matches or does not match the letter you saw at an earlier point in the sequence. **Press f** if the letter you see on-screen matches the one you saw a specific number of letter ago and **Press J** when it does not.

For example M n t N P Q p. For this sequence of letters, we will apply the '**2 back**' rule so you will need to decide if the letter displayed on the screen matches the letter displayed **two places** earlier in the sequence. So here you would **Press F** when the fourth letter (the N) is displayed, as the same letter (the n) was displayed 2 places before it in the sequence. You would also **Press F** when the seventh letter (the p) was displayed because the same letter (the P) was displayed 2 places before in it the sequence. For all the other letter in this sequence, you would **Press J**.

Note: Matching in this task is **not case sensitive**. For example valid matches for the letter P would include: P and P, p and p, P and p, p and P. Press space bar to begin a practice session.

A.10.4.1 TMTA Task instructions for SW1

In this task you have to click on the various numbers in ascending order (1 to 25), as quickly as you can. Numbers will turn blue if correct then green once the next correct number has been pressed. They will disappear if pressed in the wrong order. This task will take approximately **5 minutes**. Press the **space bar** to begin.

A.10.4.2 TMTB Task instructions for SW1

Congratulations, you have finished the first part! In the next part you must click on the numbers and letters in ascending order AND follow this sequence: Number – Letter – Number – Letter (e.g. 1-A-2-B-3-C-4-D). Again letters/numbers will turn blue if correct then green once the next correct letter/number has been pressed. They will disappear if pressed in the wrong order. Press the **space bar** to begin.

A.10.4.3 TMTA Task instructions for all other cohorts

In this task you have to click on the various numbers in ascending order (1 to 25), as quickly as you can. Number will turn blue if correct then orange once the next correct number has been pressed. They will disappear if pressed in the wrong order. Click on the video below to watch a short demonstration. This task will take approximately **5 minutes**. Press the **space bar** to begin the task.

A.10.4.4 TMTB Task instructions for all other cohorts

Congratulations, you have finished the first part! In the next part you must click on the numbers and letters in ascending order AND follow this sequence: Number – Letter – Number – Letter (e.g. 1-A-2-B-3-C-4-D). Again letters/numbers will turn blue if correct then orange once the next correct letter/number has been pressed. They will disappear if pressed in the wrong order. Click the video for a short demonstration. Press the **space bar** to begin the task.

A.10.5 Eriksen flanker task instructions

You will see 5 letters at a time. You need to respond to the one in the middle. Place you index fingers on the 'F' and 'J' keys. If you see an **S**, you press the F key. If you see an **H** you press the J key. For example here you would press the F key as the letter in the middle is an S. Try to be as fast and as accurate as possible. Press space bar to continue.

You will now do a practise run of the task at a slower speed – the practise will let you know when you have responded correctly or incorrectly with a green tick or red cross. Press space bar to begin

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