UNIVERSITY OF SOUTHAMPTON

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Psychology

The Effect of Fatigue on Performance in Complex Visuo-Cognitive Tasks

by

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ABSTRACT

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Sleep disruption literature has largely focused on exploring sleep disruptions effects on relatively simple tasks with less attention given to how it impacts more complex tasks. Further, research has given very little attention on how performance fairs when participants also have to switch between tasks, in both a voluntary and forced state. The goal of this thesis was, therefore, to expand on previous investigations of sleep loss and its effects on performance of complex visuo-cognitive tasks whilst either voluntarily or forcibly task switching. Over the course of four experiments this was examined. Experiment 1 and 2 explored the effects of both sleep restriction and sleep deprivation and the cost they have on voluntary task switching performance. These experiments revealed that individuals can largely compensate for the negative effects of sleep restriction especially when they spend longer preparing for an upcoming switch in tasks. However, when they have experienced sleep deprivation these effects become more severe, causing fewer words to be generated and an increase in the number of switches made. Experiment 3, explored how the removal of control over the task in terms of forcing them when to switch, impacted performance between sleep conditions, while also seeing how it compares to voluntary switching. Results highlighted that once control of the task was removed a larger profile of errors emerged.

Specifically, with the reduction in the number of words in both the sleep deprived condition and the forced switching condition, as well as, sleep deprived participants having a longer resumption lag. Finally, Experiment 4 addressed two key components. The first component addressed the sensitivity of subjective measures of sleepiness versus objective measures of sleepiness. Results highlighted that subjective measures of sleepiness are more sensitive to the feelings of fatigue and are resilient against individual differences unlike the objective measures. The second component aimed to address the differences between voluntary versus forced switching and sleep deprived versus Control while switching between two tasks that contained two different types of cognitive task goals. Issues arose during data collection that hindered collection of a full dataset and subsequently no firm conclusions can be drawn. Based on the results from these experiments, this thesis demonstrates that the negative effects of sleep loss are dependent on the task constraints and the amount of sleep lost. However, it is clear the harder the task becomes the more difficult it is for individuals to compensate for the negative effects of fatigue when performing complex visuo-cognitive tasks. The implication of this research is that both fatigue and task switching are an important consideration when managing small daily tasks whilst also addressing the potential impact it poses on safety concerns in many industries.

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Research Thesis: Declaration of Authorship

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I declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
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6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission

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Chapter 1

Literature Review

1.1 General Introduction

The issue explored in this thesis is how fatigue influences task performance. Fatigue is known to have a deleterious effect on how well tasks are performed. The particular situation of concern to the present thesis is how fatigue influences task performance specifically when switching between two tasks, a situation that is commonplace in the real world. These situations occur whenever operatives (e.g. security guards, technicians in control rooms, mariners on a ship's bridge) are required to repeatedly and sequentially monitor and respond to discrete displays of information. In monitoring and responding to repeating, sequential discrete displays of information, operatives can sometimes have a choice as to how to allocate attention to displays. In doing so they can consider and calibrate to the processing demands needed to monitor and respond to specific information displays. In other situations, operatives have no such ability as they are forced to switch according to external factors (for example, the requirement to ensure some display is checked according to a particular time scale). These situations reflect the ability to voluntarily switch at a time best suited to the operative, or when forced to do so irrespective of the whether it is a good time for the operative to switch or not. The voluntary and forced task switching situations create very different cognitive challenges. This thesis will explore how effectively these challenges are managed as participants become fatigued.

1.2 Task Switching

Cognitive control is the ability to regulate, coordinate, and sequence thoughts and actions in accordance with internally maintained behavioural goals and is an important factor in task switching (Braver, Reynolds, & Donaldson, 2003). Cognitive control allows both information processing and behaviour to vary adaptively depending on a given situation and it is with this in mind that the Dual Mechanisms of Control framework (DMC[1]; Braver, Gray & Burgess., 2007) was developed. This framework suggested that there were two distinct modes of cognitive control; proactive and reactive. Proactive control reflects the sustained maintenance of goal-relevant information and occurs in anticipation of a cognitively demanding situation occurring. Proactive control ensures that attention, perception and subsequent action systems are all set in a goal-driven manner to prevent interference and can be thought of as a form of 'early' selection (Braver, 2012). In contrast, reactive control is transient and stimulus-driven and is a form of 'late correction' to resolve the effect of interference after it has occurred (Jacoby et al., 1999; as cited in Braver, 2012). Performing a switch in tasks is thought to increase demand for both of these control processes and the specific level of demand placed on each mode of control is entirely dependent on the situation. For example, if a switch in task is forced the individual will be unaware of a forthcoming switch and therefore will be likely to implement reactive control in response to the switch. Whereas, if the switch between tasks is voluntary it will likely result in the individual implementing proactive control to aid maintenance of goal-relevant information.

Attention is a critical consideration in task switching. William James (1890) defined attention as the process of concentrating on one aspect of the external or internal environment. James proposed that attention operates in a 'voluntary' and 'involuntary'

[1] Other accounts of task switching (e.g. Rubinstein, Meyer, & Evans, 2001) also invoke two processes (e.g. goal shifting and rule activation [Rubinstein, Meyer, & Evans, 2001]).

manner (as cited in Lim & Dinges, 2008). Today we consider voluntary attention as 'top-down' or 'goal-directed' and involuntary attention as 'bottom-up' or 'stimulus-driven' (Sarter, Givens & Bruno, 2001). Top-down attention is driven by knowledge-based mechanisms that enhance the processing of relevant sensory input and produce biases toward relevant stimulus features (Sarter et al., 2001). In this way, top-down control directs and biases attention toward stimuli that are relevant to the current goals of the observer (Awh, Belopolsky, & Theeuwes, 2012). In contrast, bottom-up attention refers to attention that rapidly and involuntarily shifts towards salient features, independent of the current goals (Egeth & Yantis, 1997; Sarter et al., 2001). While salience is usually thought of in terms of stimulus features only, recent studies suggest we must also consider prior history with items as influencing attention (Awh et al., 2012). The important conclusion to draw is that the allocation of attention is influenced by both top-down and bottom-up attention. An example of this is within task switching activities where attention will initially be driven in a top-down manner whilst performing the primary task, however when a switch in task occurs bottom-up attention will take over.

There is a general consensus in the literature that switching from one task to another incurs a cost (commonly referred to as a *switch cost*) to performance. The measurement of switch cost is typically the difference in response accuracy and reaction time between switch trials and trials where no switch has occurred (referred to as non-switch trials; Wylie & Allport, 2000). Task switching is associated with slowed response times and a higher error rates relative to not switching (Hodgetts & Jones, 2006; Monsell, 2003; Rogers & Monsell, 1995). However, the switch in task is less costly if the forced switch occurs during the completion of a subtask (Adamczyk & Bailey, 2004) or when an individual voluntarily chooses to switch tasks (Payne, Duggan, & Neth, 2007).

There are top-down and bottom-up accounts of switch costs (Rogers & Monsell, 1995). Top-down accounts describe executive processes that actively configure the cognitive system to perform a given task. Top-down accounts describe the internal process that prepares individuals for the upcoming task by disengaging and actively inhibiting the task set goals from a current task, while actively reconfiguring to a new task (Arrington & Logan, 2005; Dreisbach, Haider, & Kluwe, 2002; Mayr, 2002; Mayr, Gladasch, Haase, & Grtittner, 2000). Enabling new task goals involves updating goals in working memory (Sohn & Anderson, 2001), retrieving stimulus-response mappings from long-term memory (Mayr & Kliegl, 2000, 2003; Rubinstein, Meyer, & Evans, 2001), and adjusting attentional biases and priorities (Arrington, 2002; Logan & Gordon, 2001; Meiran, 2000). Bottom-up accounts describe response conflicts between activated task-sets that occur successively. On switch trials, the activation of one set of task goals may interfere with another set.

Some researchers have posited that switching between tasks optimally occurs upon the completion of a subtask (Adamczyk & Bailey, 2004; Payne et al., 2007). Katidioti and Taatgen (2014) lend support to this notion suggesting that when cognitive resources are available, the probability of switching from one task to another is increased. Other researchers have turned to the foraging literature to provide insights into task switching. Foraging behaviour in animals is explained by these authors as a trade-off between continuing to eat diminishing supplies in one area versus moving to a new area. Payne et al., (2007, see also Pirolli & Card, 1999) specifically applied this rationale to their task-switching paradigm. In their experiment, Payne et al's used a word generation task where participants were shown a set of seven letters on a screen and were asked to generate as many words as possible from them. Each participant had access to two separate sets of seven letters that they could either freely switch back and forth between (interleave-free) or one of two constraints were applied to their switching; (1) participants could switch freely but ultimately had to spend five minutes on each letterset (interleave-equal), or (2) were forcibly switched back and forth (interleave-forced). In accounting for their results, Payne et al. extended the foraging analogy comparing 'areas' with 'tasks', as well as the 'number of food items eaten' with the 'number of words generated'. Payne et al. proposed three rules that might explain participants task-switching behaviour in their word generation task. Firstly, a time-based leaving rule where participants would spend time on a task independent of the number of words they had generated. Secondly, an item-based rule where participants would continue until broadly the same number of words were generated in each task. Finally, a rule based on giving-up time and rate-of-return that would result in participants spending more time on the task with higher rates of return (Payne et al., 2007). The results of their experiment showed that participants in the interleave-free condition spent more time on the easy rather than hard tasks suggesting that they were trying to allocate their time in an adaptive manner. However, they also reported that individuals in the interleave-equal condition were still inclined to switch between tasks suggesting that switching in favour of the easier task is not the only motive for switching (Payne et al., 2007).

Payne et al's study, is an important one in this thesis, it has provided the task switching paradigm in which this thesis aims to expand upon. Payne et al's focus was to understand the reasons for switching and explore task switching behaviour comparing it specifically when there was an easy and hard task and when the task switching paradigm was controlled either allowing for complete free switching, free switching with some restrictions or completely controlled by the program. It was this paradigm that was of specific interest in the present thesis. Limited research has explored sleep loss and its effects on task switching specifically in terms of investigating specific differences in their switching behaviour with most studies focusing on the basic RT and performance measures. Payne et al's study went beyond this creating a number of additional measures in which to look at switching behaviour, specifically giving-up time, resumption lag, time on task, number of switches, as well as, the usual correct responses, and number of errors. Additionally, Payne et al's study focused on manipulating the different levels of control participants had over their switching and observed how this changed their behaviour. This paradigm was something that had not been addressed within the sleep literature. Currently there was limited understanding of how varying levels of sleep loss impacts specific switching strategies and how this might change when control over switching was modified; this was what this thesis aimed to address, providing a profile of switching behaviour across varying levels of sleep loss.

1.3 Consequence of Interruptions

Both top-down and bottom-up attentional control is required when switching between tasks. Performance on the primary task elicits top-down attention in order to maintain activation of the current task goals. Following an interruption however, attention is driven in a bottom-up manner to resolve the conflicting activations of the task goals for the primary task with those of the interrupting task. Interruptions have been found to lead to a decrease in performance on the tasks, as well as, producing a longer resumption lag when resuming the primary task (Salvucci, Taatgen, & Borst, 2009). The resumption lag is used as a measure of the cost of interruption (Monk, Trafton, & Boehm-Davis, 2008). Resumption lag is increased when the duration of the interrupting task increases (Hodgetts & Jones, 2006; Monk et al., 2008). While a resumption lag is lessened if an interruption occurs at the completion of a task rather than during one (Tanaka et al., 2014; Adamczyk & Bailey, 2004; Czerwinski, Cutrell, & Horvitz, 2000; Salvucci & Bogunovich, 2010; Iqbal & Bailey, 2005).

The resumption lag is thought to result from decay of the mental representation of the primary task (see the Memory for Goals [MfG] model: Altmann & Trafton, 2002, 2007; Katidioti & Taatgen, 2014; Salvucci & Taatgen, 2008; Tanaka, Taatgen, Aoki, & Fujita, 2014). The MfG model describes goal-directed behaviour in terms of interfering tasks producing their own activation which then competes with the activation of the current task goals. The MfG model suggests that the activation level for current goals deteriorates following an interruption and continues to deteriorate with increasing time spent away from the primary task (Foroughi, Werner, Mckendrick, Cades, & Boehm-Davis, 2016). In addition, the more the activation level of the interrupted task increases, the greater the increase in interference for the primary task. If the primary task still maintains a greater activation compared to the activation of the interrupting task then it is likely the primary task will be resumed, however if the activation for the primary task falls below that of the interrupting task it will not be resumed (Altmann & Trafton, 2002; Foroughi et al., 2016).

A number of factors have been identified as causing interference to task performance. These include the type of task being performed when an interruption occurs (Bailey, Konstan, & Carlis, 2000; Zijlstra, Roe, Leonora, & Krediet, 1999), the mental workload (defined as the resources required to perform the task [Hoedemacker, 2002; as cited in Silva, 2014], Adamczyk & Bailey, 2004; Salvucci & Bogunovich, 2010), arousal (Adler & Benbunan-Fich, 2012; Altmann & Trafton, 2002; Speier, Valacich, & Vessey, 1999; Speier, Vessey, & Valacich, 2003) and the opportunity to practice or prepare for the interruption (Trafton, Altmann, Brock, & Mintz, 2003). Though logically independent, these factors can interact (Liu, Wadeson, Kim, & Nam, 2016; Wickens, 2008; Speier, Vessey, & Valacich, 2003).

In the main, interference causes a decrease in performance however there are exceptions to that rule. Research shows that interference causes improvement in task performance when completing an easy task and occurs as a result of the interruption subsequently re-focusing attention that had otherwise been wandering (Speier et al., 2003). Specifically, when an interruption is unexpected it has been observed to increase arousal or decrease boredom both of which can facilitate performance on the primary task (Adler & Benbunan-Fich, 2012; Altmann & Trafton, 2002; Speier et al., 1999, 2003). However, increasing arousal can result in an overload in arousal and a decline in performance (Altmann

& Trafton, 2002). This is referred to as the inverted-U theory proposed by Yerkes and Dodson (1908 as cited in Adler & Benbunan-Fich, 2014).

Lavie's (1995) perceptual load theory suggests that the capacity for perceptual processing is finite and only once we have reached the capacity limit do we become more selective with respect to the information we process such that only task-relevant information is selected. Harder tasks have higher perceptual loads and as such cause an increased demand on the limited mental resources. Therefore when an interruption occurs there is no more resources available and as such causes an overload to attention (Gillie & Broadbent, 1989). It has further been suggested situations with a high perceptual load can lead to a narrowing of attention with important information being missed (Speier et al., 2003). Conversely, situations with a low perceptual load leave attentional resources available to process interruptions without affecting the processing of the primary task (Speier et al., 2003). However, it has been argued that the remaining capacity might allow for the involuntary processing of irrelevant information to impede performance (Lavie, 1995; Roper, Cosman, & Vecera, 2013). Adler and Benbunan-Fich (2014) reasoned that both easy and hard tasks are negatively impacted, with hard tasks leading to an overload in resources causing important information to potentially be missed, while easier tasks results in the processing of distractions and irrelevant information.

The impact of task difficulty on perceptual processing may only be an issue when the two tasks use the same perceptual system (Rice et al., 2012). When tasks share a perceptual system, the working memory capacity associated with that system is limited (Baddeley and Hitch, 1974), thereby causing competition for resources and a compromise to performance (Rice et al., 2012).

The impact of workload on task switching is also largely dependent on whether the individual is able to choose when to be interrupted. With research demonstrating that individuals are more likely to voluntarily switch between tasks during a period of lower workload (Iqbal & Bailey, 2005; Salvucci & Bogunovich, 2010). Salvucci and Bogunovich (2010) demonstrated that when individuals experienced interruptions that did not require immediate attention during periods of high workload, they were strongly inclined to delay the processing of the interruption until a period of lower workload or until the mental workload on the primary task had been lessened. Their analysis showed that during periods of lower workload individuals switched to the interrupting task 94% of the time, while during periods of high workload individuals only switched 6% of the time (Salvucci & Bogunovich, 2010). The reason for switching during periods of lower workload can be attributed to findings that suggest that switching tasks or dealing with interruptions during periods of lower workload will result in less disruption and shorter resumption lags (Adamczyk & Bailey, 2004; Iqbal & Bailey, 2005; Salvucci & Bogunovich, 2010). This is also in line with research that suggests that individuals are more likely to switch following the completion of a subtask compared to switching mid-way through a task. Switching at the completion of a subtask is in line with the memory for goals model (MfG; Altmann & Trafton, 2002) which suggests a need for maintaining activation of the primary task while supressing activation of the interfering task and those who are able to withstand this interference will have a smaller resumption lag and resume the primary task more accurately (Foroughi et al., 2016). Therefore, by switching at the completion of a subtask, and thus lower workload, there is less information to maintain and reload in order to resume the primary task.

Incentives can also influence when an individual is likely to switch tasks. Individuals will often adjust their behaviour in response to incentives due to a change in their priorities (Janssen et al., 2011). However, an individual’s priorities vary and as such their individual incentives to perform a task will differ from person-to-person (Locke & Braver, 2008). Some individuals may be eager to perform their best while others are simply motivated by monetary means. A distinction therefore exists between intrinsic (e.g. enjoyment and interest) and extrinsic (e.g. rewards, deadlines or competitive pressure) incentives (Robinson et al., 2012). Generally, performance on neuropsychological tests tends to improve, in terms of reaction time and accuracy, when participants are financially rewarded or punished (Robinson et al., 2012). Furthermore, Taylor et al., (2004) established that speed of response decreased as the level of the financial incentive increased.

Neuroimaging studies have similarly provided further support revealing differences in brain activation depending on the incentives given, suggesting that incentives may elicit enhanced processing and the relationship between reward and brain activity is dependent on how the individual perceives the incentive (Locke & Braver, 2008; Pochon et al., 2002). Janssen and Brumby (2015) suggest that task switching strategies are affected not only by incentives, but by three factors that influence individuals' behaviour and task performance, which are incentives, task characteristics and individual differences in skill level for task performance. Individual differences particularly play a key role behind people's incentives in task switching behaviour, either due to their skill level for the task, their interest in the task, or the level of priority they have placed on the task (Janssen & Brumby, 2015).

1.4 Working Memory

There are some cognitive factors that might make some people more vulnerable than others to the negative effects of task switching on performance. The level of working memory capacity (WMC) is one. WMC affects both active maintenance of current task goals and the blocking of distractors (Kane & Engle, 2002). Specifically, research has demonstrated that individuals with high WMC have a greater capacity to remain attended to specific information while ignoring irrelevant information compared to their low WMC counterparts (Kane & Engle, 2003). The Memory for Goals (MfG) framework explains this by suggesting that, in comparison to individuals with low WMC, those with high WMC are more likely to maintain the activation level of the primary task while also being better at supressing any interference activations (Foroughi et al., 2016).

Other studies have also established this relationship between WMC and vulnerability to interference. Kane and Engle (2000), for example, established that, following a 16 second interrupting task between the presentation of 10 words and their subsequent recall, low WMC individuals showed more proactive interference and lower recall compared to individuals with high WMC. Similarly, individuals with low WMC were found to be more susceptible to distracting information in a replication of the cocktail party phenomenon (Conway, Cowan, & Bunting, 2001). They detected their name in an irrelevant message 65% time compared to only 20% of the time in high WMC individuals (Conway et al., 2001). These findings demonstrate the variable nature of an individual's ability to cope with distracting information and therefore it is something that needs to be considered in the current research paradigm. The current research will therefore include measures of WMC to establish whether those individuals with high WMC are more effective at task switching and can equally compensate for the interfering effects of fatigue.

1.5 Real-world Application

Although it is commonplace to switch back and forth between different tasks (e.g. replying to an email and then answering the phone) little is understood about when and why people decide to perform more than one attention-demanding task at a time (Sanbonmatsu, Strayer, Medeiros-Ward, & Watson, 2013). However there are many examples of where individuals are required to switch between multiple tasks to complete multiple goals, and it is this increase in mental workload which can result in a deterioration of performance (Casner & Schooler, 2015; Watanabe, 2016). This deterioration in performance can be harmless in a lab-based setting however in the real world it can result in more devasting effects. For example, research reveals that using a mobile phone while driving results in accidents being five times more likely to occur compared to driving without using a mobile phone (Violanti & Marshall, 1996). It is statistics like these that provide clear practical implications of exploring research on attention and switching between tasks either voluntarily or forcibly with application to real-world scenarios.

Understanding task switching within real-world scenarios has largely focused research within the domain of transportation. The impact that distraction and inattention can have on safety poses a major concern for many industries, including driving (Strayer & Johnston, 2001), aviation (Casner & Schooler, 2015) and the maritime industry (Othman, Fadzil, & Abdul Rahman, 2015). Understanding more about both task switching and fatigue in applied settings matters in all transport sectors. However, of specific interest within this thesis is how these findings can be related to the maritime domain. This application to Maritime is of great interest to the funders of this thesis (TK Foundation and Leverhulme Trust) but it also addresses an important gap within the research. Currently, there is substantial research exploring both task switching and fatigue within driving scenarios but there is very limited experimental or observational research exploring the effects on board ships.

Despite the limited research, the maritime industry recognises interruptions and distractions as a prominent cause of accidents, near-misses and incidents (US coast Guard, 2012, as cited in Arslan & Er, 2007) Although the current body of research exploring the effects of interruptions on driving might share similar attributes to the maritime industry, there are also some distinct differences between these two industries. Driving is often a solitary task whereas mariners work as part of a team and that may cause different types of interruptions to arise that are not prevalent in driving scenarios. Additionally, in tasks requiring navigation the time between identifying danger and having a collision is often much shorter in cars compared to ships, so the process of making decisions and predictions is operating at a different timescale, with a slower rate of interaction and more time between action and consequence. Consequently, ship navigation tasks may require longer bouts of transient but frequent attention which differs from the type of attention required when driving a car. Despite this obvious difference between driving and working on board a ship, the way individuals respond to switches in tasks is what is of consequence.

Although there is an absence of work focusing on maritime there are a number of core cognitive components that are continually involved regardless of the applied situation. Performance on these applied tasks are really driven by core cognitive components and although this thesis is aware of the applied context it will be focusing on adding to the literature of the cognitive costs that happen as a result of fatigue. It is for this reason that controlled laboratory studies are necessary. The current research will focus on ensuring the tasks included in the experimental design use tasks that use similar cognitive components that mariners might experience on board a ship.

1.6 Fatigue as a Consequence of Sleep Loss (Sleep Restriction and Sleep Deprivation)

A loss of sleep (National Sleep Foundation, 2007, as cited in Alhola & Plo-Kantola, 2007) can be a major causal factor in disruption and have adverse effects on daily functioning. Fatigue due to sleep loss is also becoming an increasingly prominent issue with a wide variety of jobs now requiring working long or irregular hours, shift work, or due to lifestyle choices (Williamson & Feyer, 2000). In 2010, an epidemiologic study revealed that about one in three workers reported sleeping less than 6 hours most nights (Centres for Disease Control and Prevention, 2010; as cited in Killgore & Weber, 2013). This was a decrease from the 1990's when 7 hours a night was the average (Gallup Organisation, 1995; as cited in Killgore & Weber, 2013). With people continuing to decrease in the number of hours sleep they get per night, it highlights the need for having a better understanding of the effects sleep loss can have on cognitive functioning and performance.

Sleep loss can be classified into two categories; sleep restricted (SR) and sleep deprived (SD). SR occurs as a result of partial sleep loss (e.g. sleeping 4 hours a night for multiple nights), while SD involves a total loss of sleep (e.g. continued wakefulness for 30 hours). SR can further be divided into two categories, chronic SR (3-4 hours asleep for multiple nights) and minor SR (5-6 hours asleep for multiple nights: Wickens, Hutchins, Laux & Sebox., 2015). SR and SD have both been found to result in a decline in performance (Alhola & Plo-Kantola, 2007; Belenky et al., 2003; May & Baldwin, 2009; Pilcher & Huffcutt, 1996).

The major effects of sleep deprivation on cognition, include its effects on alertness and vigilance, sensory perception, emotion, learning and memory, and executive functioning (Killgore & Weber, 2013). Well established research has continually demonstrated that following a loss of sleep, individuals experience slower reaction time, longer and more frequent lapses in attention and increased chances of errors and inconsistent performance (Killgore & Weber, 2013). Sleep deprivation has also been associated with negatively impacting executive functions, however the specific affects remain inconclusive with further research needed to provide a clearer understanding to the nature of these effects.

Executive function incorporates a number of higher order capacities that are involved with the directing behaviour in a goal driven manner (Killgore & Weber, 2013). The term executive function refers to a number of capacities, the most common including the ability to ignore distractions, maintain prolonged attention, plan and sequence thoughts and behaviours, inhibit irrelevant thoughts and behaviours, and the ability to rapidly and flexibly adjust behaviour to changing task demands (Couyoumdjian et al., 2010; Killgore & Weber, 2013). The ability to switch between tasks is regarded a fundamental executive function and involves many of the common capacities included in the executive function (Bratzke, Rolke, Steinborn, & Ulrich, 2009; Monsell, 2003). These capacities require the interaction of multiple brain areas but are specifically contingent on the prefrontal cortex, an area known to be particularly affected by sleep loss (Bratzke et al., 2009; Couyoumdjian et al., 2010; Durmer & Dinges, 2005; Harrison & Horne, 2000; Killgore & Weber, 2013). Research has highlighted this, observing that following SD the functional connectivity of the PFC is greatly impacted and results in reduced activation in the frontal brain regions (Couyoumdjian et al., 2010; Verweij, Romeijn, Smit, Piantoni, & Someren, 2014). Additionally, the association has been observed in both brain imaging studies (Swainson et al., 2003) and neuropsychological studies (Aron, Monsell, Sahakian, & Robbins, 2004). As a result, a number of cognitive functions that are reliant on the functionality of the PFC are impacted by SD; such as attention and divergent thinking (Wimmer, Hoffmann, Richard, & Moffitt, 1992), language (Drummond, Brown, & Gillin, 2000; Harrison & Horne, 1998), decision-making (Harrison and Horne, 1999), memory and response inhibition (Harrison & Horne, 2000), serial subtraction (Drummond et al., 1999). Also and most notably for this thesis, task-switching (Braver et al., 2003; Collette, Hogge, Salmon, & Linden, 2006; Sohn, Ursu, Anderson, Stenger, & Carter, 2000).

While many studies report deficits in executive functions (Jones & Harrison, 2001), while others have failed to find any evidence of such impairments (May & Baldwin, 2009; Pace-Scott et al., 2009). These inconsistent finding suggest that perhaps not all aspects of executive functioning are impacted to the same degree by sleep loss. This notion can be supported by other studies that found differing effects of sleep loss on differing tasks (Jackson et al., 2013; Lim & Dinges, 2010; Pilcher & Huffcutt, 1996). Furthermore, there is considerable inter-individual variability on the influence of sleep loss on task performance (Van Dongen, Baynard, Maislin, & Dinges, 2004; Van Dongen, Caldwell, & Caldwell, 2011) suggesting that some people may be able to counteract the negative effects of sleep loss. These factors, along with different studies using different means to record sleep and administrating different levels of sleep loss, can make it difficult for research to be compared across studies and to predict the impact of sleep loss on performance on different tasks (Olofsen, Van Dongen, Mott, Balkin, & Terman, 2010). This highlights an important issue within sleep research and something this thesis aims to address. By maintaining the same means of measuring sleep, the same levels of sleep loss and the same tasks that participants perform, and only changing one factor at a time will allow for direct comparisons to be made across multiple studies and such this thesis will be able to provide a portfolio of sleep loss related behaviours involved in task switching.

It is understood that task switching requires higher order executive functions that are more complex involving multiple brain regions unlike tasks that measure more simple functions like attention and memory. At present the literature has been heavily focused on investigating the effects of sleep disruptions on relatively simple tasks, such as the psychomotor vigilance test (PVT) and basic reasoning tasks (Lim & Dinges, 2010). In order to perform the more complex Wickens, Hutchins, Laux and Sebok (2015) argued that it is not clear whether the effects observed in simple tasks are replicated in complex tasks and focus needs to be transferred to exploring the effects of fatigue on performing complex tasks. In a meta-analysis they reported that SD and SR both degrade performance on complex cognitive tasks; such as decision making, multitasking and tasks that involved working memory. However, within SR studies the reduction in performance of these types of tasks is highly dependent on the degree to which sleep is restricted (i.e. the number of hours asleep)

(Wickens et al., 2015). Specifically, there appears to be little effect on performance of SR when more than 4 hours of sleep a night (minor restriction) is allowed, while less than 4 hours of sleep (severe restriction) appears to cause profound effects (Wickens et al., 2015). Additionally, research suggests that the same level of performance is observed when individuals have had 8 days of SR (4 hours a night) compared with one night total SD (Van Dongen, Maislin, Mullington, & Dinges, 2003).

Many studies have specifically explored the effects of sleep loss in relation to real-world scenarios. As with task switching research, real world research on fatigue is focused on transportation. Findings from real world studies reinforce the significance of sleep loss in compromising speed of reaction time and performance accuracy (Williamson & Feyer, 2000). Specifically, Williamson and Feyer (2000) found that, on average, 18 hours of waking leads to similar performance levels observed in individuals with alcohol intoxication that is judged to be over the legal limit to drive safely.

Other studies have demonstrated that not all aspects of driving are affected by sleep loss equally. Yang et al (2009) proposed that sleep loss has a greater impact on rule-based driving tasks compared to skill-based tasks. In particular, when drivers were sleep deprived their ability to deal with unexpected disturbances degraded while performing routine driving tasks remained intact. Rule-based tasks were associated with RT tasks and tracking tasks as well as dealing with unexpected disturbances. While skill-based tasks were associated with most of the routine driving tasks, such as lane changing, vehicle following etc. Similarly, Matthews & Desmond (2002) observed that the driving of simple routes compared to more complex ones was differentially affected by sleep loss. Specifically showing that driving straight roadway sections (simple task) impaired heading error and reduced steering activity compared with when driving during curved roadway sections (complex task) which did not produce the same impairments.

Similar to the driving research, studies of fatigue within the shipping industry speak to its importance in the safety of operations ("Project Horizon", 2012). Nonetheless, research exploring fatigue within maritime contexts is limited (Allen, Wadsworth, & Smith, 2008). What is known about seafarers' fatigue seems to consist of anecdotal evidence, with very few controlled and reliable research studies having actually been conducted (Collins, Mathews and McNamara, 2000). Recent years have seen a number of projects attempting to fill this void and provide some reliable research in understanding fatigue in seafarers. An example of such study is "Project Horizon" (2012), which sought to advance understanding of seafarer fatigue. By using ship simulators, realistic working scenarios were created and experienced watch keepers were tested. Data analysis from "Project Horizon" (2012) indicated that the probability of risk occurring at sea would be highest when night watches are combined with prior reduction of sleep. They additionally established that risks are further exacerbated by passages through more difficult waters, or during reduced visibility.

There is some evidence from the "Project Horizon" (2012) research that suggests that there is individual susceptibility to fatigue and this should be a factor that is monitored. This is supported by other research that suggests there is inter-individuality to sleep loss with some people more susceptible to its effects (Van Dongen et al., 2004). A recent follow on study from the "Project Horizon" (2012) was "Project MARTHA" (2016), which looked at changes in objective measures of sleep and subjective reporting of sleep and wellbeing over the course of long journeys. This project demonstrated that the seafarers' overall amount of sleep decreased with time on board, as did their quality of sleep ("Project MARTHA", 2016). Interestingly, data from this project also established that seafarers reported feeling more fatigued at the end of a voyage compared to the beginning, with concerns over job security, environmental factors such as noise and ship motion, job demands, sleep quality, irregular working hours and limited rest hours listed as the common contributing factors to their fatigue ("Project MARTHA", 2016).

The use of both subjective and objective measures of sleep is common place in a lot of sleep research (Åkerstedt, Anund, Axelsson, & Kecklund, 2014; Haavisto et al., 2010; Jackson, Banks, & Belenky, 2016). Subjective measures of sleep are a convenient and cost effective way of gathering information about individuals sleepiness (Kaida et al., 2006). One particular subjective measure that has consistently been used in the literature is the Karolinska Sleepiness Scale (KSS - Âkerstedt & Gillberg, 1990). This 9-point scale allows for an instant record of sleepiness at that precise time. Previous studies have provided validation of the subjective measure, KSS, by demonstrating strong positive intra-individual correlations between KSS scores and alpha and theta electroencephalogram (EEG) activity (Âkerstedt & Gillberg, 1990; Kaida et al., 2006). A more recent study deemed the KSS as an equally sensitive and valid indicator of sleepiness compared to objective measures (Åkerstedt et al., 2014). Specifically, they found that the KSS was sensitive to the different manipulations known to affect sleepiness, as well as, remaining consistent across individuals. A frequently used objective measure is the psychomotor vigilance test (PVT -). The PVT has been demonstrated to be very susceptible to the effects of sleep loss (Dinges et al., 1997). Although the PVT is frequently used in sleepiness or sleep deprivation studies, the correlation between the PVT performances and EEG parameters has not ever been reported (Drummond et al., 2005). Nonetheless, it has been suggested that one measure shouldn't replace another and this is why many sleep studies combine multiple measures to get the most accurate representation of the individual's sleepiness.

Sleep loss and needing to task switch often co-occur in real world scenarios and so understanding their interaction is important. Research has explored the recovery in multitasking performance after experiencing sleep loss. One such study, had participants experience one night of sleep loss (2hr sleep) followed by one night of sleep recovery (8hrs sleep) (Sallinen et al,. 2008). Their sleep was recorded by polysomnography. Polysomnography is designed to monitor sleep stages and cycles and can establish if and when sleep patterns are disrupted. The polysomnography records individuals brain waves, oxygen level in the blood, heart rate, as well as, eye and leg movement (“Polysomnography - sleep study”, n.d.). Participants performed four seventy-minute multitasking sessions. The multitasking sessions consisted of four simultaneously running subtasks; arithmetic, short-term memory, visual monitoring, and auditory vigilance subtasks. The results showed that 8 hours sleep following one night of partial sleep loss is not sufficient for full recovery (Sallinen et al., 2008). However, after just a single night of extended sleep (i.e., beyond 8 hours) fatigued participant’s performance is improved but still worse compared to their control counterparts. Additionally, fatigued participants are also left with an increased vulnerability to further SD (Banks & Dinges, 2007; McCauley et al., 2009). The rate that individuals can recover from the negative effects associated with sleep loss is dependent on two factors (Lamond et al., 2007): The severity of the sleep loss, with more severe sleep loss resulting in a need for longer recovery time and the type of sleep loss experienced, with observations suggesting that cumulative sleep loss requires more recovery time compared to acute sleep loss.

1.7 Conclusions

Chapter One has highlighted the issues with task switching and fatigue and the implications they have in real-world situations. The rest of this thesis will be dedicated to exploring these issues within four empirical studies. Although this thesis is not an applied piece of research the tasks that have been chosen and the topic areas discussed all share fundamental attributes with many everyday scenarios and how to manage complicated tasks when fatigued. Therefore, to begin to understand this, the thesis will address a number of key issues in relation to task switching and fatigue. First, when and why individuals choose to switch tasks and how this might be impacted by fatigue. Second, how tasks are impacted when SR and then how this changes when SD and the fatigue is more severe. Finally, whether fatigue magnifies the switch cost experienced when task switching is forced compared to when it is voluntary. Overall, this thesis will examine performance when switching between two complex visuo-cognitive tasks after experiencing a loss of sleep.

Chapter 2

General Methods

2.1 Introduction

In this chapter, the methods and procedures common to the experiments in this thesis are described. They are presented here to prevent any repetition within chapters. Specifically, within this chapter is the report from a normative study that was run in order to generate the stimulus set used in the main experimental task in Experiments 1, 2 and 3. Exactly, how these stimulus sets were generated will be discussed within this chapter. Followed by a detailed account of the main experimental task in which they were used in.

Given the variable and sensitive nature of sleep, the high chance of participants withdrawing or not following the sleep manipulation requirements, as well as, needing to have sleep recorded accurately, a number of measures were put in place. These measures were selected due to their use in previous research and their subsequent validity in accurately recording sleep data. These measures are detailed within this chapter.

Of equal consideration is the involvement of working memory in participant's task performance. The variable nature of individuals ability to cope with conflicting and distracting information is related to their working memory capacity. It is for this reason that the thesis will include measures of working memory, to ensure that any results observed are completely due to the impact of the sleep manipulation, rather than individuals varying working memory ability. These working memory measures are detailed within this chapter.

2.2 Participants

Participants had to be proficient English speakers defined as having at least grade C

GCSE English Language (or equivalent). Participants were asked at the beginning of the first testing session if they had any history of sleep or memory disorders and if they used any medication that might adversely affect sleep. If they reported ‘yes’ to any of the above they were excluded from participating in the study.

Participants were recruited by an opportunity method of selection in which people volunteered to take part in exchange for undergraduate course credits (maximum of 162 credits), monetary compensation (maximum of £103.50) or a mixture of the two (where participants didn’t need the full amount in course credits the difference would be paid in the money equivalent).

All participants were fully briefed prior to participation and gave their informed consent (see Appendix 1). Participants were debriefed after their participation (see Appendix 1). All studies were passed by the University of Southampton’s Ethics Committee.

2.3 Design and Procedure

Participants took part in two separate computer-based testing sessions, each lasting up to 75 minutes. The two sessions were either 1 or 6 days apart depending on the specific study; Experiment 1 was run over six days while Experiments 2, 3 and 4 were only over two days. During the first session the entire experiment was introduced and both working memory (Ospan; Foster et al., 2015; and 3-Back; Shackman et al., 2006) and fatigue (Karolinska Sleepiness Scale; Âkerstedt & Gillberg, 1990; and Psychomotor Vigilance Task; Dinges & Powell, 1986) were measured. Each participant was given a FitBit charge 2 HR™ (activity monitor) (https://www.fitbit.com/uk/charge2) to wear for the duration of the experiment. Sleep was tracked between the two testing sessions. Participants completed the online tests at specific times depending on their assigned condition. At the second testing session, all participants returned to complete a series of computer-based tasks. Fatigue was measured using the KSS and PVT and participants were then required to complete the main experimental task. In Experiment 1 and 2 this was the Voluntary word generation task, Experiment 3 was the Forced word-generation task and Experiment 4 was the colour/number change detection task; details of which are in Chapter 6.

Testing times for both sessions were controlled and all participants were tested in the same time slots in order to control for circadian rhythm.

2.4 Stimuli and Tests

Measures of Sleep

Sleep was measured using a basket of three measures. First, participants were given a FitBit charge 2 HR™ (activity monitor) (https://www.fitbit.com/uk/charge2) to wear for the duration of the experiment. The FitBit uses a combination of movement and heart rate pattern to determine if an individual is asleep. It provides an unobtrusive and cost-efficient way to monitor sleep whilst allowing participants to remain in their home setting. The polysomnography is the 'gold standard' of measuring and monitoring sleep and is often used as the reference in which other measures of sleep are equated to (Mantua, Gravel, & Spencer, 2016). Of importance in the present thesis, the Fitbit charge 2 HR™ has been validated with research demonstrating an accuracy to detect sleep when compared with the polysomnography (Zambotti et al., 2018). Equally, previous research has further observed that it can produce both accurate total time asleep and sleep efficiency when compared with a clinical portable sleep monitor (Liang & Martell, 2018). Second, participants completed a small battery of online tests. These online tests consisted of a series of simple maths and literature related questions and a Sudoku puzzle. The time at which they completed the tests was condition dependent. For the control condition, test completion was during the day between 9am and 9pm, for those in the SR condition they had to do this before and after specific sleep times (e.g. 2am and 7am), and finally, those in the SD condition completed the tests at two- and half-hour intervals throughout the night between 10pm and 10.30am. The purpose of the tests was only to ensure that participants were active. The data gathered during these test sessions was not analysed. Finally, participants kept a sleep diary of the times they went to sleep and woke up the next day (see Appendix 3 for participants self-reported sleep diaries).

Together, the sleep measures provide objective and subjective measures of participant sleep behaviour during their participation in the experiment. Their inclusion follows similar practices used in other sleep literature (Durmer & Dinges, 2005; Goel, Rao, Durmer, & Dinges, 2009; Haavisto et al., 2010; Kaida et al., 2006; Killgore, 2010; Kosmadopoulos et al., 2014; Van Dongen et al., 2003).

Measures of Fatigue

The Karolinska Sleepiness Scale (KSS; Âkerstedt & Gillberg, 1990) was used to measure fatigue. The KSS (see Appendix 2) is a subjective measure of sleepiness with participants required to respond on a scale from 1 to 9 (1 – extremely alert to 9 – very sleepy). Participants also completed the Psychomotor Vigilance Task (PVT; Dinges & Powell, 1986). The PVT test is a sustained attention task that measures the speed of responses to stimulus onsets and false alarms (i.e. responding in the absence of a stimulus). The task comprises of a black screen with a white circle intermittently appearing in the centre of a computer screen. Participants must respond quickly to the onset of the white circle by pressing a response button.

Measures of Working Memory Capacity

Working Memory Capacity (WMC) is associated with attentional control (Kane & Engle, 2003). Two WMC tests were recorded on Day 1 in all studies. These tests were Operation Span (Ospan, Foster et al., 2015) and 3 back memory (verbal and spatial; Shackman et al., 2006) tasks.

Operation Span

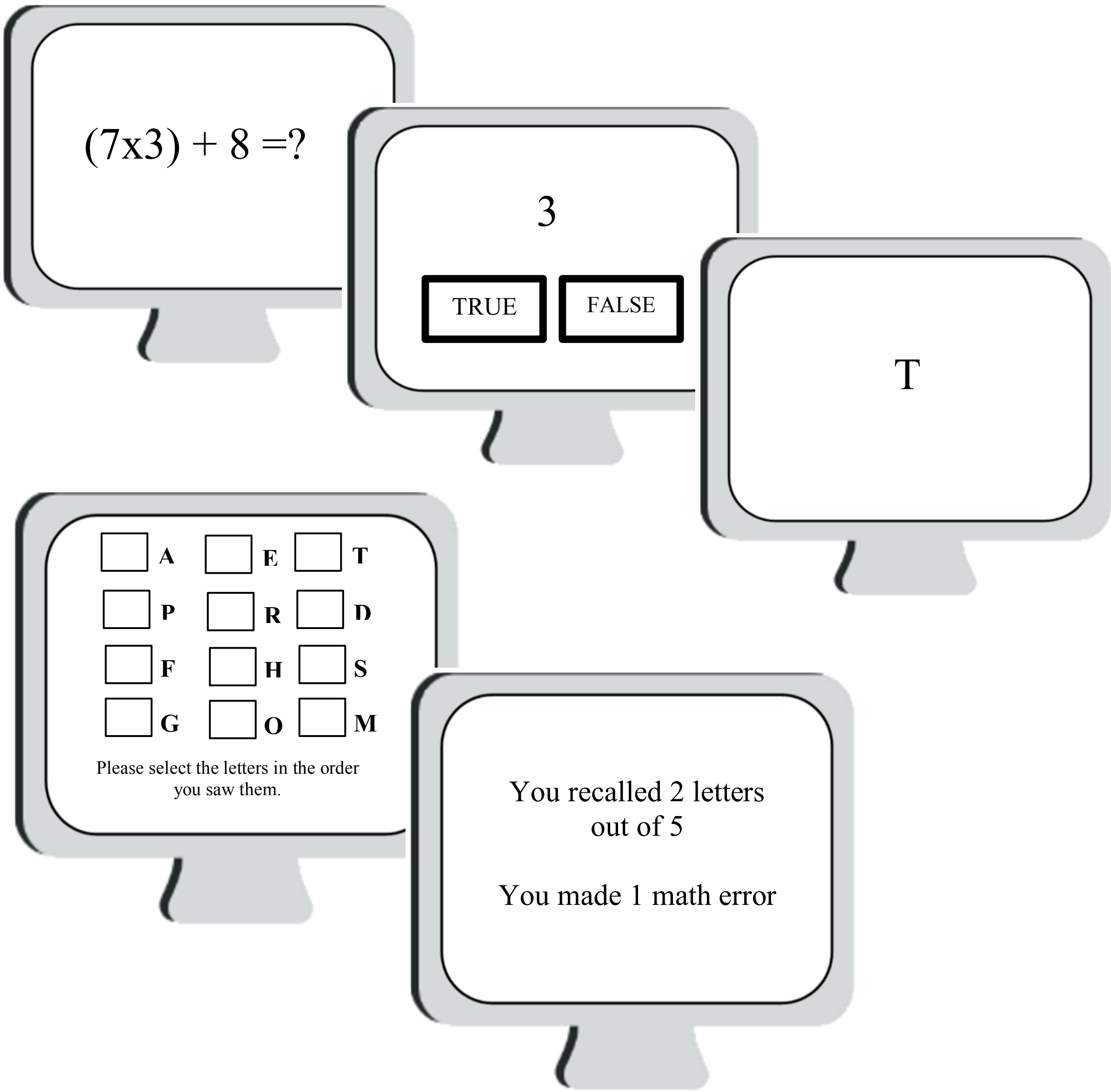

Figure 2.1 Example of the Ospan task (see below for detailed description of the task). A maths problem is presented, followed by a digit which is either correct or incorrect to the maths problem. Following this a letter is presented. Participants are then asked to recall the letters in the order they'v been seen. Finally, a feedback screen is presented.

The Ospan test (Foster et al., 2015) presents a sequence of items that participants need to remember (i.e. a sequence of letters) whilst completing a distractor task (i.e. a solving a simple mathematical equation) between each of the letters in the sequence. Firstly, a mathematical problem appears followed by an answer in which participants have to state if it is the 'True' or 'False' answer to the mathematical problem. After the mathematical problem a letter appears in the centre of the screen for a few seconds. Participants are required to remember this letter as they will be asked to recall it at the end. This mathematical problem and letter sequence will continue back and forth for a number of trials, resulting in anywhere from two to seven letters that participants will need to remember. At the end of each sequence participants are asked to recall the letters they saw, and to do so in the order they saw them. They are then presented with a feedback screen detailing how many letters they correctly recalled and how many maths errors they made. The partial score was used for the analysis and is defined as the total number of letters recalled in the order as presented.

Spatial and Verbal 3-Back Task

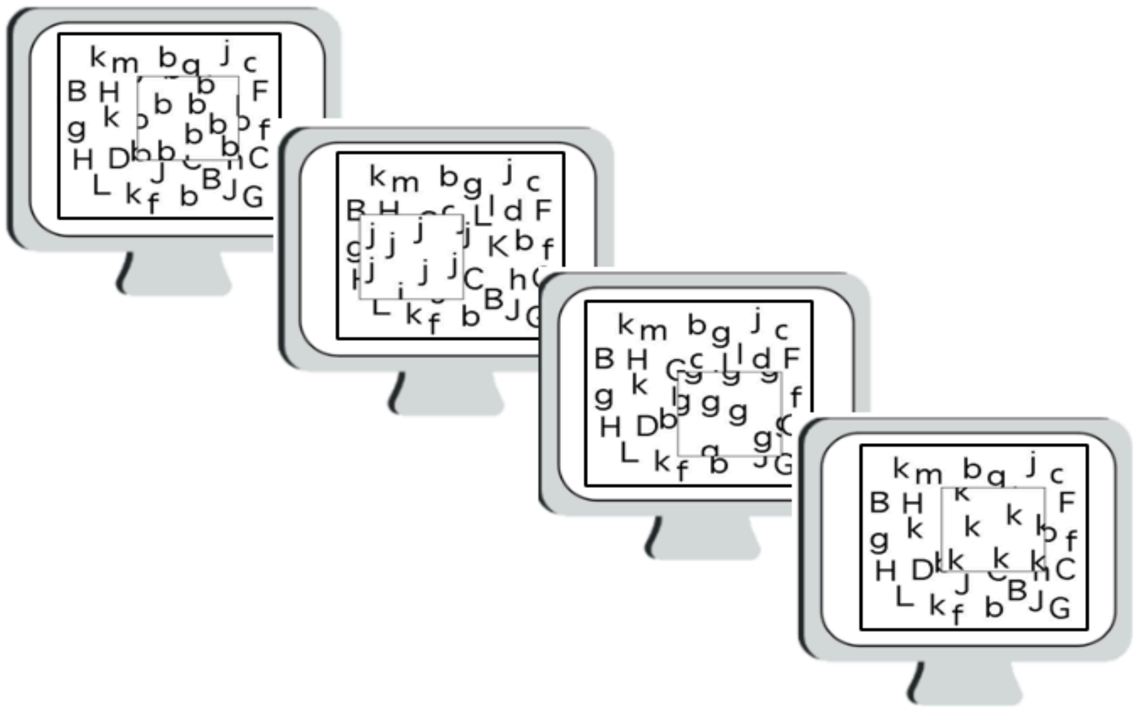

Figure 2.2 Example of both the Spatial and Verbal 3-Back task (see below for detailed description of the task).

The 3-back (Shackman et al., 2006) task requires participants to decide whether each stimulus in a sequence matches the one that appeared three items ago (Kane, Conway, Miura, & Colflesh, 2007). The verbal and spatial 3-back tasks were identical in appearance (Shackman et al., 2006). The verbal 3-back task requires participants to decide whether the letters in the small square match those letters shown in the small square three screens previously, while the spatial one required remembering the locations of the small square (see Figure 2.2 for an example of the task). There were six possible locations or letters that could appear. Screens were presented for 500ms with a 2,500ms interval between screens. Every trial required a response to indicate either a match or non-match with the stimulus presented three screens previously. No feedback was given and the task continued even if no response was made. Participants responded using a Cedrus response box with two response buttons;

one for a match and another for a non-match. The response time from all correct responses was used in the analysis.

Normative Study to Generate Stimulus Set

A normative study was conducted as a means to generate the stimulus sets for the word generation task in Experiment 1, 2 and 3. It was important that the stimulus sets used in all the studies included lettersets that could be categorised as either ‘easy’ or ‘hard’. All participants were anonymous however they all consented to being 18 years old or older and having English as their first language. Twelve participants completed survey one and eight completed survey two.

In order to generate these lettersets a number of steps needed to be taken. Firstly, each letter in the alphabet was assigned a number between 1 and 26 (e.g. A=1, B=2, C=3 etc.). Those numbers were then put into a random number generator. The number generator selected seven random numbers and those numbers were then translated back into their letter counterparts. This was done fourteen times to end up with fourteen different lettersets. Two additional lettersets from Payne et al’s (2007) study were also included. The reason for including these two lettersets was to use the mean number of words generated for these two lettersets as the baseline in which to select the other six ‘easy’ and ‘hard’ lettersets (chosen from the fourteen lettersets generated) needed for the main experimental task. These lettersets were then put into an online survey (isurvey.soton.ac.uk). Each letterset had a five-minute timer linked with it so that participants were only able to spend five minutes on each letterset and as such allowing for equality between them. The reason for only allowing five minutes per letterset was to ensure consistency because in the main experimental task participants would only have five minutes on a letterset or ten minutes between two lettersets. Therefore, it was important to keep this consistency in order to fully work out the mean number of words generated for each letterset.

Participants were asked to generate as many real words as possible from the lettersets within five-minutes before they were automatically moved to the next letterset. These words could be anything from two letter words to seven letter words long (see Appendix 3 – for list of words generated by each participant). Following examination of participants responses, any repeated words, non-words or words that used the wrong letters were discarded. The correct words were then added together in order to generate a mean for each letterset (see Table 2.1 for the individual means for each letterset).

Table 2.1 Displays the mean number of words that can be generated from each of the lettersets used in the normative study. The lettersets in bold are the lettersets that were used for the stimulus in the main experimental study. The lettersets that are underlined were the lettersets originally used in Payne et al., (2007) study and used as a baseline to select the other six lettersets.

Letterset	Mean	SE	Letterset	Mean	SE
(1) LEOXBWH	11.33	1.46	**(9) LNAOIET**	**24.38**	**1.79**
(2) CYAHLIT	**9.73**	**1.17**	**(10) ESIFLCE**	**10.13**	**1.66**
(3) SIPERLM	15.58	2.06	(11) BYTIAPJ	8.25	.80
(4) DJMKILL	7.33	.51	(12) IRCDEOE	15.38	1.44
(5) PBVWONV	4.83	.47	(13) HRTUQSF	8.00	.96
(6) TORRLPB	5.83	.66	**(14) STAUNRO**	**20.50**	**2.19**
(7) OAEWXPF	**8.36**	**1.01**	**(15) GARKTIX**	**9.00**	**.82**
(8) EMTGPEA	**17.00**	**2.46**	**(16) MTSHOEL**	**18.38**	**3.15**

As stated previously, the two lettersets underlined were originally used in Payne et al., (2007) study. These two lettersets were used as basis for selecting the other six lettersets as they had been validated in a previous study as ‘easy’ (LNAOIET) and ‘hard’ (ESIFLCE).

Therefore, of the other six lettersets, three were chosen because their mean was the closest to the mean of letterset 'LNAOIET' (M = 23.63) and the other three were chosen because their mean was the closest to the mean of letterset 'ESIFLCE' (M = 10.13). Equally it was important that there was no overlap established between the means of any of the hard lettersets chosen with any of the easy lettersets chosen. There was no overlap between the mean number of words in the Easy lettersets (SD = 2.62) compared to those in the Hard lettersets (SD = 0.42).

The frequency of the words that participants generated in the normative study was analysed for each of the sixteen lettersets. This was to ensure that each of the possible lettersets had both high and low frequency words. Equally, in the experimental studies word frequency is examined to establish whether any differences are observed between controls and sleep loss conditions and in order to prevent ceiling or floor effects occurring there needed to be a large enough difference between low and high frequency word groups.

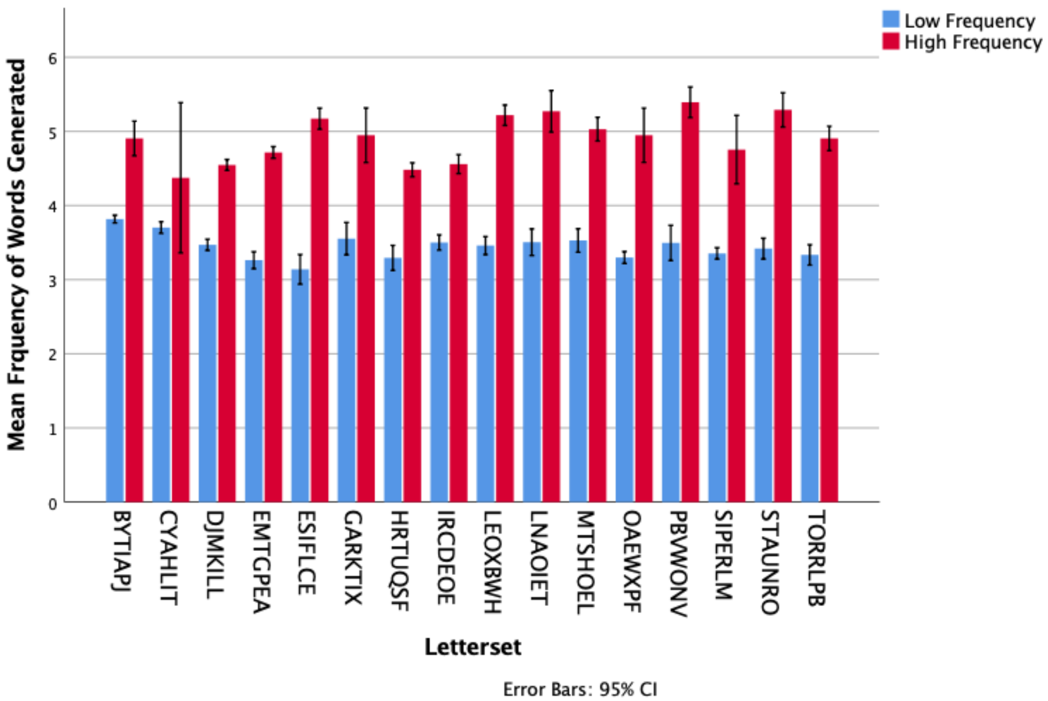

Figure 2.3 Mean Frequency of Words Generated in each of the lettersets from the Normative Study.

Word-Generation Task

Within the main experiment, participants were required to complete four ten-minute trials. Each trial consisted of an easy-hard letterset pairing (see Figure 2.3 for letterset pairings). Participants then had ten minutes to generate as many words as possible. Participants were either (1) allowed to switch between the two lettersets freely and as often as they liked within the ten minutes of the task (Voluntary switching) or (2) allowed to switch as often and as frequently as they liked but were ultimately forced to spend a total of five minutes on each letterset (Voluntary-Equal switching) or (3) forcibly switched between the two lettersets at random intervals that results in them spending five minutes on each (Forced switching). The order that participants completed each of the four trials was counterbalanced across participants.

Table 2.2 Displays the mean number of words that can be generated from each of the 'easy' and 'hard' lettersets. The lettersets in bold are the original letterset used in Payne et al.'s study.

	Easy Letterset	Mean	SE	Hard Letterset	Mean	SE
Pair 1	**LNAOIET**	**24.38**	**1.79**	**ESIFLCE**	**10.13**	**1.66**
Pair 2	STAUNRO	20.50	2.19	CYAHLIT	9.73	1.17
Pair 3	MTSHOEL	18.38	3.15	OAEWXPF	8.36	1.01
Pair 4	EMTGPEA	17.00	2.46	GARKTIX	9.00	.82

Each trial proceeds as follows. A letterset was presented on a coloured background (yellow for the 'easy' task and blue for the hard') in the centre of the screen with the total time left on the task displayed underneath. A box marked "Switch Task" was presented at the top of the screen. Participants were required to switch between lettersets by clicking this box using the mouse. Participants were then required to type out the word they wished to generate on the keyboard and the letters would appear at the bottom of the screen. Once the word was complete, the participant pressed the enter key and the word would disappear leaving a blank space available for the next response. Participants were instructed to generate as many words as possible during the task.

The rationale for having yellow highlighting one letterset and blue the other, was to notify the participants that a switch had happened – this was especially important when the participants had no control over their switching as detailed in Chapter 5. The yellow highlighted letterset was always the 'easy' letterset, and the blue was the 'hard' letterset. Participants were not notified that there was an easy or hard letterset and they were told the change in colour was to simply signal a change in letterset. The reason for not disclosing that there were differences in task difficulty was to see how participants behaviour changed and adapted and to see how this might differ between the control and experimental participants.

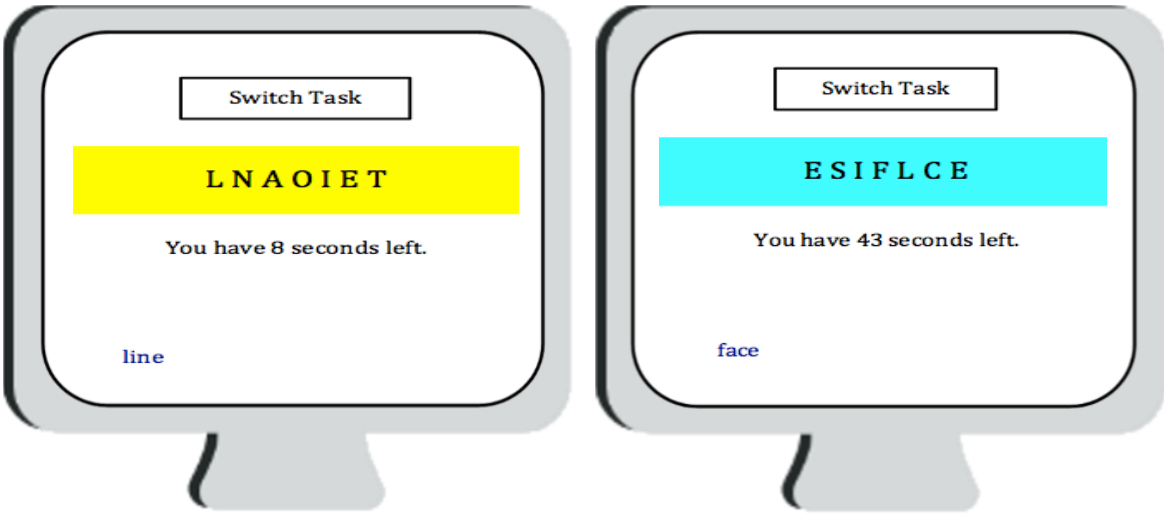

Figure 2.4 Displays a screenshot of the task depicting both the easy (image on the left) and hard (image on the right) letterset.

In the Voluntary condition the countdown clock counted down from ten minutes regardless of which letterset the participant is engaged with. In the Voluntary-Equal condition each letterset is assigned its own clock with each clock counting down from five minutes. The clock only counts down while that letterset is visible. Once the time limit for one letterset is reached (i.e. 5 minutes) the programme will automatically switch to the other letterset, and participants will no longer have the possibility of switching back. In both Voluntary and Voluntary-Equal conditions, participants were informed that they could switch between the tasks as frequently as they wish. However, in the Forced condition no clock will be present at any point.

This experimental task was chosen for a number of reasons. Firstly, it needed to replicate similar cognitive traits that would be required on board a ship. Unlike, most task switching paradigms that use simple target detection tasks this experimental paradigm uses a complex task that more closely replicates daily tasks and tasks that might be completed on board a ship. Particularly, word generation tasks use cognitive components such as working memory, cognitive flexibility and sustained attention, all components that would be used on board a ship. Secondly and more importantly, this research wanted to better understand the effects of sleep loss beyond what is currently addressed within the literature. Much of the current literature presently only explores the effects of sleep loss on two simple measures; RT and accuracy. Examining additional measures would provide a complete overview of the effects of sleep loss and whether it effects both task switching behaviour but also the strategies employed, something that has limited understanding in the current literature. Specifically of interest is the disengagement/reconfiguration process. Switching between tasks requires the disengagement from the current task followed by the reconfiguration of the task-set to be in line with the new task goals (Couyoumdjian et al., 2010). In the present task this disengagement/reconfiguration process will be observed in the giving-up time (GuT, defined as the time between last response and choosing to switch) and resumption lag (RL, defined as the time between the switch and the first response) measures. These two measures are particularly informative as they will be able to highlight whether this process is affected by sleep loss and in what way. Whether sleep deprived participants require longer to achieve this process or whether they are unable to complete it successfully at all, and without this process then what happens to their task performance. In order to measure the GuT and RL the task needed to allow for participants to be able to finish or start the task whenever they were ready without missing any vital task-relevant information; this word generation task allows this. Additional measures include, time on task (ToT), words generated, number of errors and frequency of the words generated.

2.5 Apparatus

All stimuli were displayed on a 21-inch CRT monitor operating at a resolution of 1,024 x 768 and a refresh rate of 120Hz. Participants were seated 60cm from the display. The word-generation task and the Ospan task were programmed using E-prime 2.0 software and participants made responses using the keyboard and the mouse. The 3-Back task was programmed using Presentation and the PVT was programmed using SR Research Experiment Builder and both had participants responding using a 2-button Cedrus box.

2.6 Summary

In summary, all the experiments presented in this thesis have the same measures of sleep, fatigue and working memory. Experiments 1, 2 and 3, also have the word generation task in common, with the exception of the switching allocation. This chapter has therefore noted the common elements used throughout the thesis, while any differences will be detailed in specific chapters.

Chapter 3

The Effects of Sleep Restriction on Voluntary Task Switching

3.1 Introduction

Task Switching

A fundamental problem for the human information processing system to solve when required to perform multiple tasks is deciding which task to work on and when to switch between tasks (Payne et al., 2007). Sometimes choice is removed when individuals are forced to change between tasks through some imposed scheduling, but other occasions allow choice. Studies have examined forced task switching more than voluntary task switching (Panepinto, 2010). This is surprising as research has observed that in real-world situations voluntary task switching is common, accounting for up to half of all interruptions (Czerwinski, Horvitz, & Wilhite, 2004; González & Mark, 2004).

The voluntary versus forced distinction is important because the effects of switching on performance are likely to differ between the two. For example, forced switching can lead to a lag in the time taken to resume a task after an interruption has occurred (Adamczyk & Bailey, 2004), whereas voluntary switching allows for preparation and selection of a more optimum point to switch (Iqbal & Bailey, 2005; Payne et al., 2007). Nevertheless, both forced and voluntary task switching have been found to result in increased reaction times (RTs) and errors compared to continuing on a single task. The cost to RT and errors on performance when moving between tasks is known as the 'switch cost' (Arrington & Logan, 2004; Gutzwiller, 2014; Monsell, 2003; Spector & Bierderman, 1976; Wylie & Allport, 2000). Switch cost effects are less severe in the voluntary task switching paradigms compared to the forced switching (Arrington & Logan, 2004).

Switching between tasks requires the preparation of task-set reconfiguration needed to execute the new task and disengage from the previous task (Couyoumdjian et al., 2010). The switch costs usually associated with a switch in tasks is reduced if there is an opportunity to prepare before the stimulus is presented, with the switch cost decreasing when more time is available for task-set reconfiguration (Couyoumdjian et al., 2010; Meiran, 2000). However, when the interval between finishing the primary task and switching to the new task was longer the switch cost was greater (Arrington & Logan, 2004; Meiran, 2000).

Sleep Restriction

Sleep loss leads to a general deficit in decision-making and reasoning skills (Glass, Maddox, Markman, & Schnyer, 2009). This can result in a deterioration in multitasking, information assimilation, poor updating of strategies to accommodate new information, and risk assessment (Durmer & Dinges, 2005; Sallinen et al., 2008). Sleep loss also leads to reduced mood and motor function (Durmer & Dinges, 2005).

Simple short duration tasks (e.g. target detection, arithmetic and visual and auditory monitoring) are particularly sensitive to cumulative deterioration of sleep (Haavisto et al., 2010). Sleep restriction (SR) has also been found to exacerbate the time-on-task effect (also referred to as the vigilance decrement), which is the progressive deterioration of performance over the course of the task as a result of reduced attentional vigilance (Dinges & Kribbs, 1991; Haavisto et al., 2010).

A necessary part of successful task-switching is the disengagement and reconfiguration process. It is this process that has been shown to be directly affected following one night of total sleep deprivation (SD) with a reduction occurring in both the preparation component (reducing the ability to reconfigure the task-set) and the disengagement component (reducing the ability to disengage from the previous task set (Couyoumdjian et al., 2010). Research has yet to investigate whether this process is affected by more mild sleep loss, such as SR, something that is of interest in this investigation.

Much of the research has focussed on examining the effects of SD on behaviour and performance by measuring basic skills such as vigilance and aspects of memory (Harrison & Horne, 2000; Pilcher & Huffcutt, 1996). Measuring these basic skills within a monotonous task and with a lack of environmental stimulation increases the adverse effects induced by a loss of sleep (Harrison & Horne, 2000). High-level complex skills are relatively unaffected by SD as a result of the interest that the tasks generates and the subsequent additional effort individuals deploy in order to overcome their sleepiness (Harrison & Horne, 2000). Although the majority of research has focused on the effects of SD on simple tasks, research has also highlighted that for basic skills like vigilance, it is impacted by SR. Specifically, research has demonstrated that the more severe the SR the more the behaviour is impaired (Banks & Dinges, 2007). Therefore, of interest in the present study is whether SR produces this same pattern when the task is more complex.

Working Memory

Baddeley posited that working memory (WM) is dependent on a central executive system (1992; 2001), with further suggestions that the constructs of the executive attention and that of WM are closely related (Engle, 2002; Kane, Bleckley, Conway, & Engle, 2001). Specifically, without the ability to sustain attention it would be impossible to perform tasks in a goal-directed manner, therefore both constructs are thought to be fundamental to performance. Performance on WM tasks are predictive of performance on a range of other cognitive tests (Engle, 2002). Specifically, previous research has established working memory is a key process in successfully switching between tasks (Kane & Engle, 2002).

With individuals with high working memory capacity (WMC) much more able to maintain activation of task goals while also supressing interfering activations in comparison to low WMC individuals (Foroughi et al., 2016). It is therefore prudent that given the involvement of WM in both sleep loss and task switching ability that it is controlled for within the present experiment.

Different cognitive skills have been found to be differentially impacted by sleep loss (Durmer & Dinges, 2005; Pilcher & Huffcutt, 1996). Brain imaging studies have highlighted the impact just one night of sleep deprivation has on tasks, specifically those requiring high-level processing; such as working memory and language (Carpenter, 2001). However, there is evidence that indicates individual differences in these deficits and that these differences may be as a result of trait-like vulnerabilities (Van Dongen et al., 2004). Van Dongen et al., suggested that this cognitive vulnerability to sleep loss could be related to three domains: (1) self-evaluation of sleepiness; (2) cognitive processing capability (e.g. working memory): and (3) alertness. It is these differences in susceptibility to sleep that are believed to account for the different findings observed within the literature of cognitive performance following sleep loss and why conducting sleep research is particularly troublesome (Van Dongen et al., 2003).

Rationale

Sleep restriction will lead to increased errors and 'giving up' time, as well as, reduced word generation, number of switches, and resumption time following a switch compared to Controls.

3.2 Method

Experiment 1 compares behavioural and cognitive performance between individuals who have maintained normal sleep with those who have had their sleep restricted to 4 hours per night for 3 nights.

Participants

Eighty-one participants were initially recruited but seventeen dropped out or were removed due to not following experimental procedures correctly. Not following experimental procedures was categorised as sleeping over the hours stipulated, removing the Fitbit, or not attending all testing sessions at the specified times. Participants that dropped out named the reasons as either the study was more of a commitment than they thought or that they couldn't cope with the lack of sleep. Sixty-four undergraduate and postgraduate students took part in Experiment 1 (41 females; M =20.17, SD =2.64, age range = 18 - 31 years old). All participants had normal vision or corrected-to-normal vision.

Design

In this section the specific details of the experiment are detailed (for an overview of the basic method see Chapter 2). Experiment 1 had two between-participant factors, task-switching rule (free choice of time spent on each of the two word-generation tasks versus fixed equal time, hereafter called Voluntary and Voluntary-Equal[2]) and sleep condition (restricted versus normal). Participants were assigned randomly to the between-participant conditions. Those in the SR condition slept for four hours between the hours of 3:00 a.m.

[2] The reason for only using two of the three conditions that Payne et al used in their study is that initially the current research wanted to investigate switching between tasks when the choice is voluntary before in a later study exploring how behaviour is affected when the voluntary choice is removed (see Chapter 5).

and 7:00 a.m. for three nights (on experimental Days 3-5); those in the normal sleep condition maintained their normal sleep patterns for those three nights.

3.3 Results

There are two sections to the results. The first section tests whether the sleep manipulation induced fatigue. The second section tests the impact of SR on task performance and switching.

Was the fatigue manipulation effective?

Independent samples *t*-test were used to compare the hours slept from the three nights, KSS score and PVT measures between control participants and SR participants. The measures of the PVT used were the reciprocal RT, false alarms and the number of lapses in attention (e.g. any RTs that were greater than 500ms). The mean of the reciprocal RT was used as a measure due to the RTs being skewed. By doing a reciprocal transformation on the RT data it made the distribution normal. The KSS and PVT data were taken from the second testing session, except for the within-group comparisons.

Due to a technical error with the Fitbit devices, 26 participants failed to have some of their sleep data properly recorded (16 SR participants and 10 Control participants). This therefore effects the number of hours slept data and needs to be considered when examining the data. To compensate for this missing data however, a multiple regression was run in order to predict the missing Fitbit hours for those 26 participants using only the thirty-eight participants who had full datasets. The regression addressed the missing data by predicting the hours participants slept from their self-reported sleep diaries (See Appendix 3 for all of the participants self-reported sleep diary data). The participants self-reported sleep diaries consisted of them noting down as accurately as possible the time they fell asleep and the time the woke the next morning for every night of the experiment (i.e. went to sleep at 11pm and woke at 7am). From the thirty-eight full participant data-sets their hours slept on the last three nights according to their self-reported hours were added together, as was the last three nights of recorded hours sleep on the Fitbits. The sum of the Fitbit hours was set as the dependent variable and the sum of the self-reported sleep was the independent variable. In order to calculate the missing Fitbit data, the data from the regression ($R_2 = .59$, $p < .001$) was then used within the following equation: $Y = b_1 X + b_0$ (estimated Fitbit hours = .521 x Sum of last 3 nights of self-reported sleep data + 9.047). This equation estimates the amount the Fitbit hours will change based on the self-reported sleep data. Once this has been established calculating the Fitbit hours for participants who have missing data can be done using the self-reported sleep data (See Appendix 3 for all of the participants self-reported sleep diary data). The use of subjective reporting of their sleep hours is a continually used tool and is thought of as an accurate and feasible method to screen for sleep behaviours and disorders (Jungquist, Pender, Kilngman & Mund, 2015). These are used as standard to support the objective measures of sleep. Additionally, the sleep diary data was cross checked with their online surveys to ensure that each was completed to the times specified in the experiment criteria and thus further supports the times they were awake.

SR participants slept less hours compared to the Control condition over the three nights ($M = 16.19$, $SD = 2.76$ versus $M = 20.04$, $SD = 3.64$), $t(62) = 4.82$, $p < .001$, $d = 1.19$. When the total hours slept for the three nights was averaged, SR participants on average slept less hours a night compared to the Control condition ($M = 5.40$, $SD = .92$ versus $M = 6.68$, $SD = 1.22$), $t(62) = 4.82$, $p < .001$, $d = 1.19$; and had increased fatigue as measured by the KSS compared to controls, ($M = 6.61$, $SD = 1.73$ versus $M = 4.93$, $SD = 2.05$; $t(62) = -3.56$, $p = .001$, $d = .90$.

There was significantly more PVT false alarms in the SR condition compared to the Control condition ($M = 1.31$, $SD = 2.66$ versus $M = .36$, $SD = .78$; $t(42.49) = -2.03$, $p = .05$, $d = .48$). There was no significant difference in the number of PVT lapses in the SR condition compared to the Control condition ($M = 7.28$, $SD = 16.24$ versus $M = 2.54$, $SD = 3.38$; $t(38.86) = -1.71$, $p = .10$). There was also no significant difference between the SR and Control conditions for the PVT RT, $t(62) = .59$, $p = .56$.

With respect to within-group comparisons, SR led to increased KSS scores, RT and lapses in attention on Day 2 compared to Day 1 ($M = 6.66$, $SD = 1.65$ vs. $M = 3.83$, $SD = 1.31$, $p < .001$, $d = 1.90$; $M = .004$, $SD = .001$ vs $M = .004$, $SD = .00$, $p = .001$, $d = .82$; $M = 7.83$, $SD = 17.98$ vs $M = .76$, $SD = 1.22$, $p = .044$, $d = .55$ respectively). But no differences in false alarms were observed ($p = .79$).

In comparison Controls did not differ between Day 2 and Day 1 on KSS scores ($M = 4.76$, $SD = 1.64$ versus $M = 4.19$, $SD = 1.40$, $p = .104$), lapses in attention ($M = 2.50$, $SD = 3.59$ versus $M = 1.23$, $SD = 1.79$, $p = .07$) and false alarms ($M = .36$, $SD = .79$ versus $M = .59$, $SD = 2.36$, $p = .68$). They did however, differ on their reciprocal RT on Day 2 compared to Day 1 ($M = .004$, $SD = .00$ versus $M = .004$, $SD = .00$, $p = .001$, $d = .50$).

Table 3.1 Participant means for the fatigue measures (hours slept, KSS and PVT).

Measure	Controls		Sleep Restricted	
	Voluntary	Voluntary-Equal	Voluntary	Voluntary-Equal
No. of Participants	15	13	18	18
Sleep Hours	*M* =20.14, *SD*=3.58	*M*=19.93, *SD*=3.86	*M*=16.31, *SD*=2.86	*M*=16.06, *SD*=2.74
Average Sleep from 3 nights	*M* = 6.71, *SD*=1.19	*M* =.6.65, *SD*=1.29	*M* =5.44, *SD*=.95	*M* =5.35, *SD*=.91
KSS Score	*M*=4.80, *SD*=2.04	*M*=5.08, *SD*=2.14	*M*=6.89, *SD*=1.94	*M*=6.33, *SD*=1.49
PVT RT>500ms	*M*=2.93, *SD*=4.18	*M*=2.08, *SD*=2.22	*M*=7.78, *SD*=9.88	*M*=6.78, *SD*=21.09
PVT False Alarms	*M*=.40, *SD*=.83	*M*=.31, *SD*=.75	*M*=2.06, *SD*=3.47	*M*=.56, *SD*=1.15
PVT Reciprocal RT	*M*=.004, *SD*=.00	*M*=.004, *SD*=.00	*M*= .004, *SD*=.001	*M*=.004, *SD*=.001

Task Switching Measures

The data was scored in terms of correct responses, repeated words, non-words and words including letters from outside the lettersets. In Experiment 1, 17% of responses were categorised as error responses (6% repeated words, 10% non-words and 1% wrong letters used). Both correct responses and errors were included in the analysis of the timing data.

Seven 2 (Sleep condition: SR versus Control) x 2 (Switch-allocation: Voluntary versus Voluntary-Equal) x 2 (Task-difficulty: Easy versus Hard) ANOVAs were conducted on the number of errors made, number of words generated, number of switches, giving-up time, resumption lag, total time on task and word frequency. With Sleep condition and Switch-allocation as between-participants factors and Task-difficulty as a within-participants factors. Greenhouse-Geisser F values, degrees of freedom, and p values are reported for repeated-measures ANOVA results wherever tests of sphericity are violated (i.e. Mauchly's test of sphericity shows a p value of less than .05). In the following results, any significant effects or interactions were further analysed using t-tests. All t-tests that were conducted had their p values Bonferroni-corrected before being reported. In all figures, error bars represent ±S.E.M.

Does the KSS predict the PVT?

The results of the regression indicated that KSS score predicted RT from the PVT explaining 13% of the variance, ($F(1,62)=9.39$, $p=.003$). Additionally, KSS scores predicted the lapses in the PVT explaining 9% of the variance, ($F(1,62) = 5.67$, $p = .02$). KSS scores however did not predict the number of false alarms, ($F(1,62) = .03$, $p = .86$).

Investigating error rate and word generation

Errors were considered in two ways, summed together and considered as individual types of errors. Word generation was based on the number of correct words participants were able to generate.

Number of errors: The main effect of task difficulty was significant, $F(1,62) = 24.08$, $p < .001$, $\eta^2 = .28$, with more errors made on the easy than hard task ($M = 25.20$, $SD = 37.35$ vs $M = 19.19$, $SD = 33.59$. No other main effects or interactions were significant (all $F<.81$, all $p>.37$).

When the individual types of errors were considered, no main effects were significant (all $F < 2.65$, all $p > .11$; see Figure 3.3).

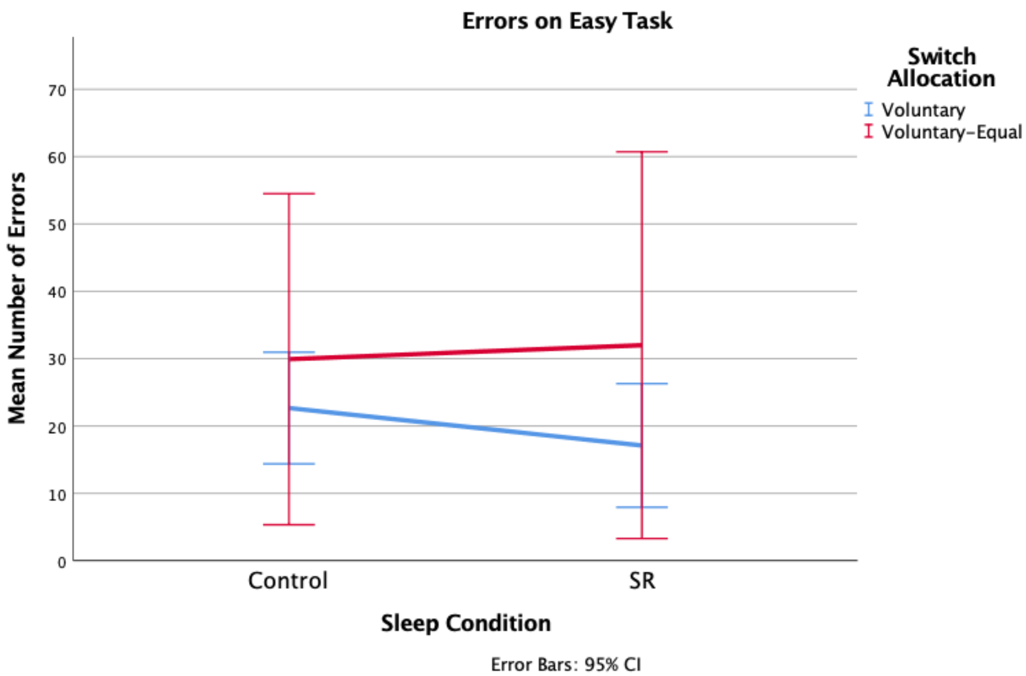

Figure 3.1 A line graph displaying the number of errors produced in the Control and SR participants for both voluntary and voluntary-equal conditions on the easy task.

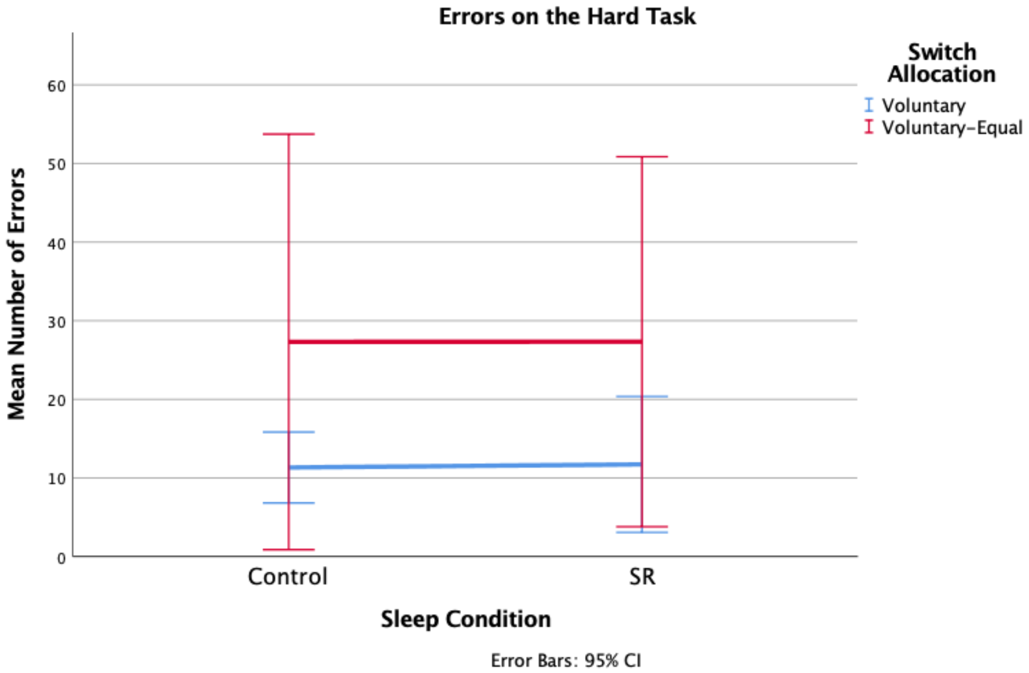

Figure 3.2 A line graph displaying the number of errors produced in the Control and SR participants for both voluntary and voluntary-equal conditions on the hard task.

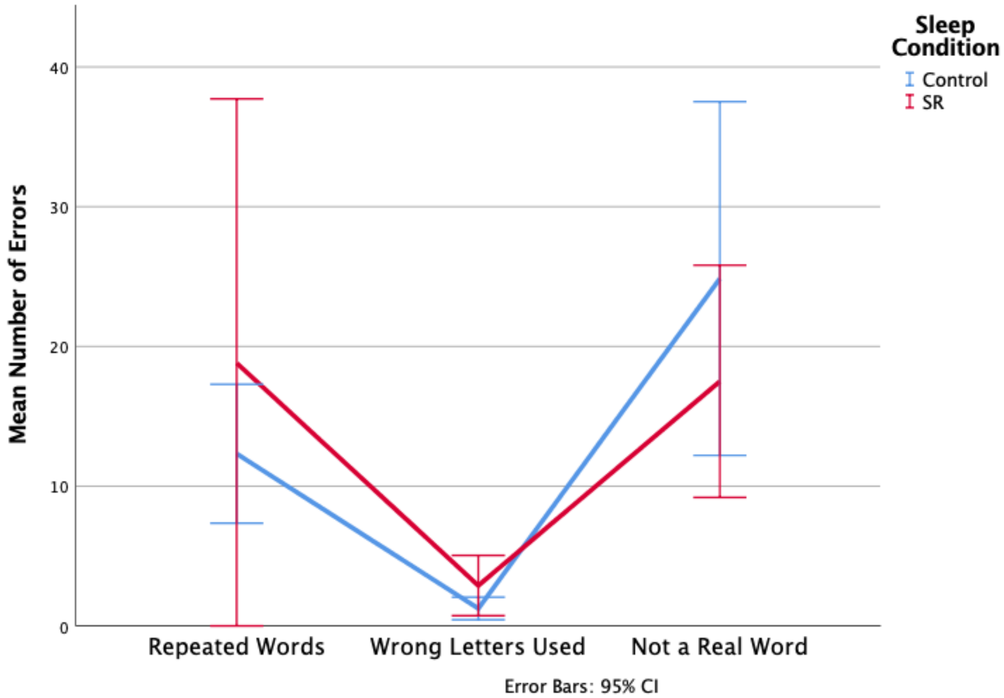

Figure 3.3 A line graph displaying the types of errors produced in the Control and SR participants.

Number of words generated: The main effects of task difficulty and switch allocation were significant, $F(1,60) = 215.36$, $p < .001$, $\eta^2 = .78$ and $F(1,60) = 6.26$, $p = .02$, $\eta^2 = .10$ respectively. Fewer words were generated in the hard ($M = 69.29$, $SD = 51.97$) compared with the easy task ($M = 129.61$, $SD = 56.36$) and in the Voluntary ($M = 50.91$, $SD = 20.25$) rather than Voluntary-Equal ($M = 88.87$, $SD = 66.83$) conditions. The main effect of sleep condition did not reach significance, $F(1,60) =.30$, $p = .58$, $\eta^2 = .01$. No other interactions approached significance (all $F < 3.63$, all $p > .06$).

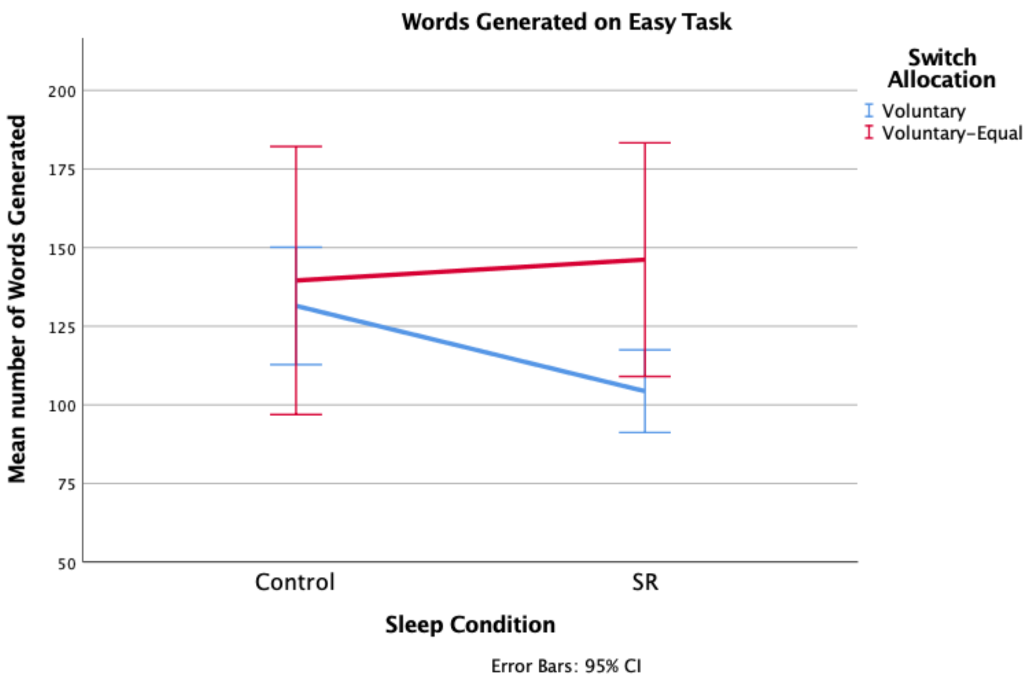

Figure 3.4 A line graph displaying the number of words generated in the Control and SR participants for both voluntary and voluntary-equal conditions on the easy task.

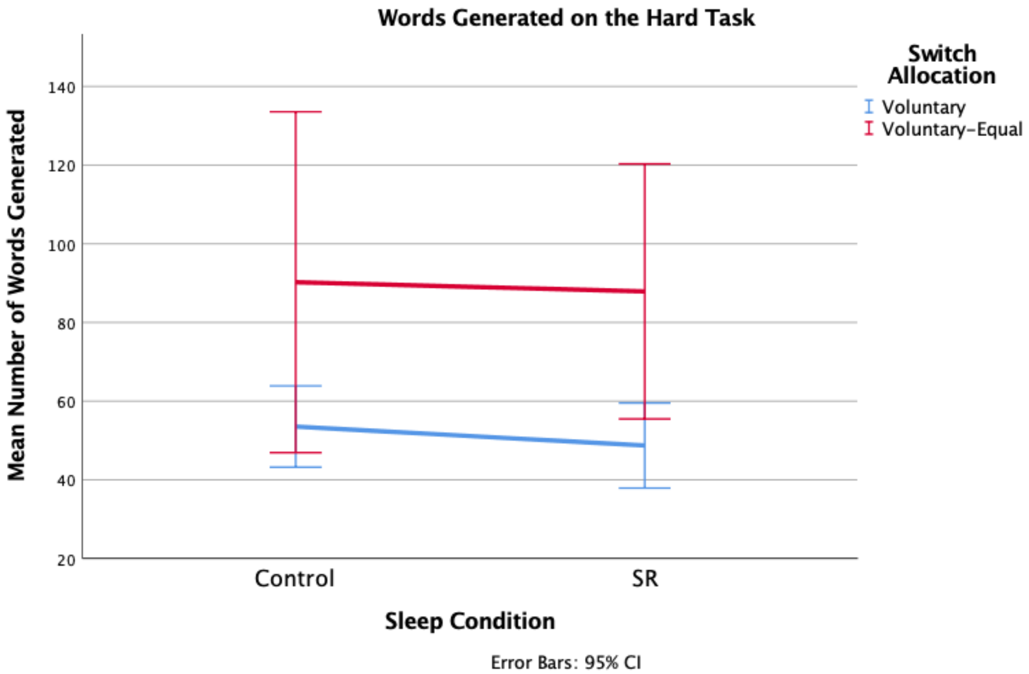

Figure 3.5 A line graph displaying the number of words generated in the Control and SR participants for both voluntary and voluntary-equal conditions on the hard task.

Ratio Analysis

To establish whether the number of errors produced is contingent on the number of overall responses generated some ratio analysis was conducted. The total number of words entered was divided by the errors on the easy task and then for the hard task.

Results showed the main effect of task difficulty were significant, $F(1,58) = 4.17$, $p = .046$, $\eta^2 = .07$. There were less words generated for every error produced on the hard task ($M = 8.66$, $SD = 8.46$) compared with the easy task ($M = 10.66$, $SD = 9.50$). No other main effects or interactions approached significance (all $F < 3.95$, all $p > .06$).

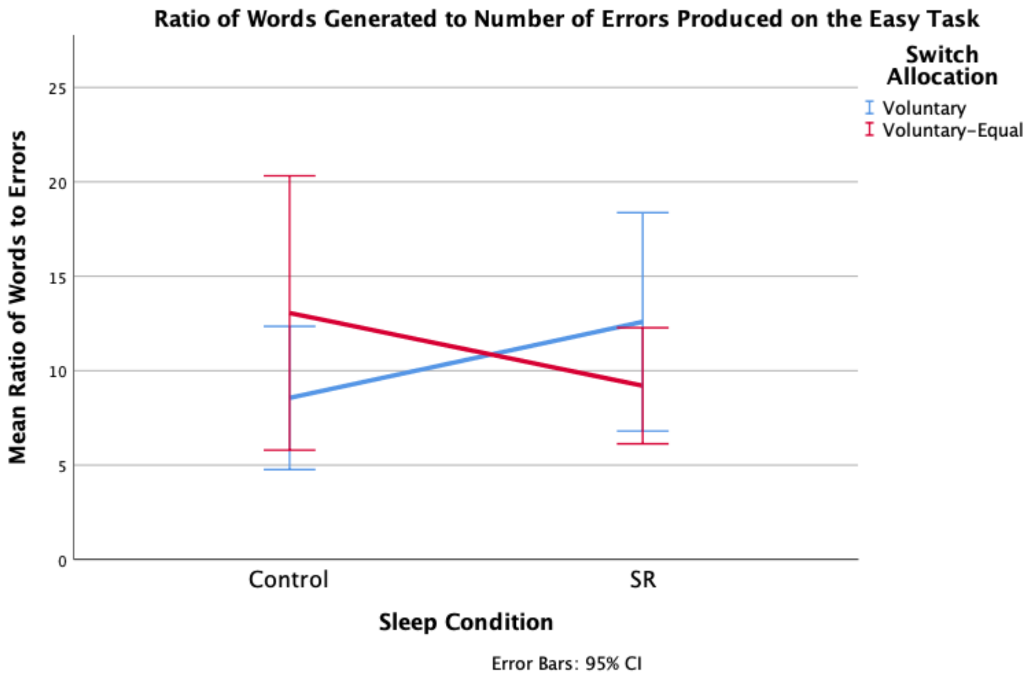

Figure 3.6 A line graph displaying the ration of the number of words generated with the number of errors produced in the Control and SR participants for both voluntary and voluntary-equal conditions on the easy task.

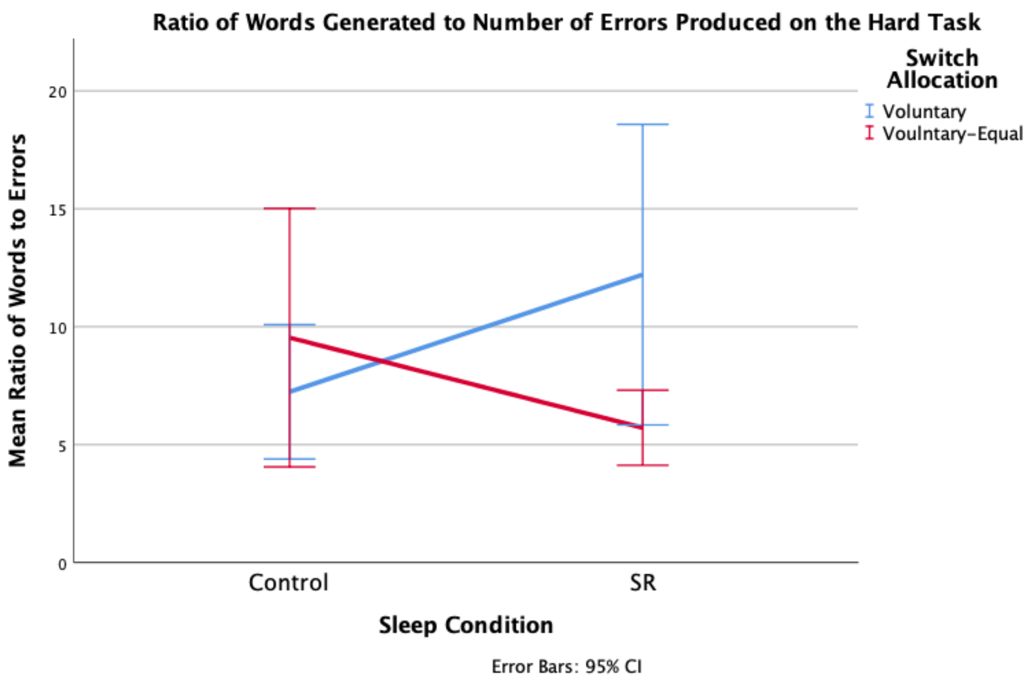

Figure 3.7 A line graph displaying the ration of the number of words generated with the number of errors produced in the Control and SR participants for both voluntary and voluntary-equal conditions on the hard task.

Differences in switching behaviour

Number of switches: The main effect of switch allocation was significant, $F(1,60) = 35.15$, $p < .001$, $\eta^2 = .37$. More switches were made in the Voluntary ($M = 11.91$, $SD = 4.58$) than the Voluntary-Equal condition ($M = 5.58$, $SD = 4.00$). No other significant main effects or interactions reached significance (all $F < .59$, all $p > .44$).

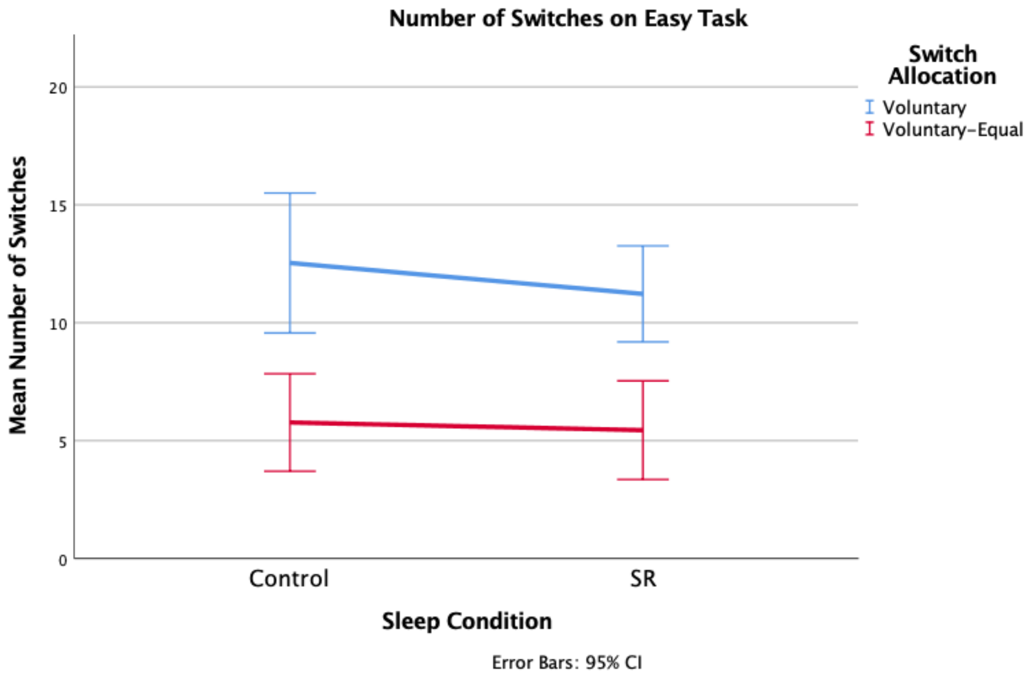

Figure 3.8 A line graph displaying the number of switches made in the Control and SR participants for both voluntary and voluntary-equal conditions on the easy task.

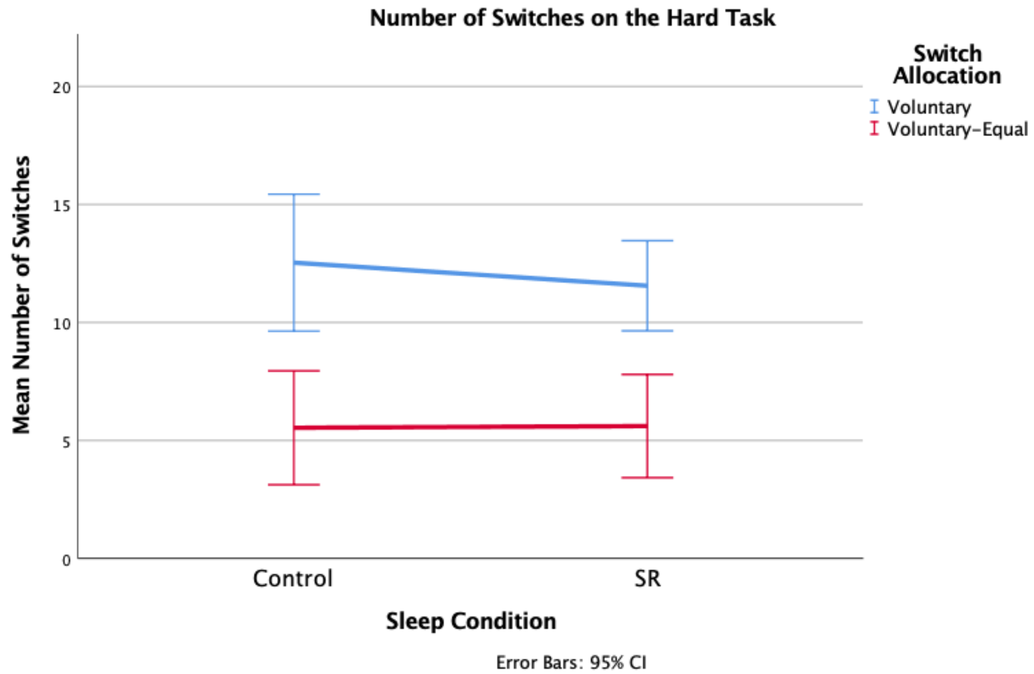

Figure 3.9 A line graph displaying the number of switches made in the Control and SR participants for both voluntary and voluntary-equal conditions on the hard task.

Giving-Up Time (GuT) and Resumption Lag (RL)

Giving-up time was defined as the time between the last word generated and participants subsequently deciding to switch to the other task. While Resumption lag time was defined as the time between switching tasks and then generating the first word.

Giving-up Time: The main effect of task difficulty was significant, $F(1,60) = 17.04$, $p < .001$, $\eta^2 = .22$. GuT was longer in the hard ($M = 22429.62$ msec, $SD = 12169.40$) than the easy task ($M = 15819.49$ msec, $SD = 8277.67$). There was a significant interaction between task difficulty and sleep condition, $F(1,60) = 5.63$, $p = .02$, $\eta^2 = .09$. No other significant main effects or interactions reached significance (all $F < 2.58$, all $p > .11$).

Post-hoc analysis of the task difficulty and sleep condition interaction revealed an effect of task difficulty in just the SR condition, $t(35) = -4.24$, $p < .0125$ but not the Control condition. GuT was longer in the SR than Control condition but only in the Hard task, $t(62) = -2.19$, $p = .03$ not the Easy task, $t(62) = .20$, $p = .84$.

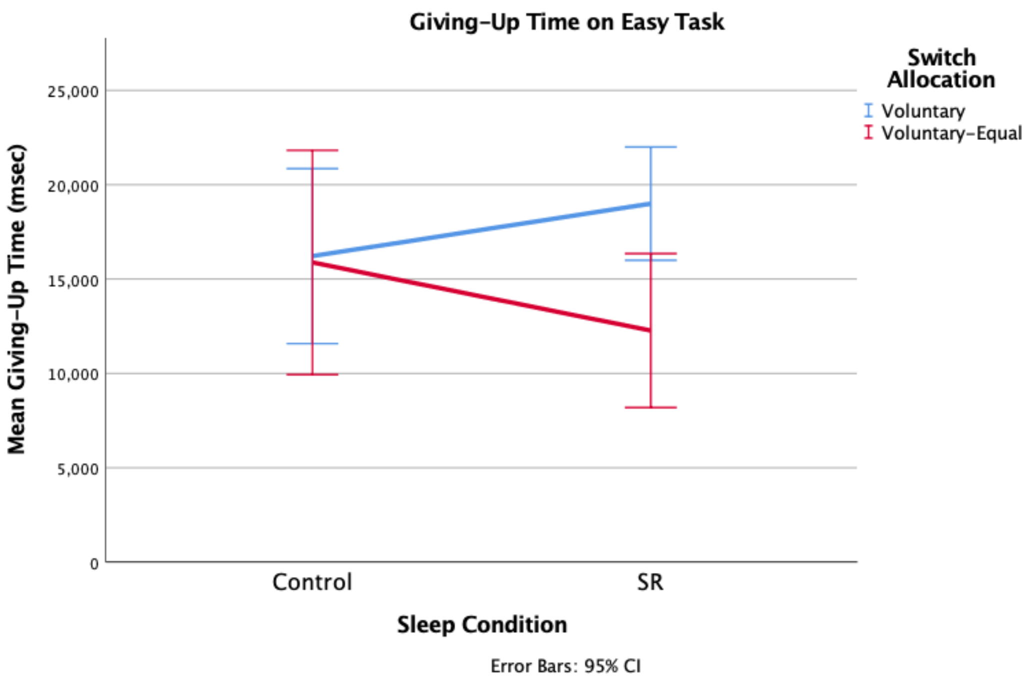

Figure 3.10 A line graph displaying the giving-up time in the Control and SR participants for both voluntary and voluntary-equal conditions on the easy task.

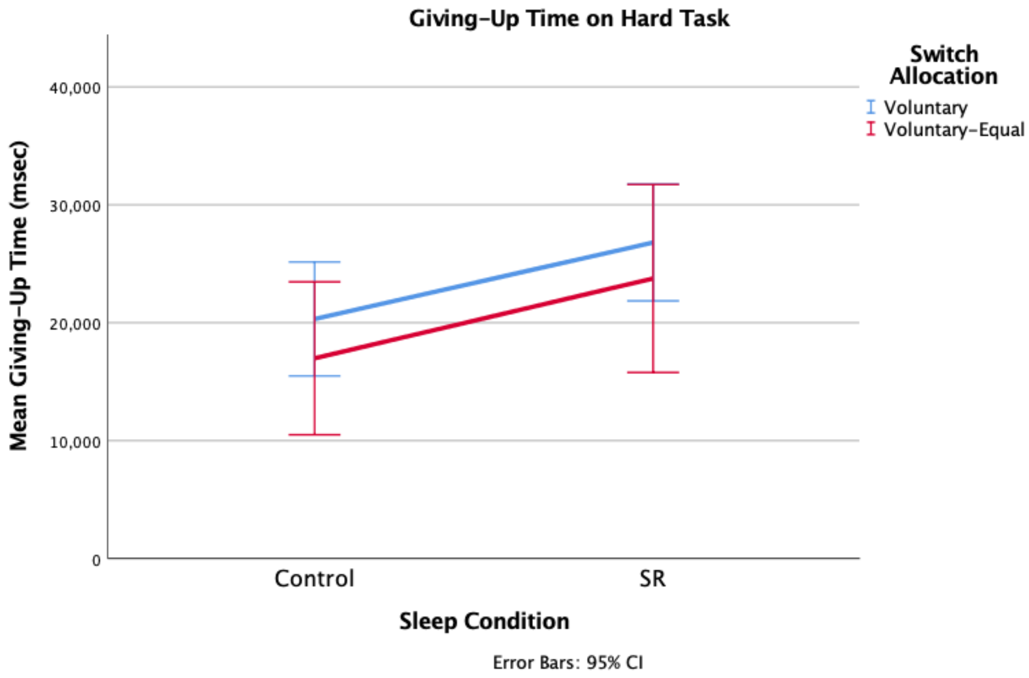

Figure 3.11 A line graph displaying the giving-up time in the Control and SR participants for both voluntary and voluntary-equal conditions on the hard task.

Resumption lag time: There was no significant main effects or interactions on resumption lag time (all $F < 3.49$, all $p > .07$).

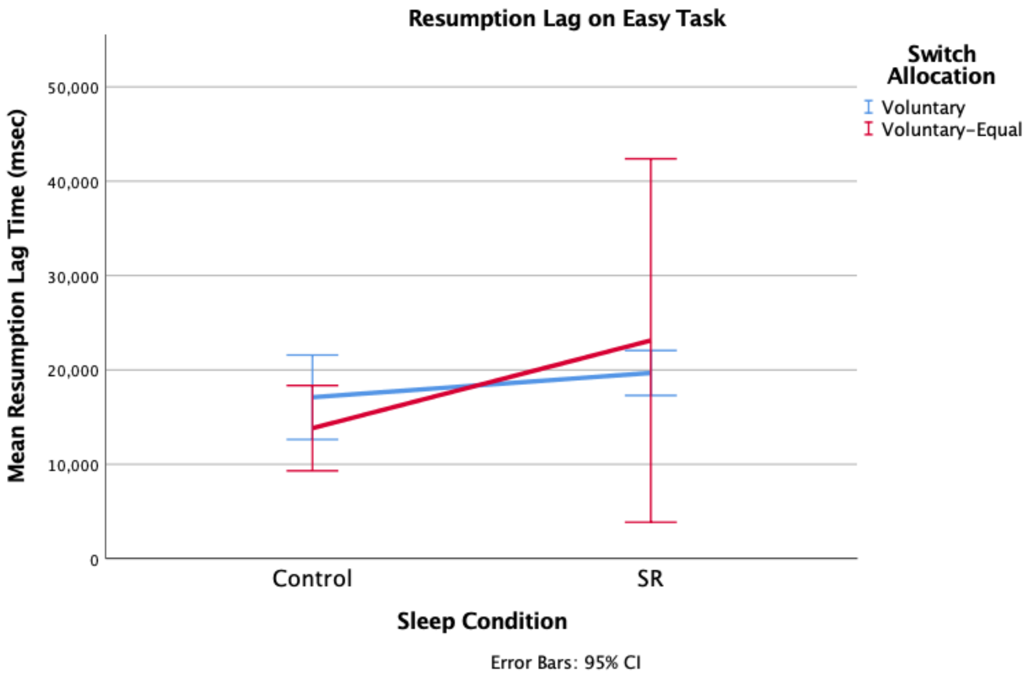

Figure 3.12 A line graph displaying the resumption lag in the Control and SR participants for both voluntary and voluntary-equal conditions on the easy task.

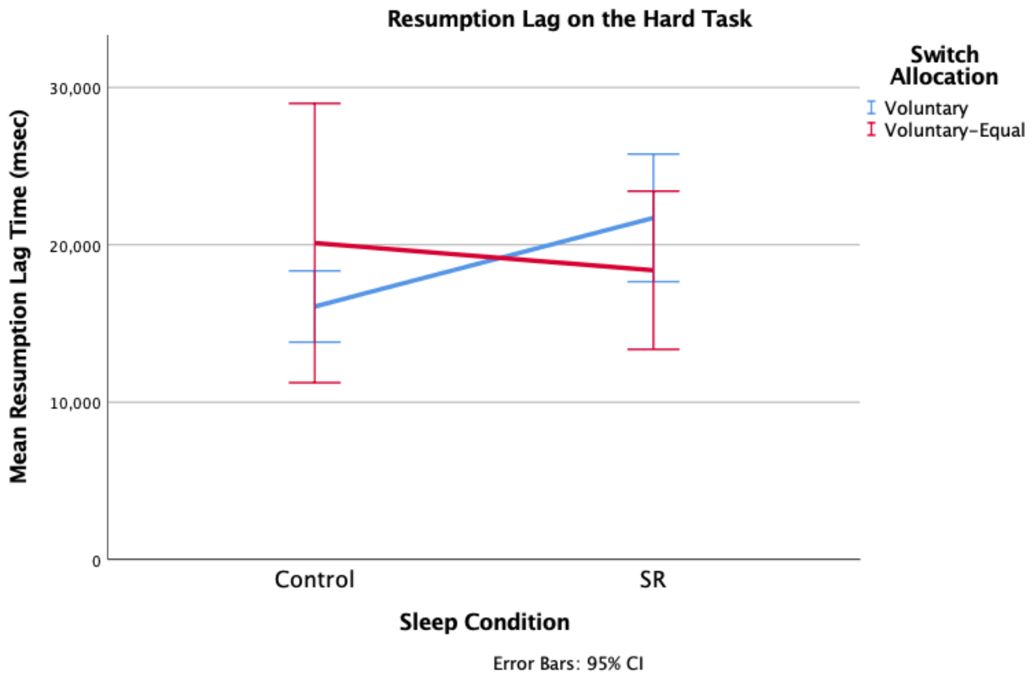

Figure 3.13 A line graph displaying the resumption lag in the Control and SR participants for both voluntary and voluntary-equal conditions on the hard task.

Examining differences in decision making – word frequency, time on task (ToT)

The frequency of words was determined by the English Lexicon Project (Balota et al., 2007). For the total time on task analysis only the participants in the Voluntary condition were included as they were the only ones who had complete control over their timings.

Word Frequency: The main effect of task difficulty was significant, $F(1, 60) = 71.09$, $p < .001$, $\eta^2 = .54$. Higher frequency words were generated in the easy ($M = 4.40$, $SD = .18$) versus the hard task ($M = 4.16$, $SD = .22$). There was a significant interaction between task difficulty, sleep condition and switch allocation, $F(1,60) = 5.82$, $p = .02$, $\eta^2 = .09$. No other significant main effects or interactions approached significance (all $F < 3.36$, all $p > .07$).

While the interaction between task difficulty, sleep condition and switch allocation were significant, post hoc contrasts failed to unambiguously reveal the source of the interaction on the easy or hard task (all $F < 2.65$, all $p > .11$ and $F < 2.34$, all $p > .13$ respectively).

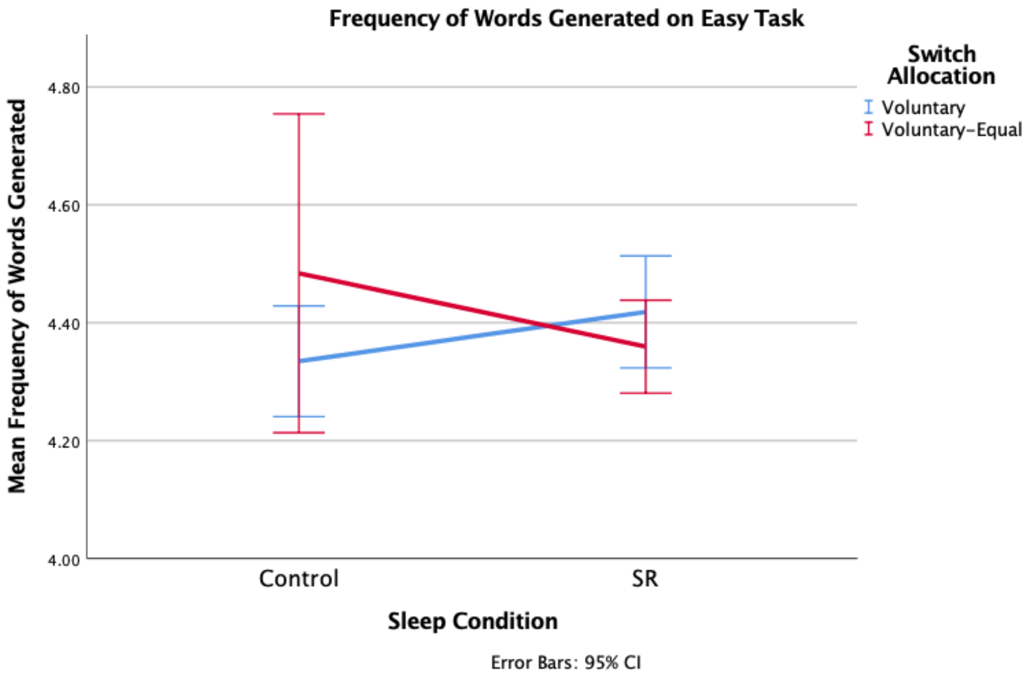

Figure 3.14 A line graph displaying the frequency of words generated in the Control and SR participants for both voluntary and voluntary-equal conditions on the easy task.

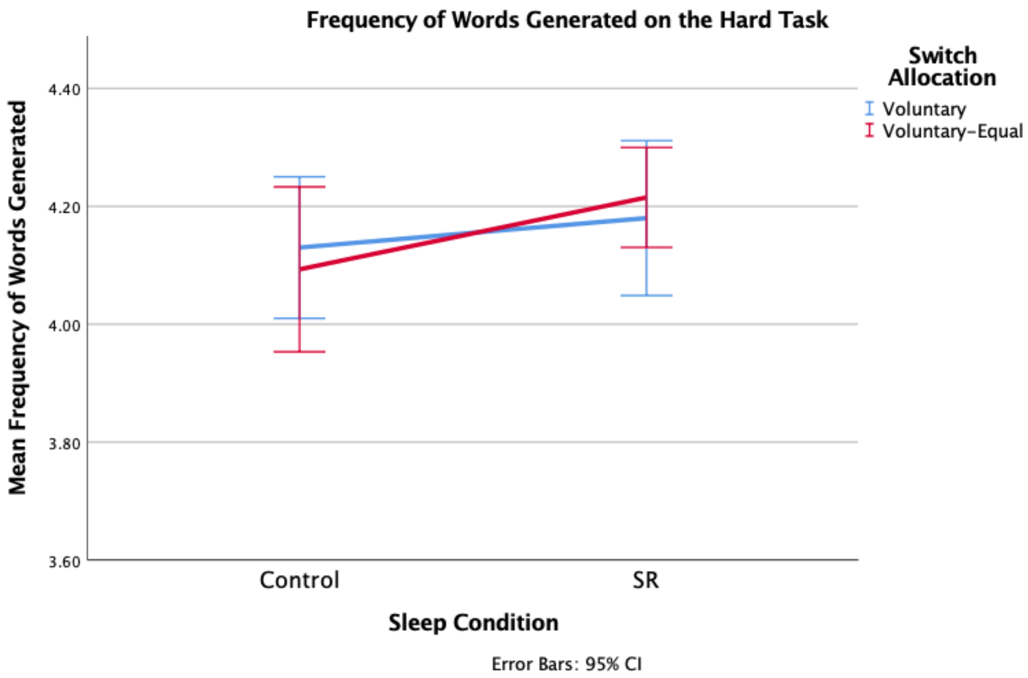

Figure 3.15 A line graph displaying the frequency of words generated in the Control and SR participants for both voluntary and voluntary-equal conditions on the hard task.

Time on task (ToT): The main effect of task difficulty was significant, $F(1,30) = 49.57$, $p < .001$, $\eta^2 = .62$. With more time spent in the easy ($M = 336.19$ seconds, $SD = 42.57$) than the hard task ($M = 228.63$ seconds, $SD = 55.64$). No other main effects or interactions reached significance (all $F < 2.12$, all $p > .08$).

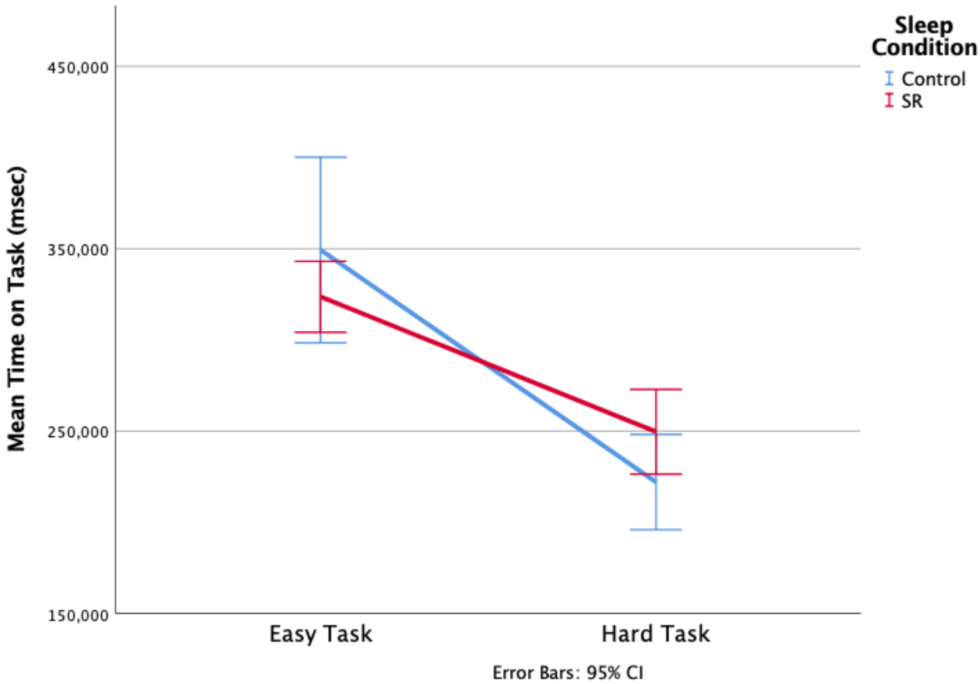

Figure 3.16 A line graph displaying the total time spent on easy task in the Control and SR participants for voluntary only as the voluntary-equal condition forces participants to spend equal time on both tasks.

Examining effects of Working Memory Capacity (WMC) on performance

While it is not a primary focus of the present study given the importance place on WM, any variable that fatigue seemed to effect was further explored using regression analysis. The aim was to see if the impact of fatigue was influenced by WMC. The Ospan and average 3-back data did not correlate and therefore both were used in the multiple regression analysis as predictors.

A multiple linear regression was calculated to investigate whether WMC, as measured by Ospan and 3-Back, predicted performance on GuT and word frequency and then to see if this differed between SR and Control participant groups. The reason for just examining these measures was because these were the only measures to have been found to have a significant main effect or interaction. It was therefore with this reason that it was important to see on these measures whether WMC had any involvement. Results of the multiple linear regression indicated that there was no significant effect between the Ospan and 3-back for SR participants (all $F < 2.49$, all $p > .10$) or Control participants (all $F < .59$, all $p > .56$).

Table 3.2 Results of the multiple regression analysis for the SR participants data.

		t	*p*	*β*	*F*	*df*	*p*	*adj.*R^2
GuT - Easy								
	Overall Model				2.49	2, 26	.10	.10
	Ospan Partial	-1.67	.11	-.31				
	Average 3-Back	-1.08	.29	-.19				
GuT - Hard								
	Overall Model				.33	2, 26	.72	-.05
	Ospan Partial	-.43	.67	-.09				
	Average 3-Back	.77	.45	.15				
Word Frequency - Easy								
	Overall Model				.85	2, 26	.44	-.01
	Ospan Partial	-.45	.66	-.09				
	Average 3-Back	-1.09	.28	-.21				
Word Frequency - Hard								
	Overall Model				.03	2, 26	.97	-.07
	Ospan Partial	-.24	.81	-.05				
	Average 3-Back	.09	.93	.02				

Table 3.3 Results of the multiple regression analysis for the Control participants data.

	t	p	β	F	df	p	$adj.R^2$
GuT - Easy							
Overall Model				.43	2, 19	.66	-.06
Ospan Partial	-.43	.67	-.09				
Average 3-Back	-.79	.44	-.18				
GuT - Hard							
Overall Model				.59	2, 19	.56	-.04
Ospan Partial	-.92	.37	-.20				
Average 3-Back	-.53	.60	-.19				
Word Frequency - Easy							
Overall Model				.06	2, 19	.94	-.09
Ospan Partial	.34	.73	.08				
Average 3-Back	-.07	.95	-.02				
Word Frequency - Hard							
Overall Model				.29	2, 19	.75	-.07
Ospan Partial	.75	.46	.17				
Average 3-Back	.03	.97	.01				

3.4 Discussion

Experiment 1 investigated the difference in task-switching behaviour between individuals who have experienced a loss of sleep and individuals who have not. Based on previous findings it was hypothesised that sleep restriction would lead to increased errors and 'giving up' time, as well as, reduced word generation, number of switches, and a reduced resumption time following a switch.

Was the fatigue manipulation effective?

In the current Experiment, both the KSS scores and number of hours slept were significantly different between SR and Control participants. While, on the PVT there was significantly more false alarms for the SR participants compared to the Controls. There was however, no difference for the RT or lapses in attention on the PVT between SR and Control participants. A possible reason for the differential effects between the KSS and PVT may be that the level of subjective sleepiness (in Jewett et al., study it was measured by the Stanford sleepiness scale) is linearly related to sleep restriction. In comparison, PVT performance deteriorates exponentially as levels of sleep loss increase (Jewett et al., 1999; as cited in Kaida et al., 2006). Thus, suggesting that moderate sleep restriction (e.g. study 1; 4 hours a night) does not seem to influence lapses and reciprocal response time whereas sleep deprivation might.

Another factor that may influence the lack of strong differences in the PVT measures in the SR group could be that participants in the sleep-restricted condition may have slept for longer than they were supposed to. They were supposed to get 4 hours of sleep per night for the last three nights of the experiment (total of 12 hours) however, the results show that on average sleep-restricted participants were sleeping a total of 16.19 hours over those nights. Despite the number of additional hours slept, the SR condition slept significantly less than the Control condition but still more than originally anticipated. Equally, participants sleep prior to the experimental days was not recorded and as such participants could have unwillingly been included in the study who had in the nights leading up to the start of the experiment experienced sleep loss and incurred sleep debt. Both of these factors could in turn be affecting the results of the study. As determined from the literature, 8 hours sleep following 1 night of partial sleep loss is not sufficient for full recovery (Sallinen et al., 2008). Equally, the more severe the sleep loss the more time is needed for full recovery (Lamond et al., 2007). Despite this possibility control participants were still found to have had more sleep compared to the sleep restricted participants.

Experiment 1 was a naturalistic study. Although experiments conducted in a sleep lab may have better control allowing for sleep to be monitored and precisely manipulated, those studies also open themselves up to other extraneous variables. Specifically, individuals in sleep labs may not get the same quality of sleep and may be subject to disruptions in their usual sleep routines that have not been enforced by the requirements of the experiment. Using self-report and Fitbit recordings as measures of sleep allows for participants to remain most true to their usual sleep routines. It is also this use of combining multiple measures of sleep data that compensated for some of the earlier participants loss of Fitbit data. By taking multiple measures of sleep data it adds validity as the different measures provide evidence that simply reinforces the amount of sleep each participant has received.

These results demonstrate that sleep restriction was strong enough to induce an effect on the KSS, but not quite strong enough to stimulate an effect in the PVT. These findings provide reason to investigate the same experimental design but use a stronger sleep manipulation that may elicit more consistent differences compared to the Controls. This will be addressed in Chapter 4.

Effect of Sleep Manipulation on Task Switching

The main finding in the current experiment established that the sleep restricted condition had a longer giving-up time than that observed in the control condition in the more difficult task. The giving-up time (GuT) is categorised as the time from the participants last response to them selecting to switch to the other task. The longer GuT could occur for at least two different reasons; (1) fatigue causes longer preparation time needed before switching, (2) when fatigued it takes longer to search memory to decide whether there are any more words that could be generated before switching.

As mentioned previously, to successfully switch tasks requires preparation of the task-set reconfiguration is needed to execute the new task, as well as, the disengagement from the previous task (Couyoumdjian et al., 2010). Rogers and Monsell (1995) attributed this preparation effect (in the present study this is referred to as GuT) as the time-consuming internal task-set reconfiguration processes that occurs in anticipation of a task switch (Monsell, 2003). This task-set reconfiguration can either take place as soon as participants have given their last response to the previous task and before the new task has begun or following stimulus onset for the new task (Monsell, 2003). This suggests that the time spent prior to the switch or time spent straight after the switch reflects the preparation and reconfiguration process. In the present study the giving-up time (time between the last response and switching tasks) and resumption lag (time from the switch in task to the first response) reflects this preparation process. Consequently, observing effects on these components in the sleep restricted condition in the present study may suggest that these components are particularly sensitive to sleep loss.

Both the preparation and disengagement components are negatively affected by sleep loss (Couyoumdjian et al., 2010). It is these two components (preparation and disengagement) that are thought to be vital for successful task switching. Therefore the more time made available to these components the less deleterious the switch costs will be (Couyoumdjian et al., 2010).

The present experiment demonstrated an increase in the GuT between SR and Controls on the hard task, suggesting that fatigued individuals are poor at preparing for a switch in task goals for an upcoming task and subsequently more preparation time is needed. Following the notion in previous literature that having more time to prepare for a switch results in less deleterious switch costs (Couyoumdjian et al., 2010; Panepinto, 2010) can be observed in the present experiment with no differences detected in performance (e.g. words generated and the number of errors).

The present experiment did not show a significant effect of resumption lag. There are two possible reasons why this might be. Firstly, if the slower giving-up time observed occurs as a result of preparation, then this longer preparation period before the switch could reduce the resumption lag as participants have already completed the disengagement-reconfiguration process (Payne et al., 2007). Secondly, voluntary switching allowed the participants to choose exactly at which point they wanted to switch. This allowed participants to have this time prior to switching in which to prepare and disengage from the current task, in turn minimising switch costs and resumption lag. Equally, voluntarily allowing participants to select when they wish to switch tasks enables them to select the opportune moment to switch. As research has shown switching at the completion of a subtask (Iqbal & Bailey, 2005; Payne et al., 2007) or when workload is low (Adamczyk & Bailey, 2004; Iqbal & Bailey, 2005; Salvucci & Bogunovich, 2010) reduces the resumption lag time, as well as minimising the switch costs.

Switching at opportune moments may be a factor in why there were minimal differences observed in participants performance; specifically establishing no difference in the number of errors participants produced. Switching at times that are most suitable for that person can alleviate most of the negative costs associated with switching regardless of whether they have experienced restricted sleep. By allowing participants to have this control over when to switch may be enough to help fatigued participants overcompensate their fatigue impairment. Specifically, the longer GuT observed in the SR condition could also explain the lack of differences in the number of errors. By having this additional time to disengage-reconfigure for the new task goals it allows for the impact on the task to be minimised and potential switch costs to be reduced.

A significant difference was observed between task difficulty in the number of errors, with the easy task producing a greater number of errors compared to the hard task. While this may seem counterintuitive, there are a number of simple explanations that account for these findings. Firstly, on the easy task there are more possible words that could be generated relative to the hard task therefore statistically there is a higher chance of making errors given that there are more words being typed, and a higher chance of repeating a previous word. Secondly, the easy task could be seen as being less engaging and a subsequent lack of motivation could be applied to the task which results in all participants not trying as hard. With this reasoning in mind, ratio analysis was done in order to determine whether it was a motivational issue or simply just more likely because more words were entered. Results showed that there was a significant main effect of task difficulty with the hard task generating fewer words for every error produced. This therefore suggests that actually participants were more likely to be experiencing more errors on the easy task simply because more words were generated and subsequently there is a higher chance of repeating a word.

Although not a primary focus of this experiment, given the importance placed on WM in both task switching and fatigue it was important to understand WMs role in the significant effects discovered in the present experiment and to explore whether there was any evidence of those effects being moderated by WM. It is worth noting that despite the evidence in previous literature (Alhola & Plo-Kantola, 2007; Chee & Choo, 2004) there was no evidence that the differences between the sleep conditions were in anyway affected by WMC.

3.5 Conclusion

To conclude, the present experiment demonstrated that when participants had control over when to switch tasks and the tasks they were switching between allowed the opportunity for participants to respond at their leisure, sleep restricted individuals spent longer giving-up a task especially when the task is hard. This giving-up time reflects the disengagement and preparation for the next task and in doing this, sleep restricted individuals are able to compensate for the negative effects of sleep loss and show no differences in performance accuracy. This enhances the current understanding in the literature, demonstrating that SR produces minimal effects on this type of cognitive task but is particularly sensitive to the time needed to prepare for an upcoming switch and in having this additional time it allows performance accuracy to remain consistent with non-fatigued individuals.

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Chapter 4

The Effects of Sleep Deprivation on Voluntary Task Switching

4.1 Introduction

Sleep studies have demonstrated cognitive processing declines with the amount of sleep lost (Van Dongen et al., 2003). This is also evident from research showing cumulative deterioration in accuracy and reaction time with increasing numbers of sleep restricted days or with prolonged wakefulness (Haavisto et al., 2010).

Experiment 1, highlighted some initial behavioural differences between individuals who have maintained their usual sleep compared with individuals who have experienced a moderate sleep loss (e.g. 4 hours of sleep for three nights). However, those effects were limited to a longer GuT in the SR participants. The present experiment aimed to investigate whether a more severe sleep manipulation would have a more profound effect on task performance.

Rationale

Sleep deprivation will lead to increased errors and ‘giving up’ time, as well as, reduced word generation, number of switches, and resumption time following a switch compared to Controls.

4.2 Methods

Experiment 2 compares behavioural and cognitive performance between individuals who have maintained normal sleep with those who have had thirty hours of continued wakefulness. This will be known as the sleep deprived (SD) condition.

Participants

Forty-two participants were initially recruited but three withdrew or were excluded from the study due to not following the experimental procedures correctly. Not following experimental procedures was categorised as sleeping over the hours stipulated, removing the Fitbit, or not attending all testing sessions at the specified times. Two participants dropped out naming the reasons as either the study was more of a commitment than they thought or that they couldn't cope with the lack of sleep. Thirty-seven participants were included in Experiment 2 (26 females; *M* = 19.86, *SD* = 1.26, age range = 18 - 22 years old). These participants were assigned to the sleep deprived condition. Twenty-eight Control participants (19 females; *M* = 20.45, *SD* = 2.64; age range = 18 - 31 years old) from Experiment 1 were reused in the analysis in the current experiment. All participants had normal vision or corrected-to-normal vision.

Design

Following on from Experiment 1 presented in Chapter 3, participants were required to take part in two separate computer-based testing sessions. The two sessions were a day apart for the SD participants and Control participants were previously collected as part of Experiment 1. During the first session working memory (Ospan and 3-Back) and fatigue (KSS and PVT) were measured. Each participant was also given a Fitbit to wear for the duration of the experiment. Sleep was tracked between the two sessions. Participants completed the online tests at specific times depending on their assigned condition. At the second testing sessions, participants fatigue was measured again (KSS and PVT) and then they were required to complete the main experimental task; a word generation task (see Chapter 2 for more detail). Unlike Experiment 1, this experiment examined differences in voluntary switching between SD and Control participants. For full details of Experiment 2's experimental design, see Chapter 2.

Experiment 2 had two between-participant factors, task-switching rule (free choice of time spent on each of the two word-generation tasks versus fixed equal time, hereafter called Voluntary and Voluntary-Equal) and sleep condition (deprived versus normal). The Control participants had been randomly assigned their condition within the initial data collection in Experiment 1. The SD participants were assigned randomly to the task-switching rule with the constraint that there were equal number of participants in each. Those in the SD condition were required to have thirty hours of continual wakefulness; those in the normal sleep condition maintained their normal sleep patterns for those three nights.

An important issue that needs to be addressed is the fact that some of the data being reused incorporates the data that had missing Fitbit data. Despite this, the purpose of this experiment is to replicate the previous one to see whether a SD condition is more significantly different from the Control condition compared to the SR condition and in order to do this the data needs to remain constant from the previous experiment. Equally, the participants who had missing data had their missing Fitbit hours predicted by running a multiple regression. They also had their sleep diary data cross checked with their online surveys to ensure that each was completed to the times specified in the experiment criteria and thus supports the times they were awake.

As the aim of the present experiment was to explore whether sleep deprivation would elicit more behavioural differences than those observed by the sleep restricted condition in Experiment 1 a direct comparison needs to be made and therefore it is important to keep the Control participants consistent.

It is important to note that as this experiment was based on a replication of Payne et al's (2007) study, participants per condition needed to be consistent with those in Payne et al's study. It was with this rationale that participant numbers per condition were matched to the same size as per Payne et al's study of 20 per condition.

4.3 Results

There are two sections to the results. The first section tests whether the sleep manipulation induced fatigue. The second section tests the impact of SD on task performance and switching.

Was the fatigue manipulation effective?

Independent samples *t*-test was used to compare the hours slept (for Controls there sleep over 3 nights was averaged and for SD it was over 1-night sleep, KSS score and PVT measures between control participants and SD participants. The measures of the PVT used were the reciprocal RT, false alarms and the number of lapses in attention (e.g. any RTs that were greater than 500ms). The mean of the reciprocal RT was used as a measure due to the RTs being skewed. By doing a reciprocal transformation on the RT data it made the distribution normal. The KSS and PVT data were taken from the second testing session.

SD participants slept less hours compared to the control condition (M = 0.28, SD = 0.67 versus M = 20.04, SD = 3.64; $t(28.36) = 28.36$, $p < .001$, d = 7.55), and had increased fatigue as measured by the KSS compared to controls, (M = 7.50, SD = 1.13 versus M = 4.89, SD = 2.08; $t(36.95) = -5.9$, $p < .001$, d = .64).

As measured on the PVT, the SD condition led to more lapses compared to the Control condition (M = 8.73, SD = 13.83 versus M = 2.54, SD = 3.39; $t(41.57) = -2.62$, p = .01, d = .62), more false alarms (M = 1.54, SD = 2.48 versus M = .36, SD = .78; $t(45.01)$ = -

2.73, p = .01, d = .64; and reciprocal RT (M =.003, SD = .001 versus M = .004, SD = .00; t(63) = 1.98, p = .05, d = 1.96).

With respect to within-group comparisons, on Day 2 compared to Day 1 SD led to increased KSS scores (M = 7.50, SD = 1.13 versus M = 3.95, SD = 1.23, p < .001, d =), reciprocal RT (M = .003, SD = .001 versus M = .004, SD = .00, p < .001, d =), lapses in attention (M = 8.73, SD = 13.83 versus M = 1.32, SD = 2.74, p = .002, d =), and false alarms (M = 1.54, SD = 2.48 versus M = 0.43, SD = 0.84, p = .01, d =).

In comparison Controls did not differ between Day 2 and Day 1 on KSS scores (M = 4.70, SD = 1.66 versus M = 4.25, SD = 1.41, p = .19), lapses in attention (M = 2.50, SD = 3.59 versus M = 1.23, SD = 1.79, p = .07) and false alarms (M = .36, SD = .79 versus M = 0.59, SD = 2.36, p = .68). They did however, differ on their reciprocal RT with a longer RT on Day 2 compared to Day 1 (M=.004, SD= .00 versus M= .004, SD = .00, p=.001).

Table 4.1 Participant means for the fatigue measures (average hours slept per night, KSS and PVT*)*

Measure	Controls		Sleep Deprived	
	Voluntary	Voluntary-Equal	Voluntary	Voluntary-Equal
No. of Participants	15	13	19	18
Average Sleep Hours	*M*=6.71, *SD*=1.19	*M*=6.65, *SD*=1.29	*M*=.24, *SD*=.58	*M*=.33, *SD*=.79
KSS Score	*M*=4.80, *SD*=2.04	*M*=5.08, *SD*=2.14	*M*=7.58, *SD*=.90	*M*=7.44, *SD*=1.38
PVT RT>500ms	*M*=2.93, *SD*=4.18	*M*=2.08, *SD*=2.22	*M*=7.84, *SD*=8.73	*M*=9.67, *SD*=17.96
PVT False Alarms	*M*=.40, *SD*=.83	*M*=.31, *SD*=.75	*M*=1.16, *SD*=2.03	*M*=1.94, *SD*=2.88
PVT Reciprocal RT	*M*=.004, *SD*=.00	*M*=.004, *SD*=.00	*M*=.003, *SD*=.00	*M*=.003, *SD*=.00

Was the SD manipulation more profound compared to the SR manipulation?

The aim of the present experiment was to ensure that the sleep manipulation was more significant than those produced by the sleep restricted manipulation in Experiment 1.

Five 2 (Sleep condition: SR versus SD) x 2 (Switch-allocation: Voluntary versus Voluntary-Equal) ANOVAs were conducted. With Sleep condition and Switch-allocation as between-participants factors.

Number of hours slept: The main effect of sleep condition was significant, $F(1,69) = 711.76$, $p < .001$, $\eta^2 = .91$, with SR participants having more sleep compared to the SD participants (M = 5.41, SD = .92 vs M = .28, SD = .68 respectively). No other main effects or interactions reached significance (all $F < .05$, all $p > .82$).

KSS score: The main effect of sleep condition was significant, $F(1,69) = 6.86$, $p = .01$, $\eta^2 = .09$, with SR participants reporting lower KSS score than the SD participants (M = 6.61, SD = 1.73 vs M = 7.51, SD = 1.15 respectively). No other main effects or interactions reached significance (all $F < .59$, all $p > .55$).

PVT false alarms, RT>500 ms and reciprocal RT: The main effect of sleep condition was not significant, ($F(1,69) = .17$, $p = .68$; $F(1,69) = .17$, $p = .68$; and $F(1,69) = 1.43$, $p = .24$ respectively). No other main effects or interactions reached significance (all $F < 1.01$, all $p > .32$).

Task Switching Measures

The data were scored in terms of correct responses, repeated words, non-words and words including letters from outside the lettersets. In Experiment 2 17% of responses were categorised as error responses (3% repeated words, 13% non-words and 1% wrong letters used). Both correct responses and errors were included in the analysis of the timing data.

Seven 2 (Sleep condition: SD versus Control) x 2 (Switch-allocation: Voluntary versus Voluntary-Equal) x 2 (Task-difficulty: Easy versus Hard) ANOVAs were conducted on the number of errors made, number of words generated, number of switches, giving-up time, resumption lag, total time on task and word frequency. With Sleep condition and Switch-allocation as between-participants factors and Task-difficulty as a within-participants factors. Greenhouse-Geisser F values, degrees of freedom, and p values are reported for repeated-measures ANOVA results wherever tests of sphericity are violated (i.e. Mauchly's test of sphericity shows a p value of less than .05. In the following results, any significant effects or interactions were further analysed using t-tests. All t-tests that were conducted had their *p* values Bonferroni-corrected before being reported. In all figures, error bars represent ±S.E.M.

Does the KSS predict the PVT?

The results of the regression indicated that KSS score predicted RT from the PVT explaining 16% of the variance, ($F(1,63) = 11.46, p = .001$). Additionally, KSS score predicted the lapses in the PVT explaining 12% of the variance, ($F(1,63) = 8.51, p = .01$). KSS score predicted the number of false alarms explaining 9% of the variance, ($F(1,63) = 6.07, p = .02$).

Investigating error rate and word generation

Errors were considered in two ways, summed together and considered as individual types of errors. Word generation was based on the number of correct words participants were able to generate.

Number of errors: The main effect of task difficulty was significant, $F(1,62) = 64.09$, $p < .001$, $\eta^2 = .51$, with more errors made on the easy rather than hard task ($M = 24.05$, $SD = 21.58$ vs $M = 15.32$, $SD = 21.61$. No other main effects or interactions reached significance (all $F < 1.29$, all $p > .26$).

When the individual types of errors were considered, a significant main effect of sleep condition was established on the number of repeated words, $F(1,62) = 6.14$, $p = .02$, $\eta^2 = .09$. With more repeated words made in the Control ($M = 12.32$, $SD = 12.81$) than the SD condition ($M = 6.39$, $SD = 5.79$) (see Figure 4.3). No other main effects were significant (all $F < 3.50$, all $p > .07$).

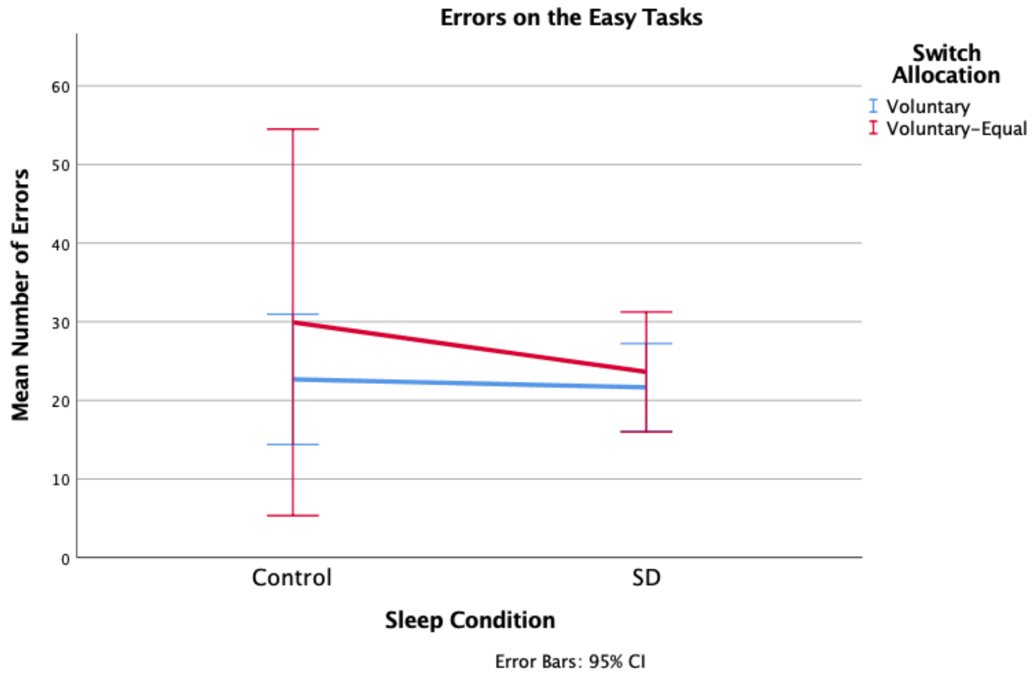

Figure 4.1 A line graph displaying the number of errors produced in the Control and SD participants for both voluntary and voluntary-equal conditions on the easy task.

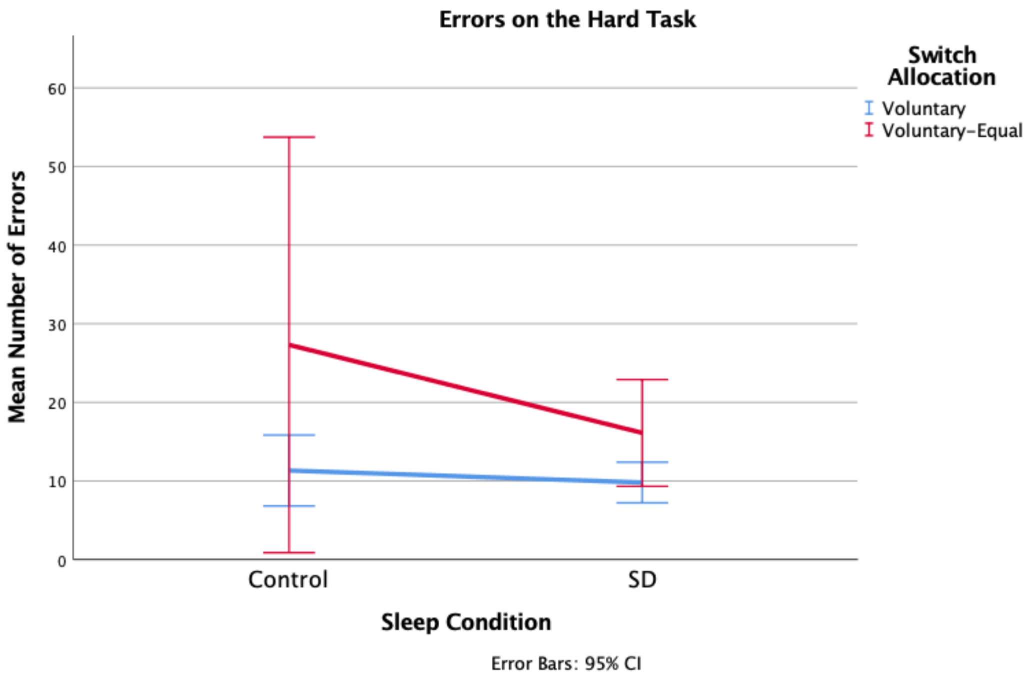

Figure 4.2 A line graph displaying the number of errors produced in the Control and SD participants for both voluntary and voluntary-equal conditions on the hard task.

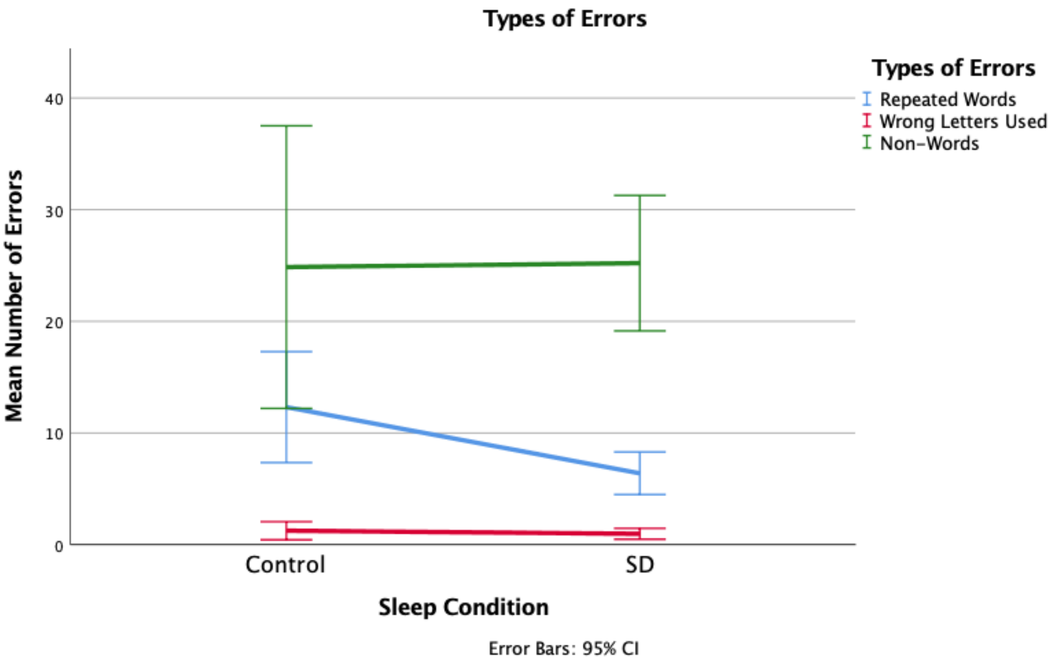

Figure 4.3 A line graph displaying the types of errors produced in the Control and SD participants.

Number of words generated: The main effects of sleep condition, task difficulty and switch allocation were all significant, $F(1,62) = 4.01$, $p = .05$, $\eta^2 = .06$, $F(1,62) = 299.06$, $p < .001$, $\eta^2 = .83$ and $F(1,62) = 4.50$, $p = .04$, $\eta^2 = .07$ respectively. Fewer words were generated in the SD ($M = 82.44$, $SD = 37.04$) than the control condition ($M = 102.89$, $SD = 53.06$), in the hard ($M = 66.06$, $SD = 43.64$) than the easy task ($M = 116.17$, $SD = 47.79$) and in the Voluntary ($M = 48.63$, $SD = 18.54$) than Voluntary-Equal ($M = 85.74$, $SD = 54.61$) conditions. Task difficulty and sleep condition interacted, as well as, the task difficulty and switch allocation, $F(1,62) = 18.01$, $p < .001$, $\eta^2 = .23$ and $F(1,62) = 26.41$, $p < .001$, $\eta^2 = .30$ respectively (see Figure 4.4).

Post-hoc analysis of the task difficulty and sleep condition interaction revealed an effect of task difficulty in both the control and SD conditions, $t(27) = 11.69$, $p < 0.001$ and

$t(37) = 8.97$, $p < 0.001$ respectively. There was a significant difference between SD and control groups in the easy task ($t(64) = 2.94$, $p = .005$) but not the hard task ($t(64) = .72$, $p = .48$).

Post-hoc analysis of the task difficulty and switch allocation interaction revealed an effect of task difficulty in both the Voluntary and Voluntary-Equal conditions, $t(34) = 14.96$, $p < .001$ and $t(30) = 6.84$, $p < .001$ respectively. There was a significant difference between Voluntary and Voluntary-Equal in the hard task ($t(36.12) = 3.60$, $p = .001$) but not in the easy task ($t(64) = .53$, $p = .60$).

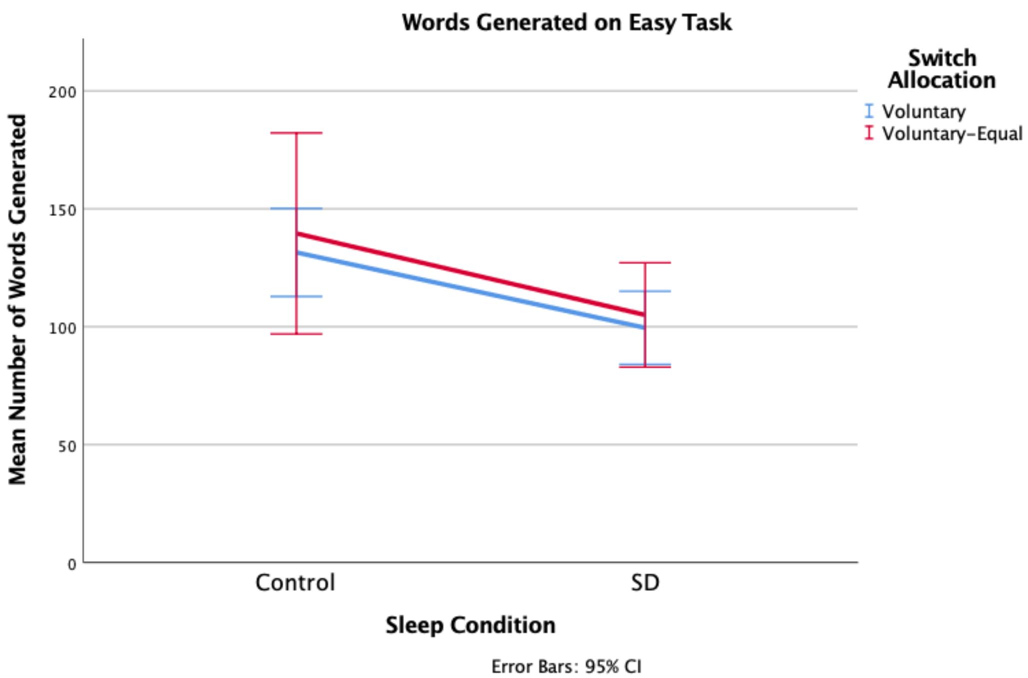

Figure 4.4 A line graph displaying the number of words generated in the Control and SD participants for both voluntary and voluntary-equal conditions on the easy task.

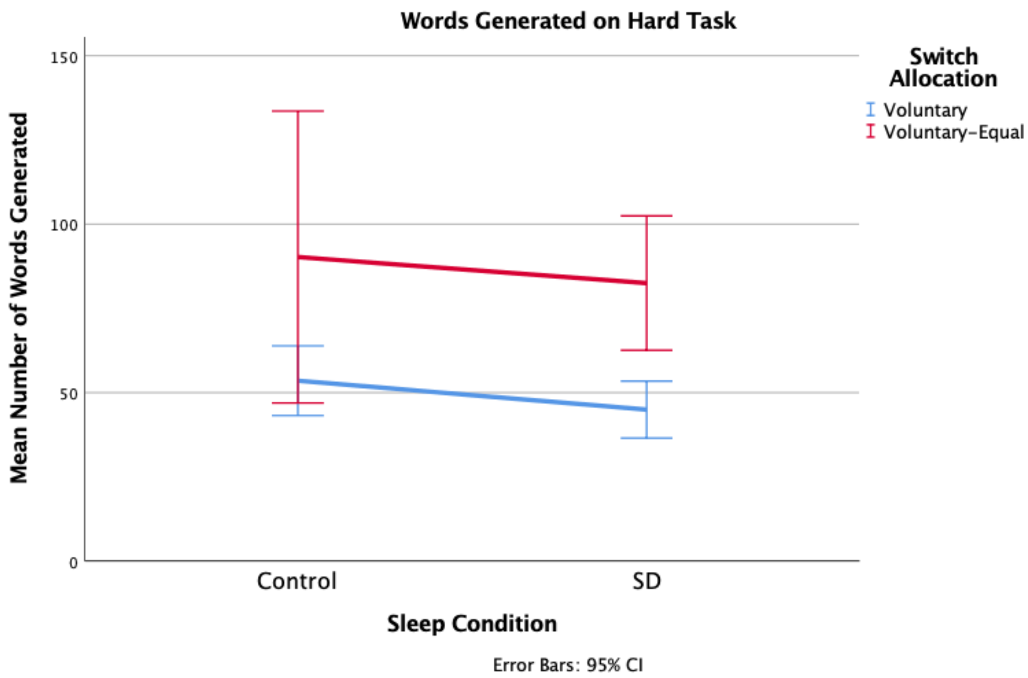

Figure 4.5 A line graph displaying the number of words generated in the Control and SD participants for both voluntary and voluntary-equal conditions on the hard task.

Ratio Analysis

To establish whether the number of errors produced is contingent on the number of overall responses generated some ratio analysis was conducted. The total number of words entered was divided by the errors on the easy task and then for the hard task.

Results showed the main effect of sleep condition was significant, $F(1,62) = 9.63$, $p = .003$, $\eta^2 = .13$. There were less words generated for every error produced in the SD condition ($M = 5.65$, $SD = 2.27$) compared with the Control condition ($M = 9.48$, $SD = 8.44$). The task difficulty and sleep condition interacted, $F(1,62) = 6.47$, $p = .013$, $\eta^2 = .10$. No other main effects or interactions approached significance (all $F < 2.40$, all $p > .13$).

Post-hoc analysis of the task difficulty and sleep condition interaction revealed an effect of SD and control groups in the easy task ($t(28.02) = 2.99$, $p = .006$) but not the hard task ($t(33.95) = 1.48$, $p = .15$). There was not a significant difference between task difficulty in both the control and SD conditions, $t(27) = 1.56$, $p = .132$ and $t(37) = -2.59$, $p = 0.014$ respectively.

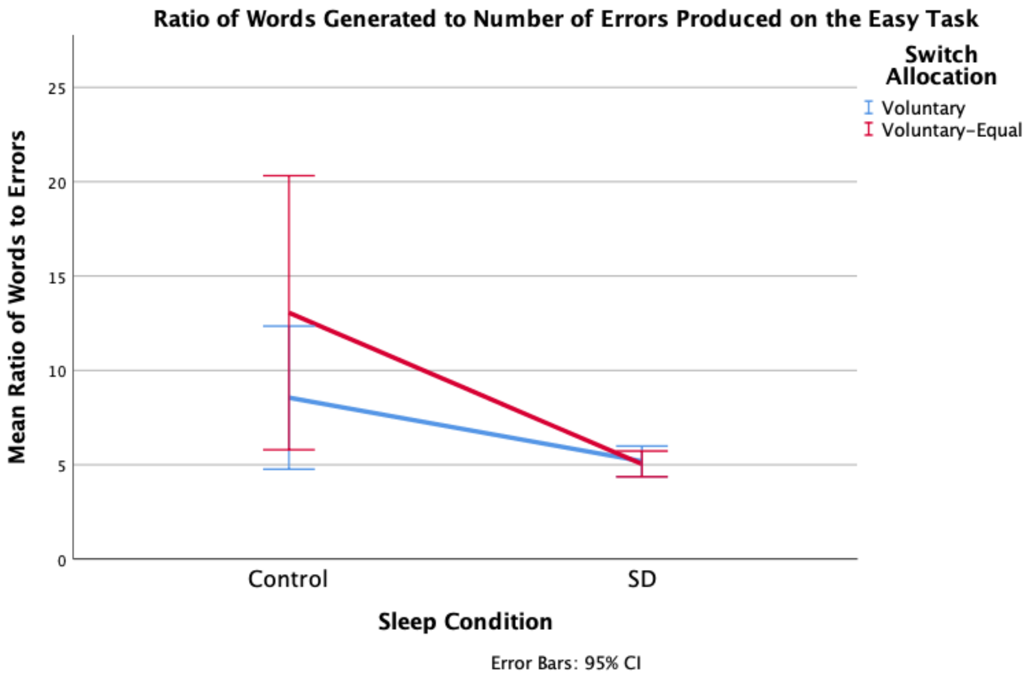

Figure 4.6 A line graph displaying the ratio of the number of words generated with the number of errors produced in the Control and SD participants for both voluntary and voluntary-equal conditions on the easy task.

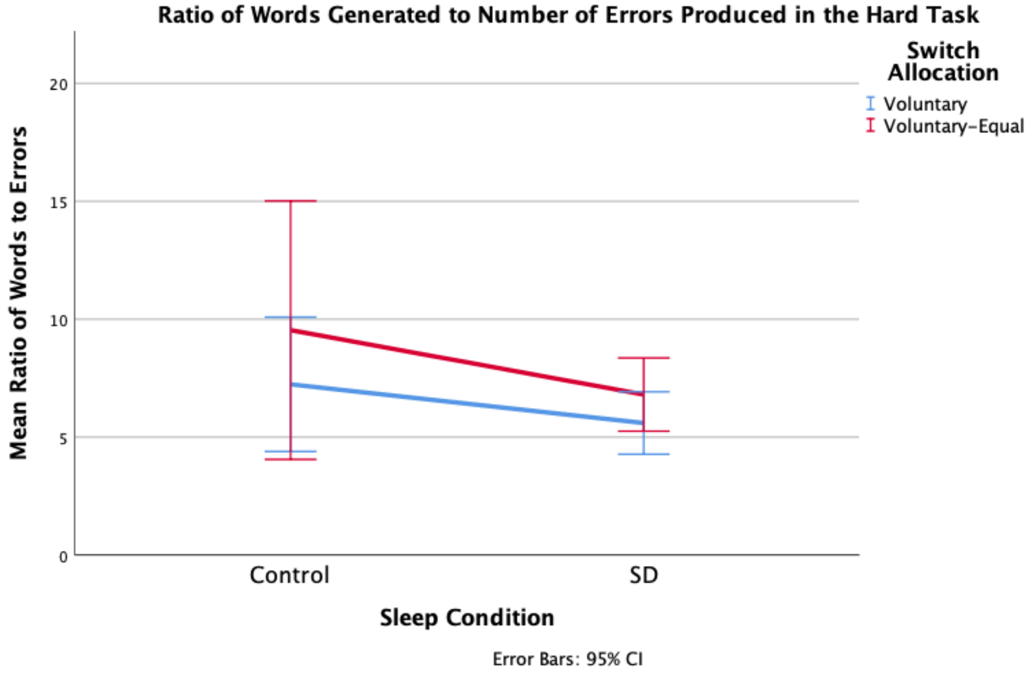

Figure 4.7 A line graph displaying the ratio of the number of words generated with the number of errors produced in the Control and SD participants for both voluntary and voluntary-equal conditions on the hard task.

Differences in switching behaviour

Number of switches: The main effect of switch allocation was significant, $F(1,62) = 24.31$, $p < .001$, $\eta^2 = .28$. More switches were made in the Voluntary ($M = 13.91$, $SD = 6.09$) than the Voluntary-Equal condition ($M = 6.65$, $SD = 4.22$). The interaction between task difficulty and switch allocation was significant, $F(1,62) = 4.86$, $p = .03$, $\eta^2 = .07$. There were no other significant main effects or interactions (all $F < 3.36$, all $p > .07$).

Post-hoc analysis of the task difficulty and switch allocation interaction showed an effect of task difficulty in the Voluntary-Equal condition, $t(30) = 2.89$, $p = .007$ but not in the Voluntary condition $t(34) = -.42$, $p = .68$. There was a significant difference with Voluntary condition switching more than the Voluntary-Equal condition on both the easy and the hard task, $t(64) = 4.15$, $p < .001$ and $t(64) = 5.56$, $p < .001$ respectively.

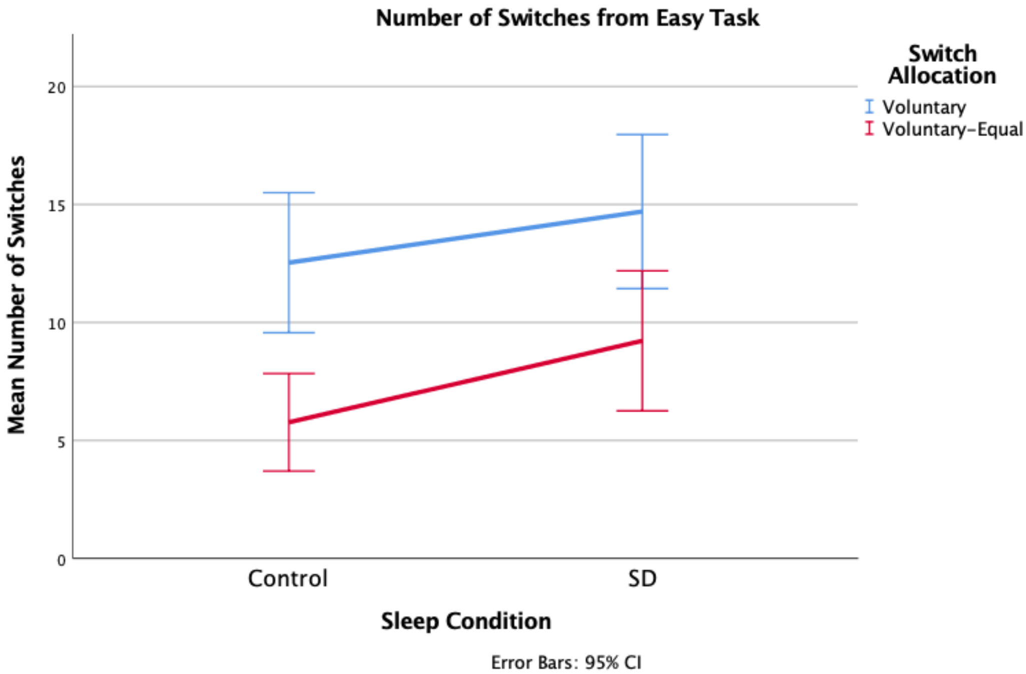

Figure 4.8 A line graph displaying the number of switches in the Control and SD participants for both voluntary and voluntary-equal conditions on the easy task.

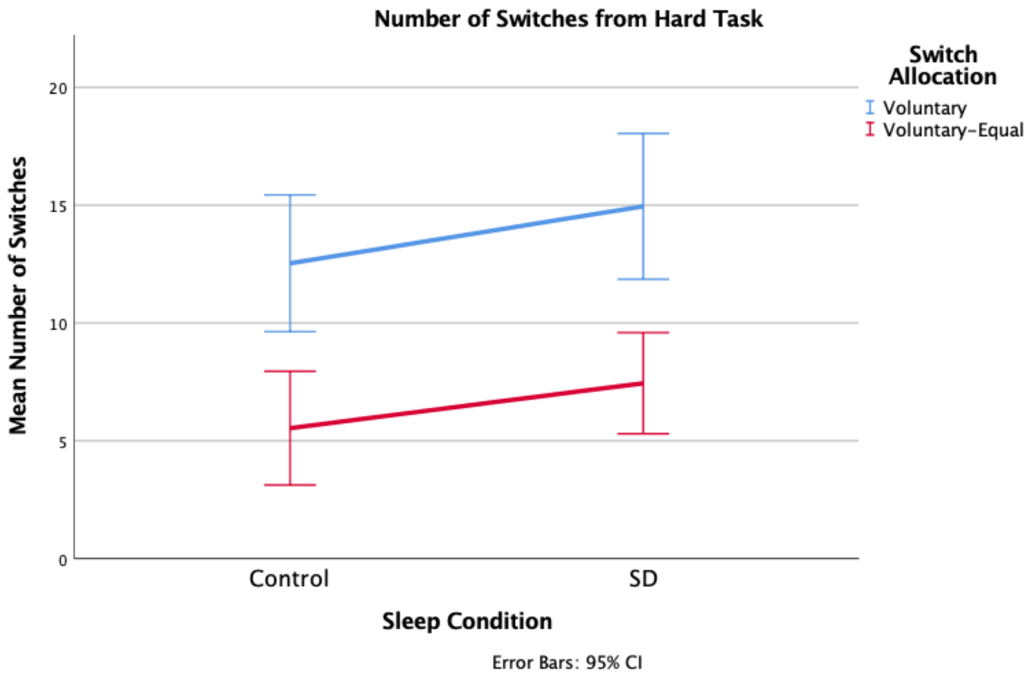

Figure 4.9 A line graph displaying the number of switches in the Control and SD participants for both voluntary and voluntary-equal conditions on the hard task.

Giving-Up Time (GuT) and Resumption Lag (RL)

Giving-up time was defined as the time between the last word generated and participants subsequently deciding to switch to the other task. While Resumption lag time was defined as the time between switching tasks and then generating the first word.

Giving-up Time: The main effect of task difficulty was significant, $F(1,62) = 14.17$, $p < .001$, $\eta^2 = .19$. GuT was longer in the hard ($M = 20564.47$ msec, $SD = 10849.67$) than the easy task ($M = 15494.28$ msec, $SD = 9165.38$). No other significant main effects or interactions approached significance (all $F < 2.82$, all $p > .10$).

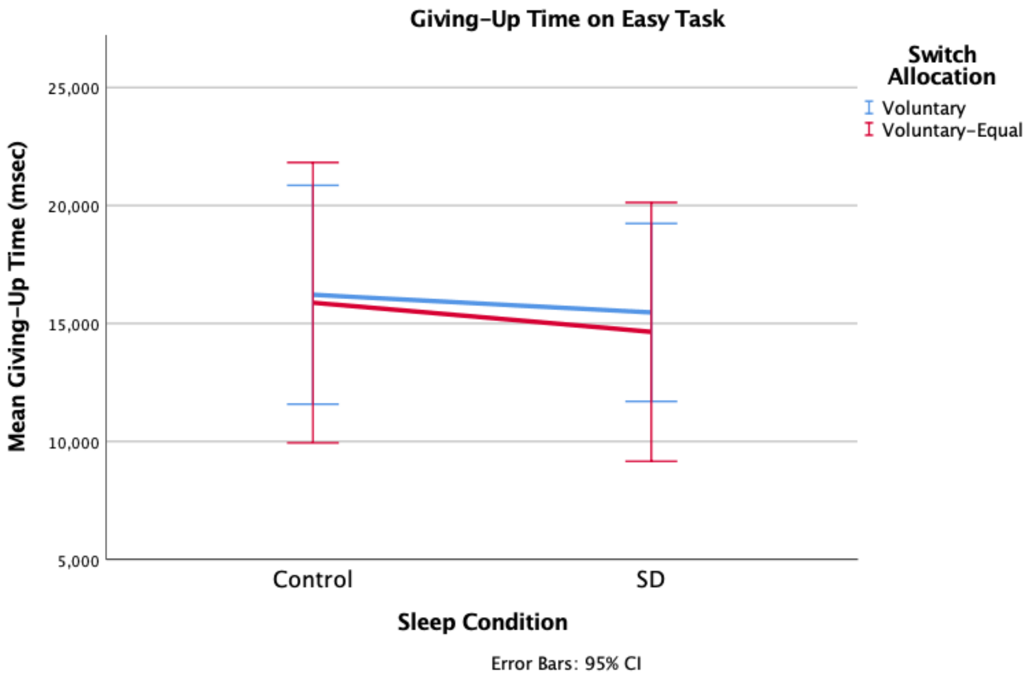

Figure 4.10 A line graph displaying the giving-up time in milliseconds in the Control and SD participants for both voluntary and voluntary-equal conditions on the easy task.

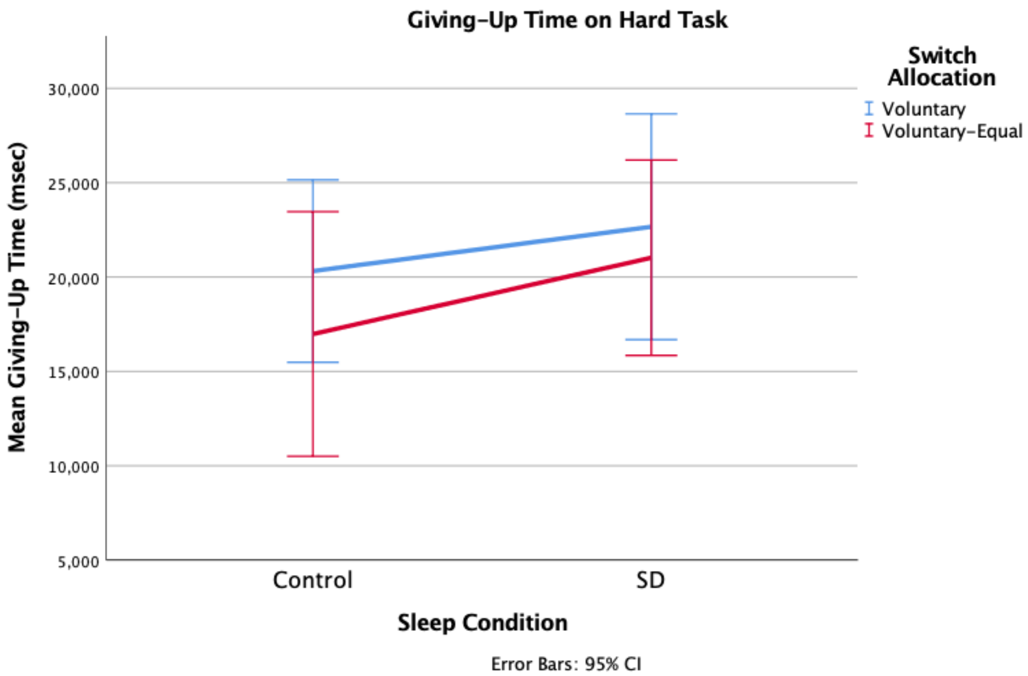

Figure 4.11 A line graph displaying the giving-up time in milliseconds in the Control and SD participants for both voluntary and voluntary-equal conditions on the hard task.

Resumption lag time: There was a significant main effect of task difficulty, $F(1,57) = 5.07$, $p = .028$, $\eta^2 = .08$. With a longer RL in the hard ($M = 20204.26$ msec, $SD = 9198.29$) than the easy task ($M = 17012.16$ msec, $SD = 6766.76$). There was a significant interaction between task difficulty, sleep condition and switch allocation, $F(1,57) = 5.23$, $p = .026$, $\eta^2 = .08$. There were no other significant main effects or interactions (all $F < 3.14$, all $p > .08$).

Exploring the interaction between task difficulty, sleep condition and switch allocation further a two-way ANOVA was run one for easy and one for hard tasks. The interaction between sleep condition and switch allocation only reached significance in the hard task, $F(1,58) = 5.14$, $p = .03$ and not the easy task (all $F < 3.12$, all $p > .08$). Switch allocation increased RL in the SD condition, $t(31.22) = 2.46$, $p = .02$ but not in the control condition, $t(12.52) = -.97$, $p = .35$.

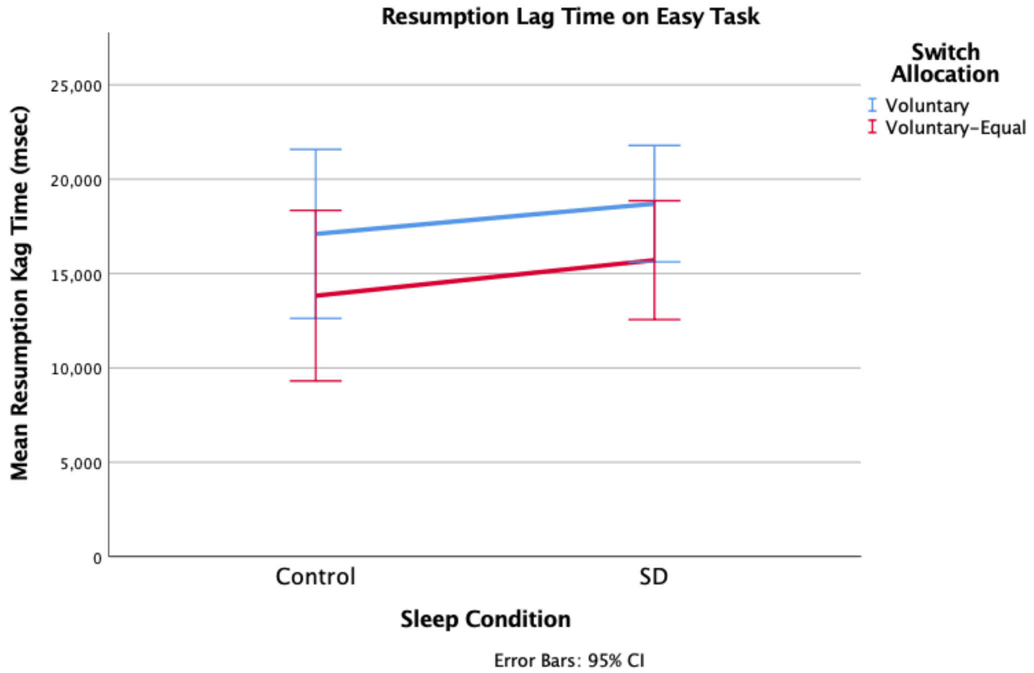

Figure 4.12 A line graph displaying the resumption lag in milliseconds in the Control and SD participants for both voluntary and voluntary-equal conditions on the easy task.

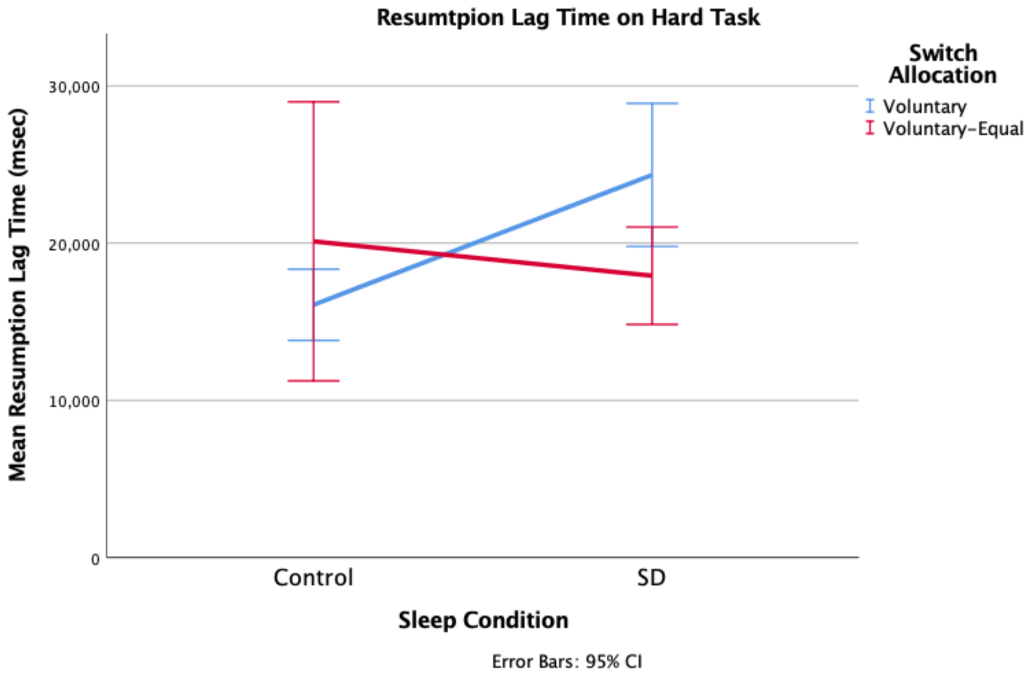

Figure 4.13 A line graph displaying the resumption lag in milliseconds in the Control and SD participants for both voluntary and voluntary-equal conditions on the hard task.

Examining differences in decision making – word frequency, time on task (ToT)

The frequency of words was determined by the English Lexicon Project (Balota et al., 2007). For the total time on task analysis only the participants in the Voluntary condition were included as they were the only ones who had complete control over their timings.

Word Frequency: The main effect of task difficulty was significant, $F(1, 62) = 54.39$, $p < .001$, $\eta^2 = .47$. With higher frequency words generated in the easy ($M = 4.40$, $SD = .28$) than the hard task ($M = 4.17$, $SD = .24$). No other main effects or interactions reached significance (all $F < 3.38$, all $p > .07$).

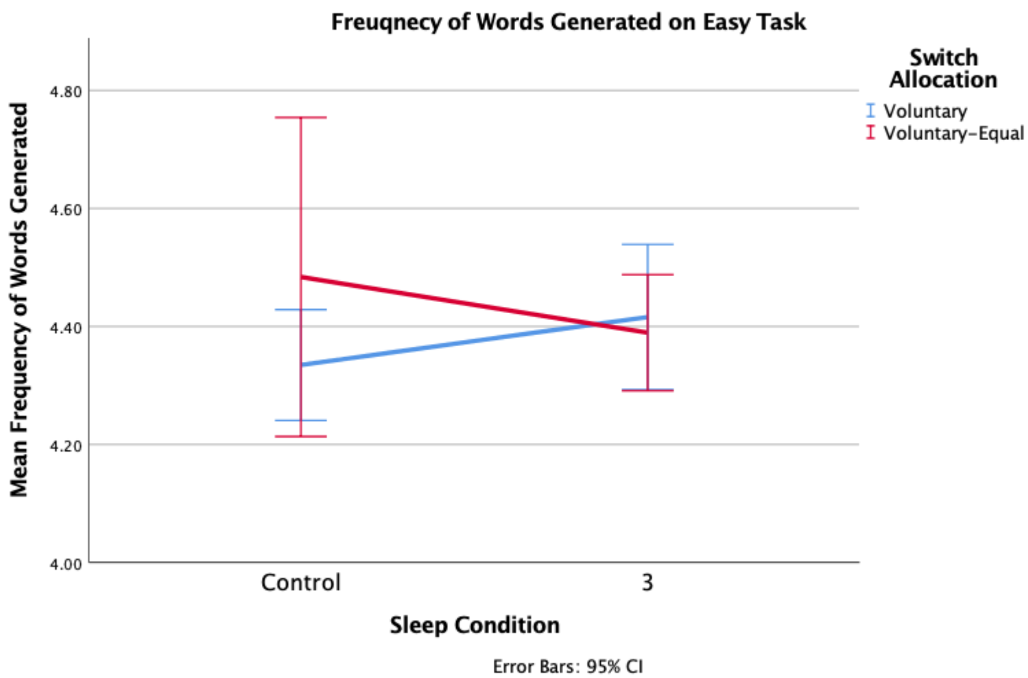

Figure 4.14 A line graph displaying the frequency of the words produced in the Control and SD participants for both voluntary and voluntary-equal conditions on the easy task.

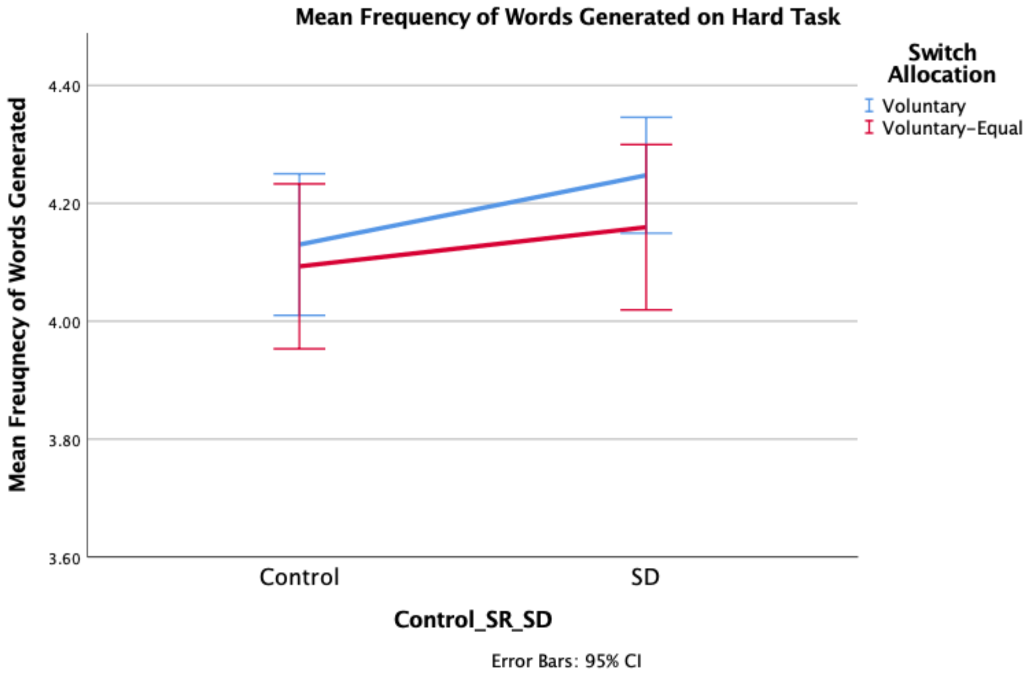

Figure 4.15 A line graph displaying the frequency of the words produced in the Control and SD participants for both voluntary and voluntary-equal conditions on the hard task.

Time on task (ToT): The main effect of task difficulty was significant, $F(1,33) = 36.32$, $p < .001$, $\eta^2 = .52$. More time was spent on the easy ($M = 325.32$ seconds, $SD = 47.50$) than the hard task ($M = 235.26$ seconds, $SD = 59.24$). There was a significant interaction between task difficulty and sleep condition, $F(1,33) = 5.27$, $p = .03$, $\eta^2 = .14$. SD led to spending longer on the hard than easy task ($M = 254.48$ seconds, $SD = 39.49$ versus $M = 209.65$ seconds, $SD = 71.94$), $t(20.28) = -2.18$, $p = .04$, for SD and controls respectively). No other main effects or interactions approached significance (all $F < 1.34$, all $p > .26$).

Post-hoc analysis of the task difficulty and sleep condition interaction showed an effect

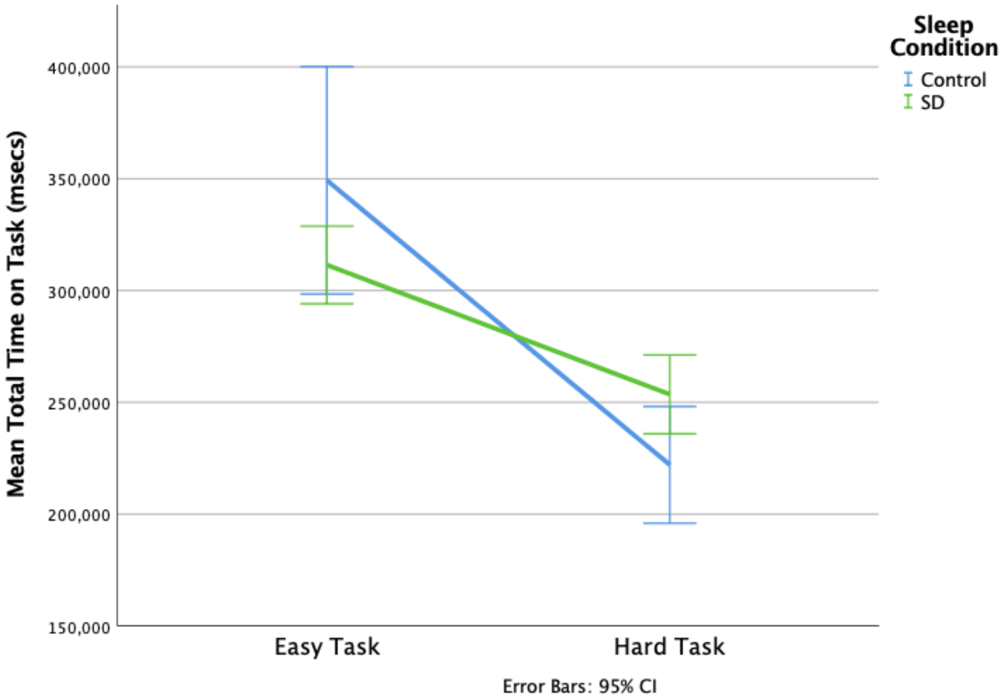

Figure 4.16 A line graph displaying the total time spent on easy task in the Control and SR participants for voluntary only as the voluntary-equal condition forces participants to spend equal time on both tasks.

Examining effects of Working Memory Capacity (WMC) on performance

While it is not a primary focus of the present study given the importance place on WM, any variable that fatigue seemed to effect was further explored using regression analysis. The aim was to see if the impact of fatigue was influenced by WMC.

A multiple linear regression was calculated to investigate whether WMC, as measured by Ospan and 3-Back, predicted performance on words generated and number of switches and then to see if this differed between SR and Control participant groups. The reason for just examining these measures was because these were the only measures to have been found to have a significant main effect or interaction. It was therefore with this reason that it was important to see on these measures whether WMC had any involvement.

Results of the multiple linear regression for the SD participants, indicated that there was a collective significant effect between the Ospan and 3 -back tests on words - easy, ($F(2, 32) = 4.09$, $p = .03$, $R^2 = .15$). The individual predictors were examined further and indicated that Ospan ($t = -2.04$, $p = .05$) was a significant predictor in the model but 3-Back ($t = -1.53$, $p = .14$) was not.

Table 4.2 Results of the multiple regression analysis for the SD participants data

		t	*p*	*β*	*F*	*df*	*p*	*adj.R²*
Words - Easy								
	Overall Model				4.09	2, 32	.03	.15
	Ospan Partial	-2.04	.05	-.33				
	Average 3-Back	-1.53	.14	-.25				
Words – Hard								
	Overall Model				2.81	2, 32	.08	.09
	Ospan Partial	-2.17	.04	-.36				
	Average 3-Back	-.46	.65	-.08				
Switches – Easy								
	Overall Model				1.21	2, 32	.31	.01
	Ospan Partial	1.11	.28	.19				
	Average 3-Back	-1.30	.20	-.23				
Switches – Hard								
	Overall Model				1.28	2, 32	.29	.02
	Ospan Partial	1.19	.24	.21				
	Average 3-Back	-1.29	.21	-.22				

Results of the multiple linear regression for the Control participants, indicated that there was not a collective significant effect between the Ospan and 3 -back tests (all $F < 2.48$, all $p < .11$).

Table 4.3 Results of the multiple regression analysis for the Control participants data

	t	*p*	*β*	*F*	*df*	*p*	*adj.R²*
Words - Easy							
Overall Model				2.07	2, 19	.15	.09
Ospan Partial	1.24	.23	.26				
Average 3-Back	1.53	.14	.32				
Words – Hard							
Overall Model				2.48	2, 19	.11	.12
Ospan Partial	.08	.43	.16				
Average 3-Back	2.02	.06	.41				
Switches – Easy							
Overall Model				.65	2, 19	.53	-.04
Ospan Partial	-1.14	.27	-.25				
Average 3-Back	.04	.97	.01				
Switches – Hard							
Overall Model				.36	2, 19	.71	-.07
Ospan Partial	-.75	.46	-.17				
Average 3-Back	-.34	.74	-.08				

4.4 Discussion

Experiment 2 aimed to replicate Experiment 1 with the exception that rather than comparing Controls to sleep restricted participants, they would be compared with sleep deprived participants. Experiment 1 established fatigue effects on performance but these were limited to giving-up time. With this in mind, the current experiment aimed to investigate whether the fatigue effects on performance would be more profound in individuals who experienced 30 hours of continued wakefulness compared to individuals who had not. Based on previous findings from Experiment 1, it was hypothesised that SD would result in further effects on performance specifically producing increased number of errors, reduced word generation, reduced frequency of switches, an increased ‘giving up’ time and reduced resumption time following a switch.

Was the fatigue manipulation effective?

The aim of the present experiment was to establish whether a more severe sleep manipulation would cause the effects found on the task performance in Experiment 1 to be more profound. As predicted these effects were more profound in the SD participants than the SR participants. To ensure that the differences observed were due to fatigue and not something else the fatigue measures needed to be compared between the two sleep manipulation groups (e.g. SD and SR). It is presumed that SD condition will lead to greater fatigue levels than the SR. Results demonstrated that the hours slept and the rated KSS scores were significantly different between the two sleep manipulation conditions, with unsurprisingly the SD condition having less hours sleep and higher KSS ratings.

There is clear evidence from the hours slept and the subjective measure of fatigue (i.e. KSS), that the present experiment successfully made participants more fatigued in the SD condition compared to the SR condition. Yet, no differences were observed between the SR and SD conditions for any of the PVT measures. This suggests that the subjective measure is more sensitive to the different levels of sleep loss compared to the objective measure. A notion that is supported by previous research that suggests subjective sleepiness is linearly related to the hours slept while objective measures (e.g. PVT performance) deteriorate exponentially as levels of sleep loss increase (Jewett et al., 1999; as cited in Kaida et al., 2006).Therefore the differential level of sleep loss between the SR and SD manipulation might not be enough to elicit the differences in the objective measure while simultaneously showing differences in the subjective measure.

The results from Experiment 1 demonstrated that sleep restriction was strong enough to induce an effect on the KSS, but not quite strong enough to stimulate an effect in the PVT. In the present experiment however, the sleep deprivation condition was successful in inducing an effect on both the KSS and the PVT measures; specifically, in the number of false alarms, lapses in attention and RT; compared to the Control condition. These results demonstrate that despite there being no significant difference between the SR (4hrs a night for 3 nights) and SD (0hrs for 1 night) on the objective measure, the stronger SD manipulation did differ from Control condition to a greater extent than the SR condition did.

Like Experiment 1, participants sleep prior to the experimental days was not recorded however, SD participants had an average night's sleep over the 1 night of M =.28 and this level of sleep loss should be enough to overcome any potential sleep debt incurred by participants in the Control condition. Equally, this is a much larger difference than that observed between the Control and SR conditions in Experiment 1.

Effect of sleep manipulation on task switching

As mentioned previously, to successfully switch tasks requires preparation of the task-set reconfiguration to execute the new task, and the disengagement from the previous task (Couyoumdjian et al., 2010). This task-set reconfiguration in Experiment 1 is reflected in the GuT, with the SR participants requiring a longer GuT compared to the Controls on the hard task. This longer GuT in the SR participants is thought to reflect the extra time needed to reconfigure task goals when fatigued and because of this additional preparation time no other performance effects were observed. In the present experiment however, there was no effect of giving-up time in the SD condition but there was a significant effect with a longer RL observed on the hard task. This lack of difference between SD and Control participants in GuT could be a result of a change in cognitive control due to the increased fatigue experienced in the SD condition. With the SR participants employing proactive control and preparing in advance of the switch (GuT in Experiment 1) compared to the SD participants implementing reactive control and preparing following the switch (RL in Experiment 2). Reactive control is stimulus-driven and is a form of 'late correction' to resolve the effect of interference after it has occurred - in this case the interference being the severe fatigue (Jacoby et al., 1999; as cited in Braver, 2012). Nonetheless, observing effects on GuT and RL in both Experiments 1 and 2 suggests that these components are particularly sensitive to sleep loss. This is supported by previous research that observed that both the preparation and disengagement components are negatively affected by sleep loss (Couyoumdjian et al., 2010).

These two components (preparation and disengagement) are thought to be vital for successful task switching. Therefore, it is understandable that with more time made available to these components the less deleterious the switch costs will be (Couyoumdjian et al., 2010;

Panepinto, 2010). This is evident in Experiment 1 with the increase in the GuT in the SR participants, resulting in no differences being observed in performance (e.g. words generated and the number of errors). In contrast, the present experiment failed to show any differences in the GuT length between SD and Control participants and subsequent performance effects were observed, specifically, with a reduction in the number of words generated and an increased number of switches. It is this lack of additional time given to reconfiguring and disengaging the task goals in the SD condition that results in poorer task performance.

The present experiment observed a difference in word generation with the SD participants producing fewer words than the control participants. Following further analyses it revealed that this difference was only present on the easy task and not the hard. A possible explanation for the reduced word generation on the easy task only, could be accounted for by the smaller range of potential words on the hard task and as such no differences would be shown; this is also known as the floor effect. A further explanation is the greater engagement required for complex tasks. Previous literature provides evidence showing that complex tasks remain relatively unaffected by sleep loss as a result of the increased interest generated from performing such a task and the subsequent implicit effort individuals apply to overcome any sleepiness (Harrison & Horne, 2000). Whereas, more simple tasks are associated with lower stimulation and boredom and therefore sleep loss may further amplify these traits (Wickens et al., 2015). Matthews & Desmond (2002) further lend support for this explanation observing that fatigued individuals have impaired heading error and reduced steering activity driving straight roadway sections (simple task). Whereas when driving during curved roadway sections (a more complex task) the same impairments were not produced. Similarly, sleep-related vehicle accidents increase on monotonous motorways in comparison to driving through urban environments that are full and so have many attention demanding tasks (Anderson & Horne, 2006; Horne & Reyner, 1995). The general consensus is that completing monotonous and undemanding tasks alongside accumulated sleep loss further facilitates sleepiness and increases the effects of sleep-related impairment (Horne & Reyner, 1995). Similar studies have demonstrated that following SD, impaired performance on simple cognitive tests deteriorates further with decreasing novelty therefore the greater the monotony the shorter the task needs to be before deterioration is evident (Dinges & Kribbs, 1991; Kjellberg, 1975; 1977). This is especially true if the test forms part of a long battery of similarly monotonous tests (Harrison and Horne, 2000).

Studies exploring decision making in people with sleep loss have found that when individuals had the choice between switching tasks more or less frequently, they opted to switch less frequently as it put less demand on their executive control (McGuire & Botvinick, 2010). This research suggests that individuals are motivated to minimise costs, and therefore decide to switch less often to achieve this (McGuire & Botvinick, 2010). It may be that when an individual is SD there decision-making is impaired resulting in more frequent switching between tasks. Equally, SD participants require increased effort to maintain their alertness on the task and so switch more frequently to aid their alertness. Whereas, SR participants are less fatigued and therefore less effort is needed to maintain alertness on the task therefore they switch less as evidenced in Experiment 1.

Switching at opportune moments may also be a factor in why there were minimal differences observed in participants performance in both studies; specifically establishing no difference in the number of errors participants produced. Switching at times that are most suitable for that person can alleviate most of the negative costs associated with switching thus it may be enough to help fatigued participants overcompensate their fatigue impairment. Another thought was that SD participants may not be putting as much effort in and so subsequently less likely to produce errors. Ratio analysis was used to understand this further. Results highlighted that actually SD participants were generating fewer words to every error produced compared to the Control participants. This was specifically found to be the case on the easy task not the hard. This reflects the results of the number of words generated being fewer on the easy task in the SD compared to Controls. This suggests that there is a difference in their error rate but SD participants were simply generating fewer words overall that this difference was then not reflected in the number of errors analysis.

Effect of working memory

Although not a primary focus of this experiment, given the importance placed on WM in both task switching and fatigue it was important to understand WMs role in the significant effects discovered in the task switching measures in the present experiment and to explore whether there was any evidence of those effects being moderated by WM. It is worth noting that there was an effect of WM measures on the number of words generated on the easy task for SD participants but not Controls. This correlation was positive which highlights that the higher the individuals WM the more words they generated. This is an important finding as it provides implications that individuals with high WM are better able to manage the deleterious effects caused by SD on the number of words they generated. This is to be expected given that the nature of working memory affects both active maintenance of current task goals and the blocking of distractors (Kane & Engle, 2002). Specifically, research has suggested that individuals with high WMC have a greater capacity to remain attended to specific information while ignoring irrelevant information, in comparison to their low WMC counterparts (Kane & Engle, 2003). Therefore, SD individuals with high WMC are better equipped to deal with the interference experienced by switching between tasks and a loss of sleep compared to their low WMC SD counterparts. Nonetheless, the influence that WMC has on words generated is still not enough to be able to fully overcome the difference in number of words generated with Controls still producing more words overall compared to the SD participants.

4.5 Conclusion

In summary, the results of the present experiment demonstrate that by increasing the severity of sleep, from partial sleep loss to total sleep deprivation it increases the negative impact on task performance. SD participants need longer to prepare for the change in the task prior to the switch happening something they were not doing which resulted in them experiencing a reduction in the number of words generated. Within the SD condition, this reduction in the number of words generated was also recognised to be predicted by WMC and importantly demonstrates that individuals with high WMC were better able to mediate the effects of SD on their performance compared to individuals with low WMC. Furthermore, a change in switching behaviour was also elicited with more frequent switches made by the SD participants compared to Control participants. No differences in the number of errors were observed and this could be a consequence of either SD not impacting performance in this way or be due to the participants having control over when to switch tasks that allowed them to minimise errors; more research is needed to determine the cause.

Chapter 5

The Effects of Sleep Deprivation on Forced Task Switching

5.1 Introduction

In chapter 4, results demonstrated that that SD was associated with increased subjective tiredness (KSS), increased objective measures of fatigue (PVT) and a broader set of performance deficits relative to SR. Specifically, SD causes a reduction in the number of words generated and an increase in RL time on the hard task only. These findings suggest that when an individual has experienced more severe sleep loss they begin to approach the task differently and it is leading to a profile of errors indicative of the impact of fatigue on strategy. In the present experiment, the SD manipulation will be repeated as this is what seems to impact participants the most, but now their control over when to switch will be removed and they will be forcibly switched back and forth between the two tasks. Of great interest is whether the same profile of errors emerge once control over the task has been removed or whether a different profile of errors appear.

Task Switching

Switching between tasks involves preparation and reconfiguration of the new task-set whilst simultaneously disengaging from the previous task (Couyoumdjian et al., 2010). Experiments 1 and 2 had free choice of when to switch and it is thought that this process was reflected in the giving-up time prior to the switch happening or in the resumption lag time after the switch has happened. Having free choice of when to switch allows individuals to predict the switch and subsequently prepare for it. Therefore, participants would not experience as much of a cognitive deficit when switching attention from one task to the next compared to if there was no prior warning of an imminent switch. However, by removing the participants free control of when the switch happens they are no longer able to prepare in advance of the switch and therefore the reconfiguration/disengagement process will have to occur within the resumption lag time after the switch.

The voluntary versus forced distinction is important because the effects of switching on performance are likely to differ between the two. This ability to prepare for a switch versus forcibly being switched creates very different cognitive challenges. Following a forced switch, individual's attention will become driven in a bottom-up manner to resolve the conflicting activations of the task goals from the previous task with those of the current task. Forced interruptions have been established to decrease performance on the task and cause longer resumption lags (Salvucci et al., 2009). Previous research has found exceptions to this typical finding, showing that following interference task performance can be improved. This notion suggests that when the task is easy, an interruption can actually serve to re-focus the attention that may otherwise have been wandering (Speier et al., 2003). This is because the unexpected interruption serves to either increase arousal of the individual or decrease their boredom both of which can facilitate performance (Adler & Benbunan-Fich, 2012; Altmann & Trafton, 2002; Speier et al., 1999, 2003). Needless to say, an interruption can cause the opposite effect with an increase in arousal resulting in an overload on cognitive resources and a subsequent decline in performance (Altmann & Trafton, 2002).

Sleep deprivation and task switching

Working memory, vigilance and flexible thinking all play vital roles in being able to successfully switch between tasks and it is these cognitive domains that have been recognised as being affected by sleep deprivation resulting in neurobehavioral deficits (Durmer & Dinges, 2005; Harrison & Horne, 1999, 2000; Pilcher & Huffcutt, 1996). Such deficits include lapses of attention, slowed working memory, reduced cognitive capacity, depressed mood, and repetition of thought (Banks & Dinges, 2007). The impact of SD on cognitive domains can be further evidenced with the results from Experiment 1 and 2 which found sleep loss to be an influencing factor on task performance, causing lapses in attention, false alarms, increased giving-up time, a decline in the number of words generated, and a longer resumption lag when the task was hard.

A number of complex skills are required when switching tasks, these skills include anticipating consequences of changing tasks, keeping track of the task goals, being innovative, avoiding distractions and irrelevant stimuli (Jones & Harrison, 2001). Recent evidence has established that these skills will show significant deterioration even after one night of SD regardless of how hard the individual tries to perform well (Harrison & Horne, 2000). More specifically, research has established that one night of total SD has negative effects on performance speed and the ability to switch between different cognitive tasks, in terms of being able to flexibly and rapidly change behaviour and adapt to changing environmental demands (Couyoumdjian et al., 2010). Both of which are arguably key components needed when forcibly switched between tasks.

Forcibly switching between tasks has been notably recognised as differing in the effects on task performance compared to voluntarily choosing when to switch. Specifically, causing longer RL times and increased severity of switch cost (Adamczyk & Bailey, 2004; Arrington & Logan, 2004). Removing the control over when to switch also removes a fundamental executive element – decision making. Decision-making has been suggested to be particularly sensitive to the effects of fatigue (Glass et al., 2009; Harrison & Horne, 1999; Wickens et al., 2015). Without this decision-making element a different strategy will need to be adopted and how this change in strategy will manifest itself when SD is yet to be understood.

Working memory and task switching

Individual differences may play a role in task switching. In Watson and Strayer's study, participants were required to complete a dual-task consisting of a 90-minute driving simulation where they were asked to follow a pace car that braked at random intervals causing them to respond accordingly by braking themselves. Results showed that on average in the dual-task scores those with high WMC performed higher on the auditory OSPAN task while having a shorter braking reaction and following distance in the driving simulations. In other words, participants with high WMC on average had a superior performance compared with the group average of low WMC (Watson & Strayer, 2010). This evidence may have significant implications within the literature as it challenges the bottleneck theory (Broadbent, 1958) that was assumed to be immutable. It suggests that the bottleneck filter varies in size between individuals, with high WMC individuals having a system that allows more information to be processed at any one time (Watson & Strayer, 2010). If this is the case then it suggests that individuals with high WM are better equipped to deal with increased workloads and conflicting information something that is needed following a forced change in tasks.

Rationale

The present study was conducted to investigate the difference in the effects of forced task switching between individuals who experienced loss of sleep and individuals who had not. There are two hypotheses and associated predictions that follow:

(1) Due to a general slowing in performance and an increase in errors found in previous research, it is predicted that participants in both the Control and SD conditions will produce more errors and generate fewer words in the forced switching condition compared to the voluntary switching condition. Additionally, SD participants will experience an

increased deterioration of performance (i.e. more errors, less words generated) compared to Control condition.

(2) Due to an impaired ability to rapidly and flexibly adjust to changes in task demands when fatigued, SD individuals will be likely to have a longer resumption lag time. Equally, this resumption time will be longer in both Control and SD conditions in the forced switch condition than that observed in the voluntary switching condition.

5.2 Methods

Participant

Seventy-five participants were used in total in the data analysis. Thirty-four participants (24 females; M = 20.09, SD =1.52; age range = 18 - 24 years old) were individuals collected in Chapter 4 and used as the voluntary switching condition[3] for both SD and Controls in the present experiment (15 Controls and 19 SD participants).

Forty new undergraduate and postgraduate students were collected for the forced switching condition in the present experiment (33 females; M = 19.98, SD =1.74; age range = 18 - 25 years old). Twenty participants were randomly assigned to Control condition and 20 to the Control condition. All participants self-reported normal vision or corrected-to-normal vision.

Design

There were two crossed between-participant factors, task-switching control (free choice of time spent on each of the two word-generation tasks versus forced switching time,

[3] The Voluntary condition data was used for comparisons with the Forced data rather than Voluntary-Equal as there was complete free choice of their switching. Therefore, only the statistics from Voluntary condition will be presented.

hereafter called Voluntary and Forced switching) and amount of sleep (deprived versus normal). The participant data for the Voluntary switching condition (both SD and Controls data) was taken from Experiment 2 presented in Chapter 4. All participants in the Forced switching condition were assigned randomly to the between-participant conditions (deprived versus normal). Those in the sleep deprived condition were instructed to maintain continual wakefulness for thirty hours between the two computer-based testing sessions; those in the normal sleep condition maintained their normal sleep patterns for that night.

Following on from Experiments 1 and 2 presented in Chapters 3 and 4, participants were required to take part in two separate computer-based testing sessions. The two sessions were a day apart. During the first session working memory (Ospan and 3-Back) and fatigue (KSS and PVT) were measured. Each participant was also given a Fitbit to wear for the duration of the experiment. Sleep was tracked between the two sessions. Participants completed the online tests at specific times depending on their assigned condition. At the second testing sessions, participants fatigue was measured again (KSS and PVT) and then they were required to complete the main experimental task; a word generation task (see Chapter 2 for more detail). Unlike Experiments 1 and 2, participants were forcibly switched back and forth between two lettersets for a total of ten minutes with participants ultimately having to spend five minutes on each of the easy and hard lettersets.

For full details of Experiment 3's experimental design, see Chapter 2.

5.3 Results

There are three parts to the results. The first tests whether the sleep manipulation induced fatigue. The second section tests the impact of SD on forced task switching and the final section tests the effect of Forced versus Voluntary switching allocation on task performance.

In order to examine one of the hypotheses; that forced switches will cause a greater impact on performance and RL than voluntary switching; the voluntary switching data for Control participants will be taken from Experiment 1 and for SD participants Experiment 2 and will be analysed alongside the data collected in the present study.

Was the manipulation effective?

The measures of the PVT used were the reciprocal response times (RT), false alarms and the number of lapses in attention (e.g. any RTs that were greater than 500ms). The mean of the reciprocal RT was used as a measure due to the RTs being skewed. By doing a reciprocal transformation on the RT data it made the distribution normal. The KSS and PVT data were taken from the second testing session.

SD participants slept less hours compared to participants in the Control condition (M = .30, SD = .84 versus M = 7.51, SD = 1.97; $t(44.78) = 20.11$, $p < .001$, d = 4.76) and had increased fatigue as measured by the KSS compared to Controls (M = 7.45, SD = 1.20 versus M = 3.74, SD = 1.92; $t(56.32) = -9.81$, $p < .001$, d = 2.32).

There was no significant difference between PVT lapses in the SD condition (M = 7.15, SD = 9.39) compared to the Control condition (M = 3.69, SD = 5.98), $t(65.13) = -1.92$, $p = .06$, $d = .44$. There was also no significant difference between the SD and Control conditions for the PVT reciprocal RT or number of false alarms, $p = .17$ and $p = .11$ respectively.

With respect to within-group comparisons, SD led to increased KSS scores, reciprocal RT, lapses in attention and false alarms on Day 2 compared to Day 1 (t(37) = -

12.00, *p* < .001, *d* = 3.04, *t*(38) = 2.39, *p* = .03, *t*(38) = -4.31, *p* < .001, *d* = 0.93 and *t*(38) = -2.36, *p* = .02, *d* = 0.53 respectively).

In comparison Controls, had no differences to KSS scores, lapses in attention and false alarms on Day 2 compared to Day 1 (*t*(30) = .97, *p* = .34, *t*(31) = -.32, *p* = .75 and *t*(31) = .61, *p* = .55 respectively). Controls had increased reciprocal RT on Day 2 and Day 1, *t*(31) = -.38, *p* = .001, *d* = 1.05.

Table 5.1 Participant means for the fatigue measures (hours slept, KSS and PVT)

Measure	Controls		Sleep Deprived	
	Voluntary	Forced	Voluntary	Forced
No. of Participants	15	20	19	20
Sleep Hours	*M*=6.71, *SD*=1.19	*M*=7.86, *SD*=2.31	*M*=.24, *SD*=.58	*M*=.38, *SD*=1.06
KSS Score	*M*=4.80, *SD*=2.04	*M*=3.09, *SD*=1.51	*M*=7.58, *SD*=.90	*M*=7.33, *SD*=1.49
PVT RT>500ms	*M*=2.93, *SD*=4.18	*M*=4.24, *SD*=7.05	*M*=7.84, *SD*=8.73	*M*=6.50, *SD*=10.15
PVT False Alarms	*M*=.40, *SD*=.83	*M*=.71, *SD*=1.15	*M*=1.16, *SD*=2.03	*M*=1.50, *SD*=3.17
PVT Reciprocal RT	*M*=.004, *SD*=.001	*M*=.004, *SD*=.001	*M*=.003, *SD*=.001	*M*=.004, *SD*=.001

Task Switching Measures

The data was scored in terms of correct responses, repeated words, non-words and words including letters from outside the lettersets. In total from the participants tested, 20% of responses were categorised as incorrect (6% repeated words, 13% non-words and 1% wrong letters used). However, all the responses, both correct and incorrect responses will be included in the timing data.

Three 2 (Sleep condition: SD versus Control) x 2 (Switch-allocation: Voluntary versus Forced) x 2 (Task difficulty: Easy versus Hard) ANOVAs were conducted on the number of errors, words generated and RL times. With Sleep condition and Switch-allocation as between-participants factors and Task difficulty as a within-participants factor. Greenhouse-Geisser *F* values, degrees of freedom, and *p* values are reported for repeated-measures ANOVA results wherever tests of sphericity are violated (i.e. Mauchly's test of sphericity shows a *p* value of less than .05). In the following results, any significant effects or interactions were further analysed using *t*-tests. All *t*-tests that were conducted had their *p* values Bonferroni-corrected before being reported. In all figures, error bars represent ±S.E.M.

Does the KSS predict the PVT?

The results of the regression indicated that KSS scores predicted RT from the PVT explaining 9% of the variance, ($F(1, 71) = 6.52$, $p = .01$). Additionally, KSS scores predicted lapses in the PVT explaining 7% of the variance, ($F(1, 71) = 5.59$, $p = .02$). KSS scores do not predict the number of false alarm ($F(1, 71) = 3.09$, $p = .08$).

Investigating error rate

Errors were considered in two ways, summed together and considered as individual types of errors. Word generation was based on the number of correct words participants were able to generate.

The main effect of task difficulty was significant, $F(1,71) = 46.98$, $p < .001$, $\eta^2 = .40$, with more errors made on the easy than hard task ($M = 21.97$, $SD = 23.89$ versus $M = 14.11$, $SD = 17.17$). There was a significant interaction established between task difficulty and switch allocation, $F(1,71) = 9.31$, $p = .003$, $\eta^2 = .12$. No other main effects or interactions were significant (all $F < .32$, all $p > .59$). When the individual types of errors were considered, no main effects were significant (all $F < 2.61$, all $p > .11$).

Post-hoc analysis of the task difficulty and switch allocation interaction showed an effect of task difficulty on both the forced switching and voluntary switching condition, $t(39) = 2.72$, $p = .01$ and $t(34) = 7.26$, $p < .001$ respectively. Specifically, more errors were produced on the easy task compared to the hard task for both the Voluntary switching condition ($M = 22.09$, $SD = 13.10$ versus $M = 10.46$, $SD = 6.71$) and the Forced switching condition ($M = 21.25$, $SD = 29.$ 99 versus $M = 16.80$, $SD = 21.96$).

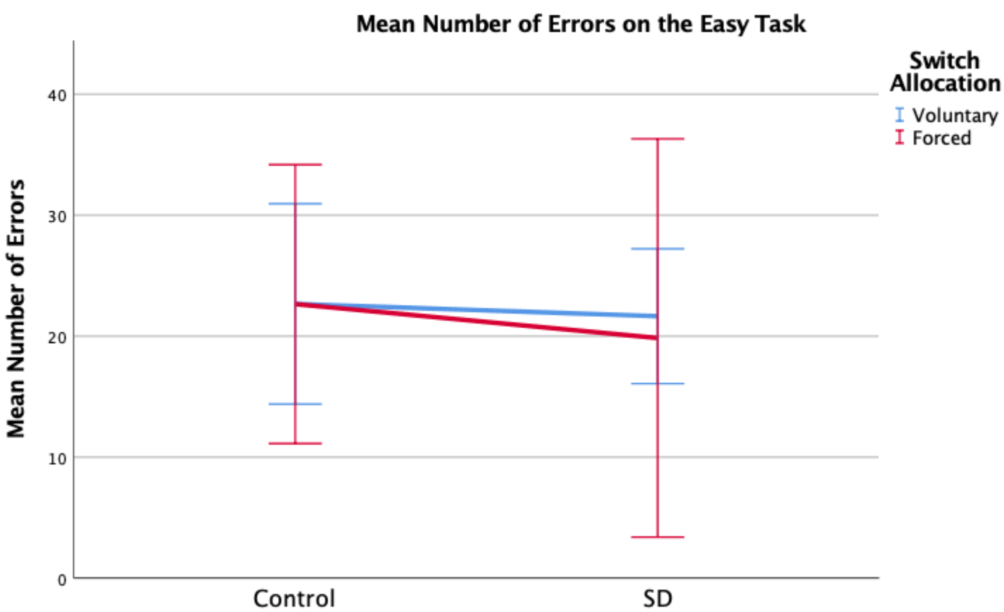

Figure 5.1 A line graph displaying the number of errors produced in the Control and SD participants for both the voluntary and forced switching conditions on the easy task.

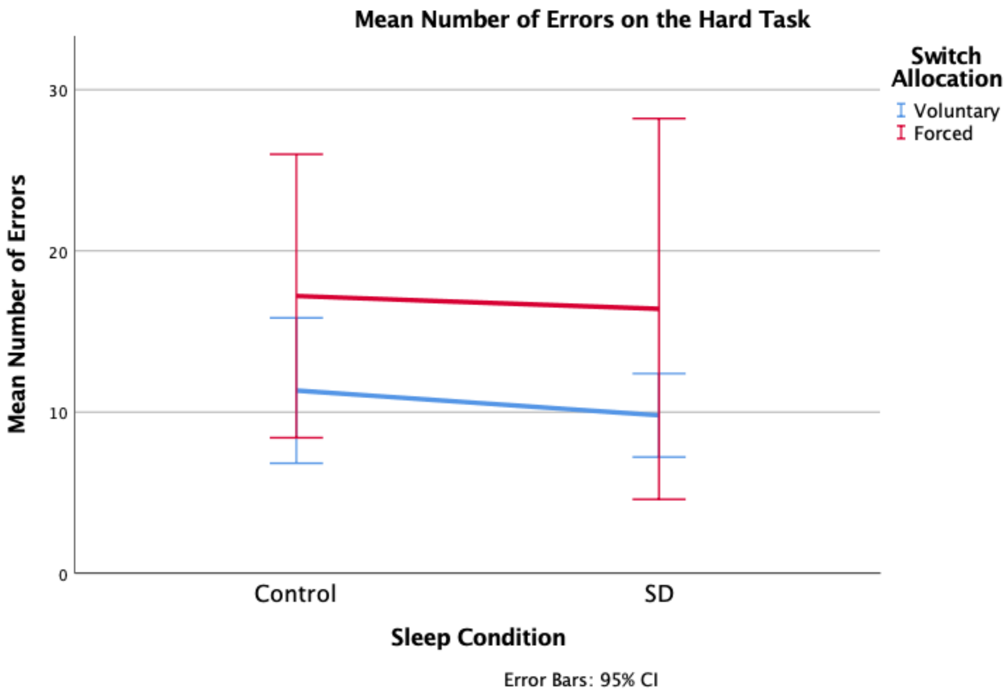

Figure 5.2 A line graph displaying the number of errors produced in the Control and SD participants for both the voluntary and forced switching conditions on the hard task.

Investigating number of correct words generated

The main effects of task difficulty, switch-allocation and sleep condition were significant, $F(1,71) = 579.86$, $p < .001$, $\eta^2 = .89$, $F(1,71) = 39.48$, $p < .001$, $\eta^2 = .36$ and $F(1,71) = 9.79$, $p = .003$, $\eta^2 = .12$ respectively. Fewer words were generated on the hard ($M = 41.00$, $SD = 16.51$) than the easy task ($M = 91.01$, $SD = 36.18$), and in the Forced switching ($M = 52.96$, $SD = 16.51$) than Voluntary switching ($M = 80.93$, $SD = 27.56$) conditions, and in the SD ($M = 60.34$, $SD = 23.55$) than the Control condition ($M = 72.49$, $SD = 28.12$). A significant interaction was observed in the task difficulty and sleep condition interaction as well as, the task difficulty and switch-allocation interaction $F(1, 71) = 12.28$, $p = .001$, $\eta^2 = .15$ and $F(1, 71) = 45.56$, $p < .001$, $\eta^2 = .39$ respectively. There were no other significant interactions (all $F < 3.69$, all $p > .06$).

Post-hoc analysis of the task difficulty and sleep condition interaction showed no effect of sleep condition on the easy task, $t(73) = 2.25$, $p = .03$, or on the hard task $t(73) = 1.57$, $p = .12$. Differences were observed between task difficulties in both the SD condition and Control condition, $t(39) = 13.29$, $p < .001$ and $t(34) = 12.83$, $p < .001$ respectively. With more words generated on the easy task versus the hard task in both the SD ($M = 82.45$, $SD = 31.46$) and Control ($M = 38.23$, $SD = 15.64$) participants.

Post-hoc analysis of the task difficulty and switch allocation interaction showed an effect of switch allocation on the easy and hard task, $t(54.35) = 5.87$, $p < .001$ and $t(53.52) = 3.99$, $p < .001$ respectively. Differences were observed between task difficulties in both the Forced and Voluntary switch conditions, $t(38) = 17.39$, $p < .001$ and $t(34) = 14.96$, $p < .001$ respectively. With more words generated on the easy task versus the hard task in both the Voluntary ($M = 113.23$, $SD = 36.57$ versus $M = 48.63$, $SD = 18.54$) and Forced ($M = 71.58$, $SD = 22.08$ versus $M = 34.33$, $SD = 10.93$) switching conditions.

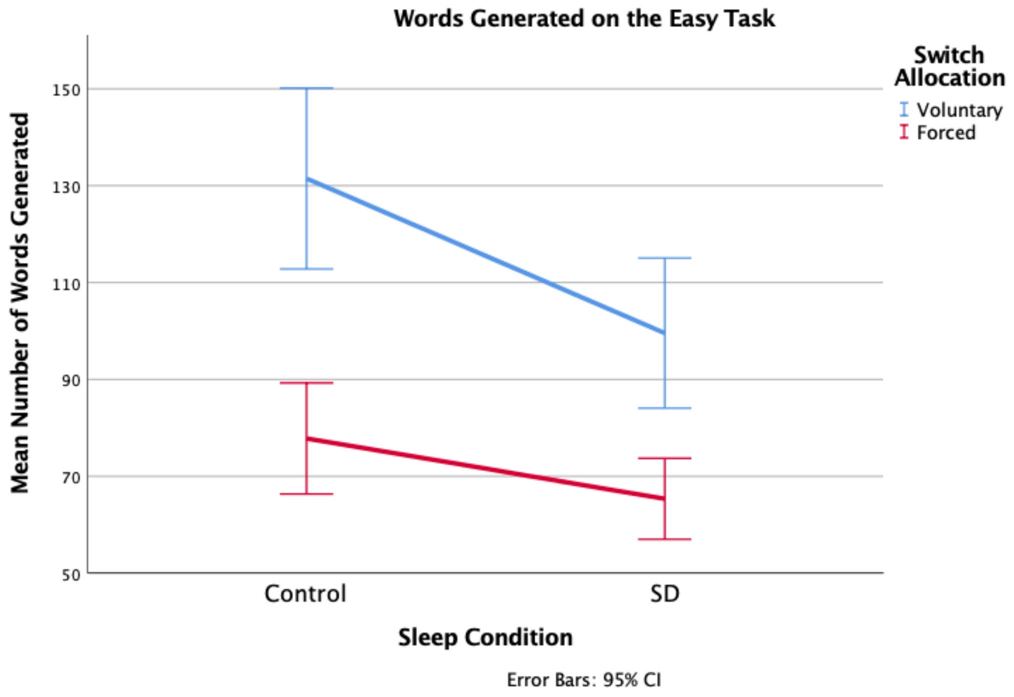

Figure 5.4 A line graph displaying the number of words generated in the Control and SD participants for both the voluntary and forced switching conditions on the easy task.

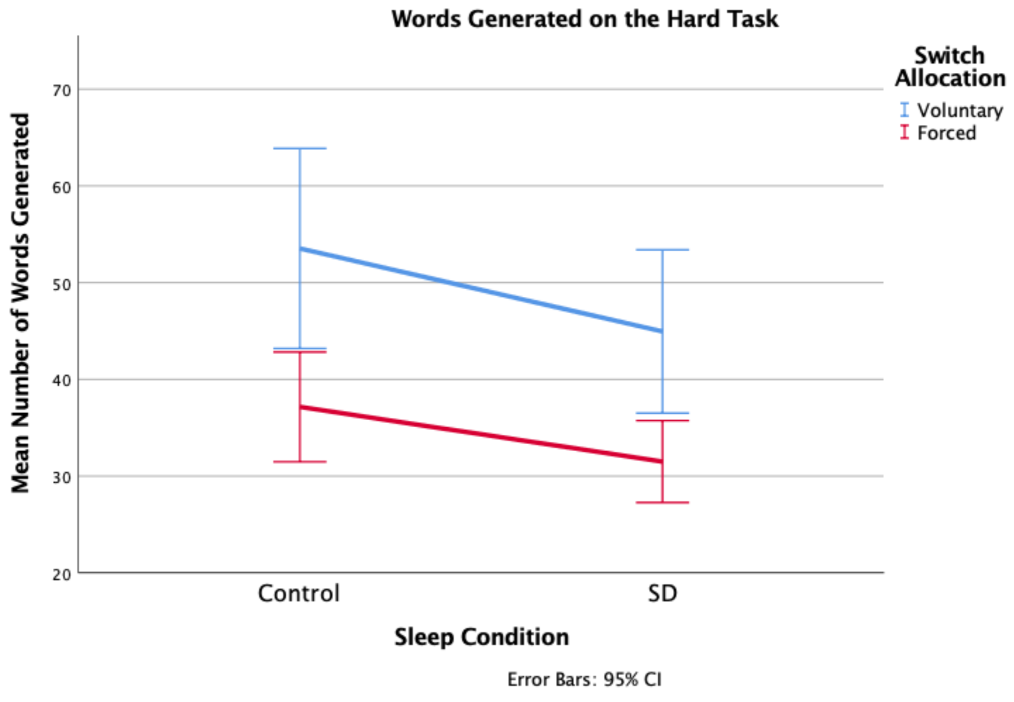

Figure 5.3 A line graph displaying the number of words generated in the Control and SD participants for both the voluntary and forced switching conditions on the hard task.

Ratio Analysis

To establish whether the number of errors produced is contingent on the number of overall responses generated some ratio analysis was conducted. The total number of words entered was divided by the errors on the easy task and then for the hard task.

Results showed the main effect of task difficulty was significant, $F(1,71) = 7.14$, $p = .009$, $\eta^2 = .09$. There were less words generated for every error produced in the hard task ($M = 5.46$, $SD = 4.64$) compared with the easy task ($M = 7.43$, $SD = 5.93$). The task difficulty and switch allocation interacted, $F(1,71) = 4.20$, $p = .044$, $\eta^2 = .06$. No other main effects or interactions approached significance (all $F < 1.67$, all $p > .20$).

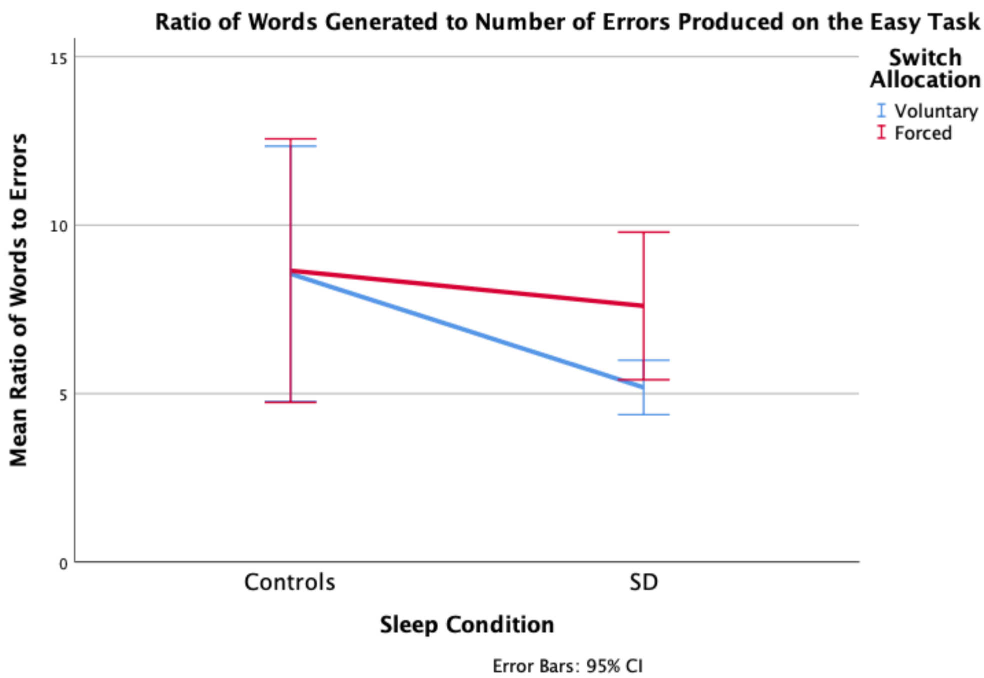

Figure 5.5 A line graph displaying the ratio of words generated to errors produced in the Control and SD participants for both the voluntary and forced switching conditions on the easy task.

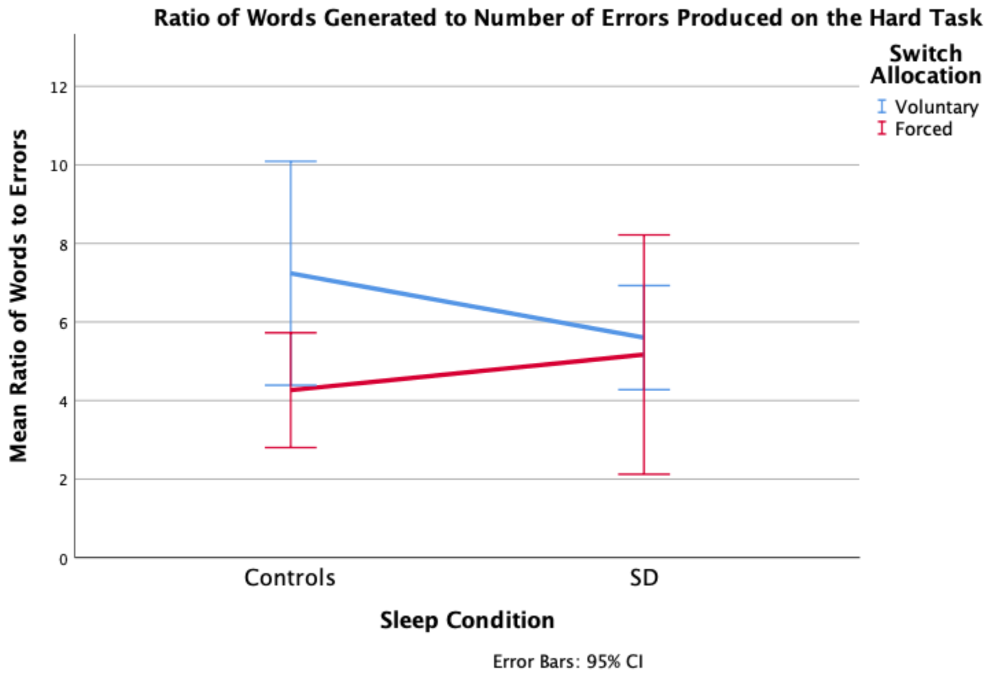

Figure 5.6 A line graph displaying the ratio of words generated to errors produced in the Control and SD participants for both the voluntary and forced switching conditions on the hard task.

Investigating resumption lag duration

Resumption lag time was defined as the time between switching tasks and then generating the first word.

The main effects of task difficulty and sleep condition were significant, $F(1,69) = 9.23$, $p = .003$, $\eta^2 = .12$ and $F(1,69) = 6.08$, $p = .02$, $\eta^2 = .08$ respectively. With longer RL on the hard task ($M = 19.93$ seconds, $SD = 7.18$) than the easy ($M = 16.57$ seconds, $SD = 6.10$) and in the SD ($M = 19.59$ seconds, $SD = 6.89$) than the Control condition ($M = 16.79$ seconds, $SD = 5.92$). There was also a significant sleep condition and switch allocation interaction. There were no other significant main effects or interactions (all $F < 2.79$, all $p > .11$).

Post-hoc analysis of the switch allocation and sleep condition interaction was investigated on the hard task. An effect of sleep condition on the Voluntary switching, $t(27.01) = -3.42$, $p = .002$. With SD participants having longer RL times compared to Control participants (M = 24.34 seconds, SD = 9.72 versus M = 16.08 seconds, SD = 4.10). This effect was not established on the Forced switching $t(38) = .17$, $p = .86$. No other significant differences were found between the switch conditions for SD or Controls, $t(28.26) = 2.29$, $p = .03$ and $t(33) = -1.72$, $p = .10$ respectively.

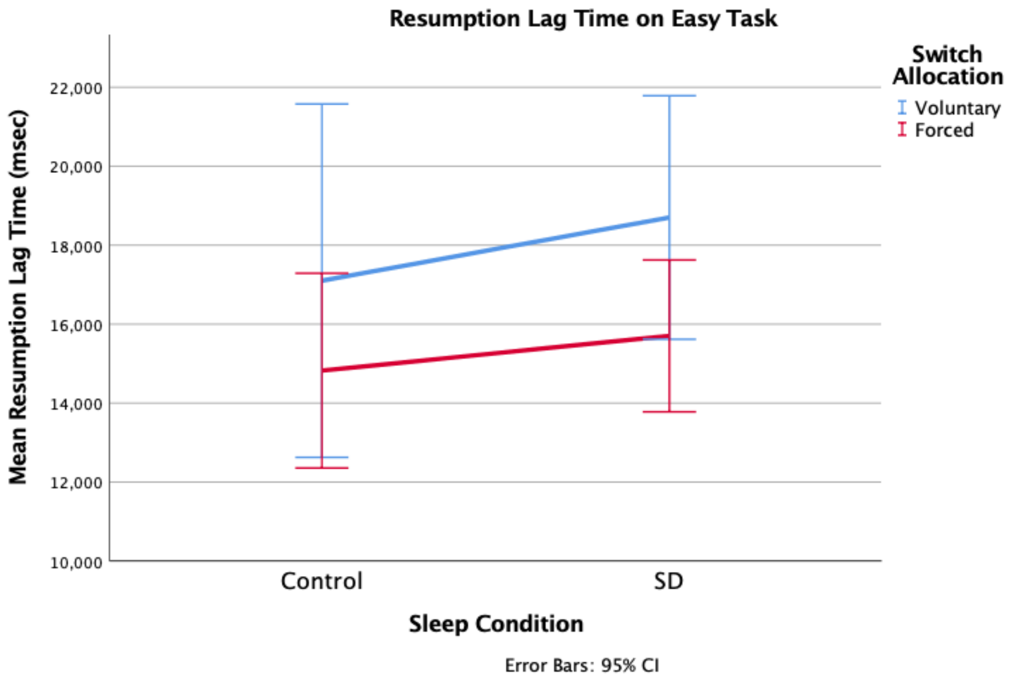

Figure 5.7 A line graph displaying the resumption lag in the Control and SD participants for both the voluntary and forced switching conditions on the easy task.

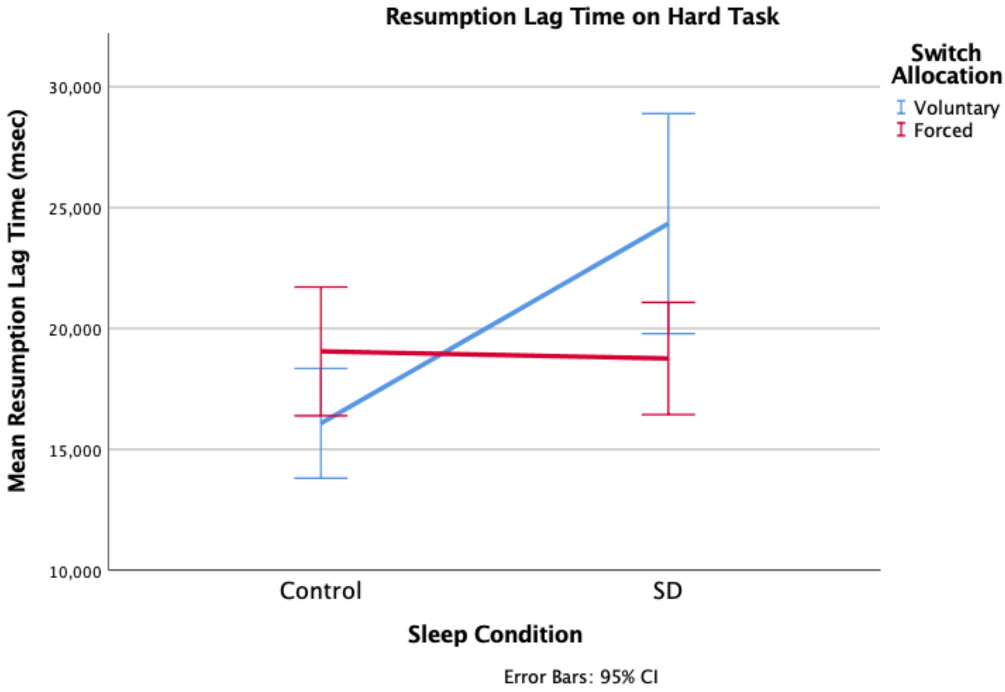

Figure 5.8 A line graph displaying the number of resumption lag in the Control and SD participants for both the voluntary and forced switching conditions on the hard task.

Examining differences in decision making – word frequency

The frequency of words was determined by the English Lexicon Project (Balota et al., 2007).

The main effect of task difficulty was significant, $F(1, 71) = 29.28$, $p < .001$, $\eta^2 = .29$. With higher frequency words generated on the easy ($M = 4.37$, $SD = .17$) than the hard task ($M = 4.22$, $SD = .23$). There was a significant interaction between sleep condition and switch allocation, $F(1,71) = 4.54$, $p = .04$, $\eta^2 = .06$. No other significant main effects or interactions approached significance (all $F < 3.48$, all $p > .07$).

Post-hoc analysis of the switch allocation and sleep condition interaction was investigated on the hard task. An effect of switch condition was found in the Control condition, $t(18.59) = -3.20$, $p = .005$ but not in the SD condition $t(38) = .84$, $p = .40$. No other significant differences were found between the sleep conditions for Forced or Voluntary switching conditions, $t(22.08) = 1.98$, $p = .06$ and $t(33) = -1.62$, $p = .12$ respectively.

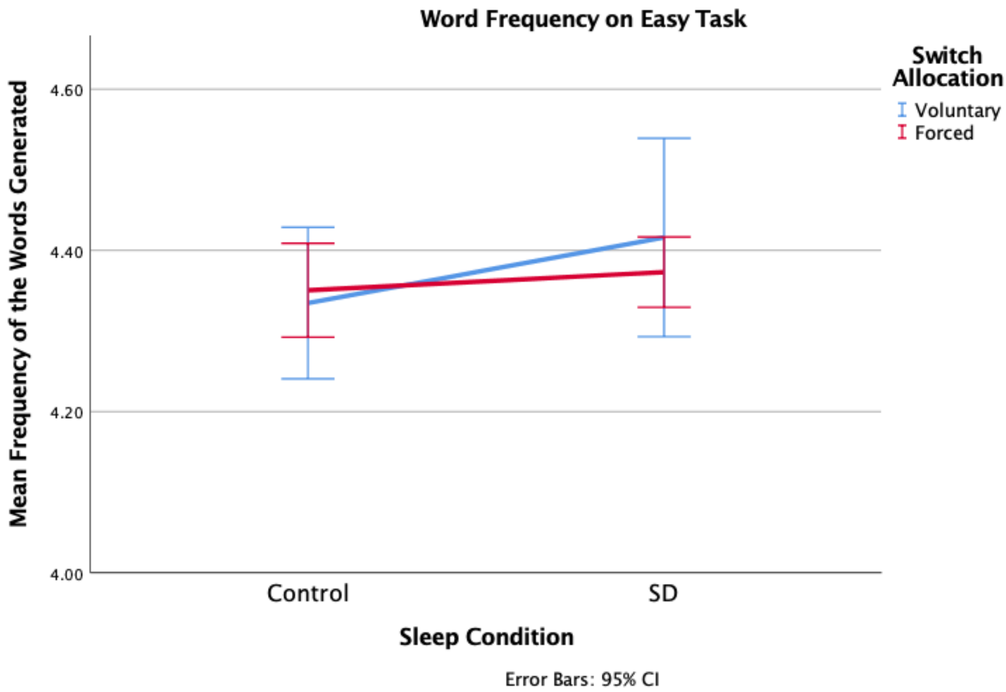

Figure 5.9 A line graph displaying the frequency of the words generated in the Control and SD participants for both the voluntary and forced switching conditions on the hard task.

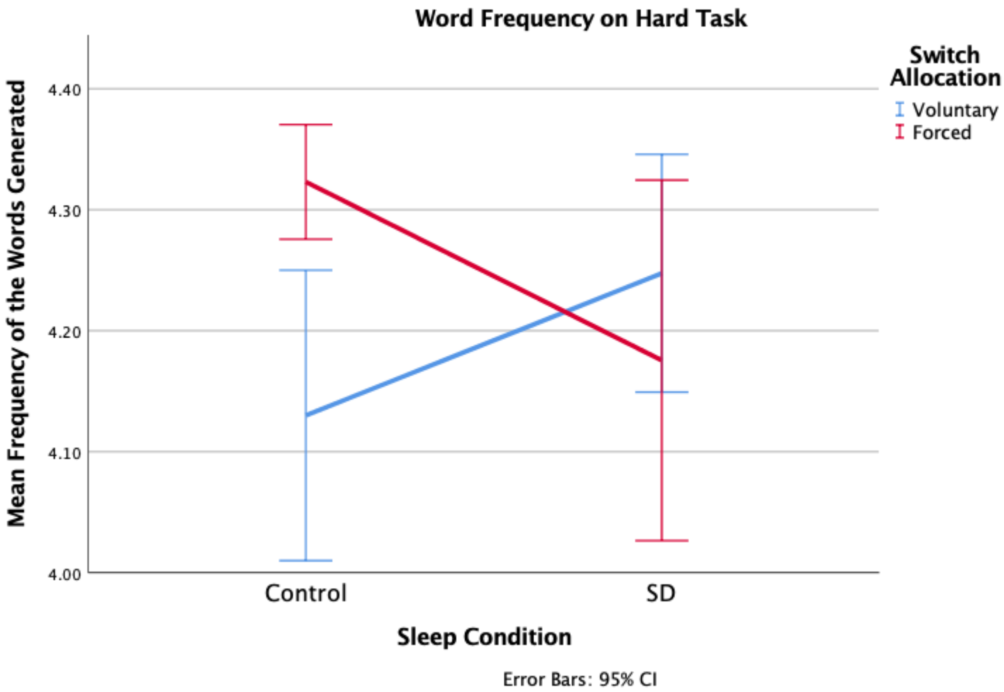

Figure 5.10 A line graph displaying the frequency of the words generated in the Control and SD participants for both the voluntary and forced switching conditions on the hard task.

Examining effects of Working Memory Capacity (WMC) on performance

While it is not a primary focus of the present study given the importance placed on WM, any variable that fatigue seemed to effect was further explored using regression analysis. The aim was to see if the impact of fatigue was in any way influenced by WMC.

A multiple linear regression was calculated to investigate whether WMC, as measured by Ospan and 3-Back, predicted performance on words generated, RL and word frequency and then to see if this differed between SD and Control participant groups. The reason for just examining these measures was because these were the only measures to have been found to have a significant main effect or interaction. It was therefore with this reason that it was important to see on these measures whether WMC had any involvement.

Results of the multiple linear regression for the SD participants, indicated that there was not a collective significant effect between the Ospan and 3 -back tests (all $F < .66$, $p > .53$).

Table 5.2 Results of Multiple Regression analysis for SD participants. Three outliers were removed from the analysis.

		t	*p*	*β*	*F*	*df*	*p*	*adj.R²*
Words - Easy								
	Overall Model				.13	2, 33	.88	-.05
	Ospan Partial	-.39	.69	-.07				
	Average 3-Back	-.24	.82	-.04				
Words – Hard								
	Overall Model				.43	2, 33	.66	-.03
	Ospan Partial	-.51	.61	-.09				
	Average 3-Back	-.66	.51	-.12				
RL – Easy								
	Overall Model				.59	2, 31	.56	-.03
	Ospan Partial	-.84	.41	-.15				
	Average 3-Back	-.51	.62	-.09				
RL – Hard								
	Overall Model				.66	2, 33	.53	-.02
	Ospan Partial	1.07	.29	.19				
	Average 3-Back	-.61	.55	-.11				
Word Frequency - Easy								
	Overall Model				.45	2, 33	.64	-.03
	Ospan Partial	-.00	.99	.00				

Average 3-Back	-.94	.36	-.16				
Word Frequency - Hard							
Overall Model				.32	2, 33	.73	-.04
Ospan Partial	.17	.86	.03				
Average 3-Back	.73	.47	.13				

Results of the multiple linear regression for the Control participants, indicated that there was a collective significant effect between the Ospan and 3 -back tests for words – easy, (F(2, 27) = 11.53, p = .001, R^2 = .42). The individual predictors were examined further and indicated that Ospan (t = 2.14, p = .04) and 3-Back (t = -4.66, p < .001) was a significant predictor in the model.

Also a collective significant effect on words – hard, (F(2, 27) = 7.69, p = .002, R^2 = .32). The individual predictors were examined further and indicated that Ospan (t = 2.09, p = .05) and 3-Back (t = -3.68, p = .001) was a significant predictor in the model.

Finally, a collective significant effect on words frequency – hard, (F(2, 27) = 3.37, p = .05, R^2 = .14). The individual predictors were examined further and indicated that 3-Back (t = 2.59, p = .02) was a significant predictor in the model but Ospan (t = -.36, p = .73) was not.

Table 5.3 Results of Multiple Regression analysis for Control participants. One outlier was removed from the analysis.

	t	*p*	*β*	*F*	*df*	*p*	*adj.R*^{2}
Words - Easy							
Overall Model				11.53	2, 27	.001	.42
Ospan Partial	2.14	.04	.31				
Average 3-Back	-4.66	.00	-.67				
Words – Hard							
Overall Model				7.69	2, 27	.002	.32
Ospan Partial	2.09	.05	.33				
Average 3-Back	-3.68	.001	-.58				
RL – Easy							
Overall Model				.51	2, 27	.61	-.04
Ospan Partial	-.98	.33	-.19				
Average 3-Back	.39	.69	.08				
RL – Hard							
Overall Model				2.54	2, 27	.10	.10
Ospan Partial	-2.25	.03	-.41				
Average 3-Back	.47	.64	.09				
Word Frequency - Easy							
Overall Model				.82	2, 27	.45	-.01
Ospan Partial	1.16	.26	.22				
Average 3-Back	.29	.78	.06				
Word Frequency - Hard							
Overall Model				3.37	2, 27	.05	.14
Ospan Partial	-.36	.73	-.06				
Average 3-Back	2.59	.02	.46				

5.4 Discussion

The goal of the present study was to explore the differences in task-switching behaviour when the switch was either freely chosen or forcibly executed. Furthermore, this study investigated whether the differences in switching allocation were further exacerbated by individuals who have experienced SD. Investigations were focused on two main measures; (1) performance - in terms of words generated and number of errors; (2) the length of the RL time. Evidence was found for fewer words generated in the forced condition and also in the SD condition. With also a longer resumption lag observed in the SD condition. No main effects of the number of errors produced was established.

Was the fatigue manipulation effective?

As in Experiments 1 and 2 the manipulation in Experiment 3 needs to be confirmed before exploring the other data. Results demonstrated that the SD individuals slept less hours and had higher KSS scores compared to Control individuals.

The within-group comparison between the fatigue measures on Day 1 compared to those taken on Day 2 revealed that the SD fatigue manipulation increased KSS scores, RTs, lapses in attention and false alarms. While the within-group comparisons in the Control condition showed no significant differences between any of the fatigue measures from Day 1 compared to Day 2.

These findings all stand to highlight that the fatigue manipulation was effective and the SD participants were sufficiently more fatigued than their Control counterparts.

Effects of sleep manipulation and switching allocation on task switching measures

Errors

This finding of a lack of errors has remained consistent throughout the present experiment, as well as, both Experiments 1 and 2. However, Experiment 2 did reveal there to be a difference in rate of errors compared to words generated with the SD participants generating fewer words for every error they made. This highlights that their performance is impaired and may not be showing up in the errors analysis simply because the SD are not producing as many words in the first place. It is with this reason that in the present experiment as a reduced number of words was observed in the SD compared to the Control participants it would be reasonable to assume that there would be a similar difference in error rate observed in Experiment 2. The ratio analysis however, did not show any differences between the two participant groups in their error rate. Therefore, it is suggested that there might be a difference in error rate but that there are other factors at play that are perhaps allowing the SD to overcome this. There are three possible explanations that may account for minimal differences in errors produced in the SD participants. Firstly, it can be explained by the reduction in energy and resources available which prevents them from trying harder on the task and as such they don't overload themselves. Secondly, the type of task they complete is such that they are not pressured to resume it following a switch and can begin the task whenever they are ready without missing any vital task-relevant information. Finally, the similarity between the two tasks that participants switch between is inadvertently cueing the task and reduces potential switch costs. More research is needed to investigate this further.

The Memory for Goals theory (Altmann & Trafton, 2002) discussed earlier, suggests that each task has a goal associated with it and each goal has an activation level. If a task is interrupted, the goal for that task is stored and begins to decay while the interrupted task goal increases in activation. The longer the time spent on the interruption, the more the interrupted task goal will increase in activation while simultaneously decreasing activation in the previous task goal making it harder for the individual to successfully resume the previous task. In the current experiment, the interruption from one task might last a longer period but the overall main goal remains consistent across the two tasks (e.g. generate words from the letters on screen). This therefore allows for continued activation of the main goal while causing minimal decay and making it easier to return to the previous task. The tasks participants were required to perform consisted of the same task goals but just presented different stimuli and as such they draw on the same cognitive resources to complete them. It could therefore be argued that while completing one task, that same task is also cueing the participant for the next task and as a result the interference in goal activation is limited. This would subsequently aid resumption of tasks and result in a decrease in resumption lag time, as well as, a decrease in errors. This is supported by previous research that found if an interruption is relevant to the original task it is less disruptive compared to an unrelated one (Czerwinski et al., 2000; Gould, Brumby, & Cox, 2013).

It has been suggested that tasks that draw on different cognitive resources may help individuals more easily disengage from the tasks because the two tasks are not competing for the same resources which in turn could help to reduce switch costs (Panepinto, 2010). Equally, similarity between the two tasks could in fact cause more interference and an increased likelihood of errors. This is due to not fully disengaging from one task and reengaging for the next resulting in an overlap of goal activation; which in the present experiment could cause the wrong letters to be used and perhaps use ones from the previous task. This however, does not appear to be the case in the present study. Nevertheless, to fully understand if similarity in tasks aids cueing for the next task - and subsequently reduces errors and minimises negative impact on the task - further research needs to be conducted. This will be discussed in Chapter 6.

Words generated

In the present experiment it was hypothesised that the SD condition and Forced condition would generate fewer words compared to Controls and Voluntary switching respectively. Results revealed that SD participants generated fewer words in both switching conditions compared to the Control participants, but overall all participants generated fewer words in the Forced condition compared to the Voluntary condition.

A possible explanation for the fewer words generated in the forced switching compared to the voluntary switching condition could be attributed to the idea that having frequent interruptions is more disruptive than having one interruption that lasts for longer (Zijlstra et al., 1999). The voluntary switching condition was entirely self-paced and participants were free to switch whenever they wished and consequently may have switched less frequently compared to the forced condition. Equally, as the task is self-paced it allows more time for individuals to disengage from one task before they choose to switch to the next, as well as, feeling less pressure to perform (Panepinto, 2010). Further, in the forced switch condition resources have to be devoted to adapting quickly and frequently to the sudden changes between tasks and the subtle changes in task goals which in turn leaves limited resources available for rehearsing the previous task goals. Whereas the voluntary switching condition allows for complete choice of when to switch and subsequently leaves more cognitive resources left available in which to rehearse the goals for both tasks keeping them equally active throughout. This in turn would result in more successful switching. Therefore having the choice of when to switch tasks decreases the likelihood that an individual will experience an overload in working memory which is likely experienced when a switch is forced (Panepinto, 2010).

When a switch in task is either known, cued in advance of the switch occurring or occurs at regular intervals there is minimal task switching costs associated compared to random task switching (e.g., Rogers & Monsell, 1995; Schneider & Logan, 2007). This can be further supported with MfGs model (Altmann & Trafton, 2002) which suggests that if there is prior knowledge of an upcoming switch then the individual is able to strengthen the goal and encode cues that will later ensure the task is easy to resume. Therefore, as mentioned earlier it could be argued that the tasks in the current study are inadvertently cueing one another. However, if this was the case then it would be expected that there would be minimal differences between groups in the number of words generated.

The present study demonstrated that when individuals have experienced sleep deprivation they produce fewer words. What can also be determined from the data is that when a switch is forced on the individual, they too produce fewer words. This is true across both the SD and Control participants. Also, of interest in the present experiment was understanding whether the introduction of a forced switch exacerbates the decline in word production to a greater extent when an individual is sleep deprived compared to when they are not. Results however, showed that individuals who had not experienced a loss of sleep suffered a greater deterioration in performance with the introduction of a forced switch. Despite the greater deterioration of words experienced by the Control participants, the SD participants still overall across both forced and voluntary switching conditions produced fewer words. These findings suggest that sleep deprived individuals appear to be overall putting in less effort and subsequently have a smaller range of words generated between the forced and voluntary switching conditions. While Control participants appear to have a larger range of words generated. This is supported by research that demonstrated that SD individuals will opt for low-effort behaviour that helps to maintain accurate responding

(Engle-Friedman et al., 2003) and so are likely to produce fewer overall responses but also have minimal errors.

The properties of an interruption and the occurrence of the interruption are both influencing factors to the level of disruptiveness experienced to task performance. Firstly, studies have demonstrated that interruptions are less disruptive at moments of low workload compared to high workloads (Iqbal & Bailey, 2005; Katidioti, Borst, Van Vugt, & Taatgen, 2016; Katidioti & Taatgen, 2014; Monk, Boehm-Davis, & Trafton, 2004). While the present study has no clear sub-tasks, it could be argued that the completion of a sub-task follows the generation and submission of a word. This in turn allows an opportunity to switch. Therefore, if a forced switch occurs during a period where an individual is trying to generate a word it demonstrates an interruption at a moment of high workload which is highly likely to be disruptive. While changes in tasks are less disruptive if individuals are given the opportunity to prepare for it which is the case when they are able to control the switch in task (Panepinto, 2010; Zijlstra et al., 1999). Equally, if individuals know that they will be forcibly switched between tasks they may overall become less engaged with it and subsequently put less effort into the tasks (Kray, 2006). This may in part explain the reduced words generated in both sleep conditions for the forced switch compared to the voluntary switch condition. This is further supported by research that has observed forced interruptions cause an increased rating of mental effort, as well as, decreased positive feelings toward the task (Panepinto, 2010; Zijlstra et al., 1999).

Resumption lag

As previously discussed, it is widely thought that in order to successfully switch between tasks several cognitive processes are involved. Firstly, the task goals need to be reconfigured to fit in line with the new task while also simultaneously disengaging from the task goals of the previous task (Couyoumdjian et al., 2010). This process is thought to occur either in anticipation of the new task before the switch has happened (reflected in the giving-up time) or following the onset of the new task (reflected in the resumption lag time) (Monsell, 2003). Experiment 1 (see Chapter 3) established that the SR condition had a longer 'giving-up' time than that observed in the control condition but only on the more difficult task. It was suggested that when a participant knows that a switch is going to occur, they perform the reconfiguration/disengagement process prior to the start of the new task. Whereas, if the switch in task is forced and unknown to the participant they would no longer be able to prepare in advance of the switch therefore this process must subsequently occur following the switch at the start of the new task. The present findings support this theory showing an increased RL in the sleep deprived individuals. As there is an increased RL observed in the SD condition it would further support the notion that when an individual experience's a loss in sleep they are slower to perform and require more time to recover from a switch in task. Equally, this increased RL may allow participants to overcome some of the negative effects of fatigue.

Word frequency effects

If lower word frequency can be seen as a measure of increased task engagement and of increased difficulty to produce then when the participants have control over their switching (e.g. voluntary) and the task is easier, it leaves more cognitive resource available to enable participants to produce words of a lower frequency. However, by removing control (i.e. forcing the switches) it creates more of a challenge for the participants and puts more strain on their resources. The Control participants respond accordingly to the increase in task difficulty by generating words of higher frequency compared to the voluntary switch condition. SD participants however, don't show this relationship having no significant difference found between the voluntary and forced switch conditions, with them actually producing words of lower frequency on the forced condition. This suggests that the strategy's Control participants employ to cope with the increase in task difficulty are not present in SD participants.

Working memory

There was an effect of WM measures on the number of words generated on both the easy and hard task for Control participants but not SD participants. This is the opposite effect found within Experiment 2. It therefore suggests that Experiment 2 was sufficiently hard for the SD participants that WM had an influence and those with high WM were able to manage some of the deleterious effects of fatigue, while Controls comparatively found it easier and were able to manage the task regardless of WM. Whereas, in the present experiment the removal of control over the task further increased the difficulty of the task and in turn resulted in WM now being a factor in the number of words Control participants generated. Specifically, the effect showed a positive correlation which highlights that the higher the WM the more words they generated. This result was no longer present in the SD participants suggesting that the task was now exceedingly hard and SD participants regardless of WM were no longer able to manage any deleterious effects.

There was also an effect of WM measures on the frequency of the words that Control participants generated on the hard task. This correlation was negative which highlights that the higher the individuals WM the lower frequency of words they produced. This finding was again not present in SD participants which suggests when the task becomes too difficult WM in SD participants no longer has any influence over performance.

5.5 Conclusion

To conclude, the results in the present experiment continued to demonstrate an effect on the number of words generated between sleep conditions, with SD participants generating fewer words compared to Control participants. The results also revealed that both sleep conditions produced fewer words in the forced switch condition compared to the voluntary switch condition. Of particular interest in the present experiment though, is that despite these behavioural differences the introduction of the forced switch begins to highlight some more subtle effects of fatigue. When the task is easy SD participants do not generate as many words but the kinds of words (i.e. frequency of the words) remain similar to Control participants. However, when the task is hard participants need to manage this increase in task difficulty and do so by working less hard, resulting in both fewer words generated and those words were of higher frequency. This relationship fails in SD participants with them actually producing words of lower frequency.

Chapter 6

Task Switching Between Cognitively Different Tasks

6.1 Introduction

Thus far, the experiments in this thesis have focused on differences in switching behaviour between different levels of sleep loss (SR and SD), as well as, differences between having complete choice over when to switch (Voluntary), limited freedom of switching (Voluntary-Equal) and no control over the switches (Forced). All of these experiments used the same task switching paradigm to investigate the effects of differential sleep loss and switching allocation on task performance. These experiments established that SR produces minor deficits on performance with the impact causing a longer giving-up time while SD produces a larger profile of performance deficits in terms of reduced words generated. However, once the control over switching was removed (e.g. in the forced switching condition) some more subtle effects of fatigue emerged. Results still highlighted a reduction in the number of words generated but additionally, showed that when the task was hard the Control participants accounted for this increased difficulty and produced words of higher frequency, in SD participants this relationship failed. A consistent finding across the previous experiments was the lack of differences in the number of errors produced on the task. This lack of difference could be due to a few different reasons, either the similarity between the two tasks were cueing one another or the fact the tasks were self-paced allowed the participants to start whenever they were ready without missing any task-relevant information. A final possibility is whether the ratio of errors to words generated was hiding performance something that was observed in Chapter 4 with SD participants producing fewer words per every error made compared to Controls. This finding however, was not consistent across the experiments in Chapter 3 and 5.

The present experiment aims to address an issue that has risen from the previous experiments; How does fatigue impact task switching performance when the two tasks have different task goals?

Task switching between different tasks

As previously discussed cognitive control is a necessity when directing thoughts and actions in line with the current goals (Braver et al., 2003), especially when there are multiple tasks at hand and this is even more important when the tasks differ in their task goals (Yeung, Nystrom, Aronson, & Cohen, 2006). However, when a change in task goal or action occurs it comes at a cost in terms of speed and accuracy of performance (Arrington & Logan, 2004; Gutzwiller, 2014; Mayr & Kliegl, 2003; Monsell, 2003; Wylie & Allport, 2000). These switch costs can be thought of as an indicator of the cognitive systems processing limitations when trying to coordinate different tasks (Mayr & Kliegl, 2003). Switch costs can be quite substantial and detrimental to performance and although there is no way to completely eradicate these costs, with time to prepare before an upcoming switch these costs can be reduced (Mayr & Kliegl, 2000, 2003; Meiran, 2000; Rogers & Monsell, 1995). This finding is evident in the previous experiments. Another thought that was summarised from the previous experiments was that perhaps the similarity of the two tasks that participants had to switch between was inadvertently cueing the next task. The tasks in the previous experiments consisted of the same task goals but just presented different stimuli and as such they draw on the same cognitive resources to complete them. It could therefore be argued that while completing one task, that same task is also cueing the participant for the next task and as a result the interference in goal activation is limited. This would subsequently aid resumption of tasks and result in a decrease in resumption lag time, as well as, a decrease in errors. This is supported by previous research that found if an interruption is relevant to the original task it is less disruptive compared to an unrelated one (Czerwinski et al., 2000; Gould et al., 2013). It is with this thought in mind that this experiment aims to investigate the relationship between fatigue whilst switching between two tasks that have different task goals, use different cognitive resources and starts from the moment the switch has happened. As suggested by previous research it would be expected that by including such conditions the cognitive processing system would reach its limitations and subsequently be overloaded causing impairments to be revealed. Furthermore, with the added demand that sleep loss puts on the cognitive processing system it would be likely that these impairments would be further exacerbated in sleep deprived individuals.

The present experiment uses a similar paradigm to that of a study conducted by Muhl-Richardson (2018). They explored an individual's predictive monitoring by getting participants to view a continually changing display of numbers and coloured squares and getting them to detect a specific colour target, number target or both. In this experiment the focus was on multitasking behaviour, with the colour and number stimuli displayed in either a discrete or contiguous configuration together on the screen at one time. It required participants to search for targets in either a single or dual target search scenario. Of interest in the study was predictive monitoring. Predictive monitoring was defined as first fixations followed by subsequent refixations to forthcoming targets. Fixations were defined as gaze staying in one location for more than 80ms and less than 1,200ms. Participants were able to see if it was a forthcoming target as both the colour and number stimuli would present itself as one or two steps away from the actual target colour/number (e.g. if the target number was '7' then a '6' would suggest a forthcoming target). Using eye movements, they established that the target detection was less accurate when searching for targets in the discrete configuration rather than one contiguous configuration. Additionally, specific eye movements associated with predictive monitoring was also reduced in the discrete configuration. It is therefore the understanding that searching for two independent targets across separate configurations impedes performance. Therefore, the present experiment wishes to understand if separating the targets on two independent displays in a task switching paradigm whether it would further encumber successful target detection. Equally, as shown in the previous study (Muhl-Richardson et al., 2018) when the displays were discrete non-fatigued individuals experienced a reduction in target detection accuracy and predictive monitoring due to an overload in resources. So, of interest in the present experiment is whether when participants are SD are these effects heightened.

The importance of using these particular tasks is that they involve complex displays of multiple different sources of information across different categories (Muhl-Richardson et al., 2018). This importantly replicates real-world examples of task switching between tasks with different goals, with seafarers required to monitor marine radars, as well as, continually checking position, direction, and speed. Equally, previous studies have established a common link with sleep loss and a reduced ability to maintain attention (Belenky et al., 2003; Bermudez et al., 2016), therefore it seemed imperative to select a task that, unlike the previous experiments, required participants to maintain constant attention or risk potentially missing important task relevant information to see how participants respond when they are sleep deprived. Previous research has addressed this type of task switching with one experiment getting participants to judge if the digit was odd or even on one task and in the other task whether the digit was larger or smaller than 5 (Couyoumdjian et al., 2010). These two tasks had separate task goals. Findings demonstrated that SD impaired both speed and accuracy, with a higher number of errors and increased switch costs compared to normal sleep individuals. This study concluded that SD affects individuals ability to flexibly and rapidly adapt to changing environmental demands (Couyoumdjian et al., 2010). It is with this in mind, that when faced with a continually changing task and switching between two tasks with differing goals, individuals who are SD are going to overloaded and more severe performance impairments will emerge. At present there is no research that has investigated the effects of SD on differing tasks that are dynamically changing, something this experiment aims to address.

Unfortunately, and most regrettably however, due to an error during data collection it resulted in some of the task switching data being unusable. Specifically, the forced switching condition failed to accurately force the switches sometimes resulting in only one switch happening per trial and thus the data was inconsistent and unusable. Additionally, in both the voluntary and forced switching conditions not all responses were recorded and subsequently there was not enough data to be able to measure the correct responses, GuT or RL. Despite this unfortunate circumstance, the present experiment is still able to examine switching behaviour and time on task. Additionally, the data collection for this experiment still has fully intact fatigue measures and as such it is still able to address the separate issue of whether subjective measures are a more sensitive predictor of fatigue compared to objective measures in Chapter 7.

Rationale

The present study aimed to investigate the difference in task-switching behaviour between individuals who have experienced a loss of sleep and individuals who have not.

Based on the data available in the main experimental task only two of the hypotheses could be tested. Sleep deprivation will lead to increased number of switches and longer time spent on the colour task compared to the Control participants.

6.2 Methods

Experiment 4 investigates task switching behaviour when the task goals for the two tasks are different from one another and the tasks begin regardless of whether the participant is attending on not.

Participants

Forty-three undergraduate and postgraduate students took part in Experiment 4 (28 females; *M*= 20.34*, SD* = 1.09, age range = 18 - 28 years old). Following programming issues of those forty-three participants only sixteen participants had complete data sets. These sixteen participants will be detailed separately below and only their data will be used in the analysis for the main experimental task. The forty-three participants had all their fatigue and working memory measures fully recorded and this data will be used in Chapter 7.

Sixteen undergraduate and postgraduate students were used in the analysis (10 females; *M* = 19.56*, SD* = 2.50, age range = 18 - 23 years old). All participants had normal vision or corrected-to-normal vision. All participants had normal visual acuity (at least 1.0 decimal VA at 70 cm), tested using the Freiburg Visual Acuity Test (Bach, 1996), and normal colour vision, tested using the City University Colour Vision Test 3rd Edition (Fletcher, 1998).

All participants reported no history of sleep or memory disorders and did not take any medication that may be adversely affected by a loss of sleep or may impact their usual sleep behaviour. Participants were recruited by an opportunity method of selection in which people volunteered to take part in exchange for course credits, monetary compensation or a mixture of the two. Participants were fully compensated for their time either in monetary compensation or course credits.

Design

Experiment 4 had two between-participant factors, task-switching rule (free choice of switching versus forced switching) and sleep condition (deprived versus normal).

Participants were assigned randomly to the between-participant condition with the constraint that there were equal number of participants in each. Those in the SD condition were required to have thirty hours of continual wakefulness; those in the normal sleep condition maintained their normal sleep patterns.

Participants took part in two separate computer-based testing sessions, each lasting up to 75 minutes. The two sessions were 1 day apart. During the first session the entire experiment was introduced and working memory (Ospan; Foster et al., 2015; and 3-Back; Shackman et al., 2006) and fatigue (KSS; Âkerstedt & Gillberg, 1990; and PVT; Dinges & Powell, 1986) were measured. Each participant was given a Fitbit to wear for the duration of the experiment. Sleep was tracked between the two testing sessions. Participants completed the online tests at specific times depending on their assigned condition. At the second testing session, all participants returned to complete a series of computer-based tasks. Fatigue was measured using the KSS and PVT and then they were required to complete the main experimental task; Colour/Number Change Detection Task.

Those in the sleep deprived condition had 30 hours of continued wakefulness, while those in the control condition maintained their normal sleep patterns for that night. Testing times for both sessions were controlled and all participants were tested in the same time slots so as to control for circadian rhythm.

Due to the programming issues during the data collection period, the sixteen participants used within the data analysis were all in the voluntary switching condition only but there were still two sleep conditions. Therefore, Experiment 3 only had one between-participant factor; sleep condition (deprived versus normal).

Materials and Tests

Colour/Number Change Detection Task

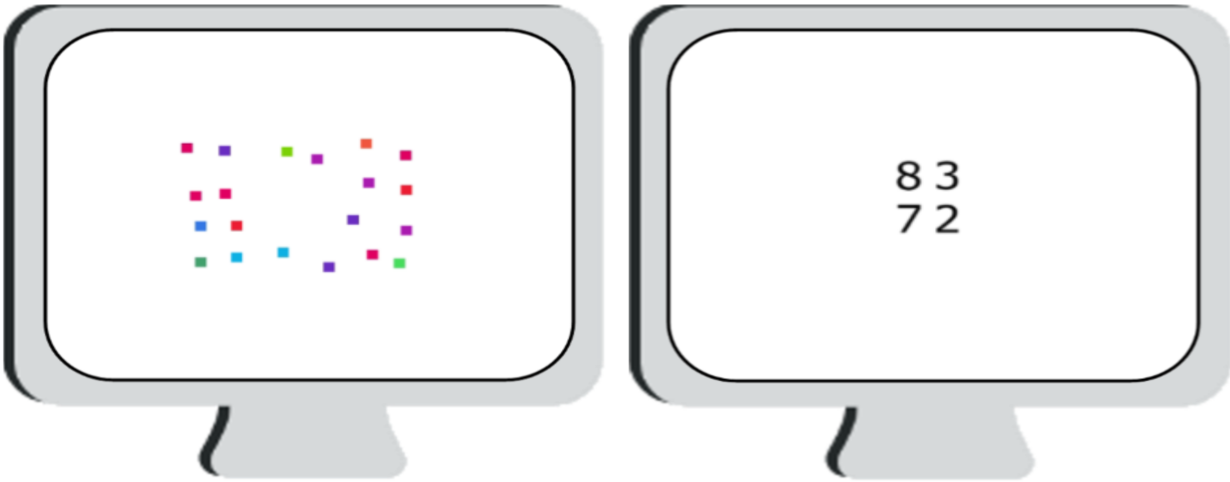

Figure 6.1 Displays a screenshot of the colour/number change detection task depicting both the colour changing task (image on the left) and the number changing task (image on the right).

Participants were first tested for normal visual acuity and colour vision. Participants were shown a static sample of the two search displays (Figure 6.1). They were then instructed to search for two targets; a particular coloured square and a number between 0 and 9. Both targets were shown prior to every trial and participants were instructed to respond as quickly as possible by clicking the mouse cursor whenever they saw the targets. Participants were told that trials might contain no targets, a single target, or more than one target, but that only the coloured square target would appear on one task and the target number on the other task. Trials began with a 1s reminder of the two targets, followed by a 1s fixation point, and then each trial lasted 10 minutes (see Figure 6.2 for an example of the trial sequence). Participants were either (1) able to freely switch back and forth between the number and colour squares tasks as frequently as they liked for 10 minutes or (2) were forcibly switched between the two tasks at random intervals with ultimately five minutes spent on each task. In the condition where participants were freely able to switch, they could do so by pushing the 'space bar' on the keyboard. They were able to switch back and forth between the two tasks as frequently as they liked.

All number displays consisted of four digits located within a rectangular shape and all colour square displays consisted of a set of 20 coloured squares. Throughout the time spent on one of the tasks (e.g. colour or number) the stimulus will remain in the same location but the number/colour being presented will change (see Figure 6.2 for an example of the numbers changing) through a sequence of 16 colours or 10 numbers. Each participant was told prior to their participation that they needed to select as many coloured square or number targets as possible.

A single number and a single colour were randomly generated at the start of each trial as targets (e.g. '7' and 'red') and for each new trail a new set of targets was given. Each trial lasted 10 minutes. As can be seen in Figure 6.2, an example of the target cues (colour and number) are presented to participants before each trial began.

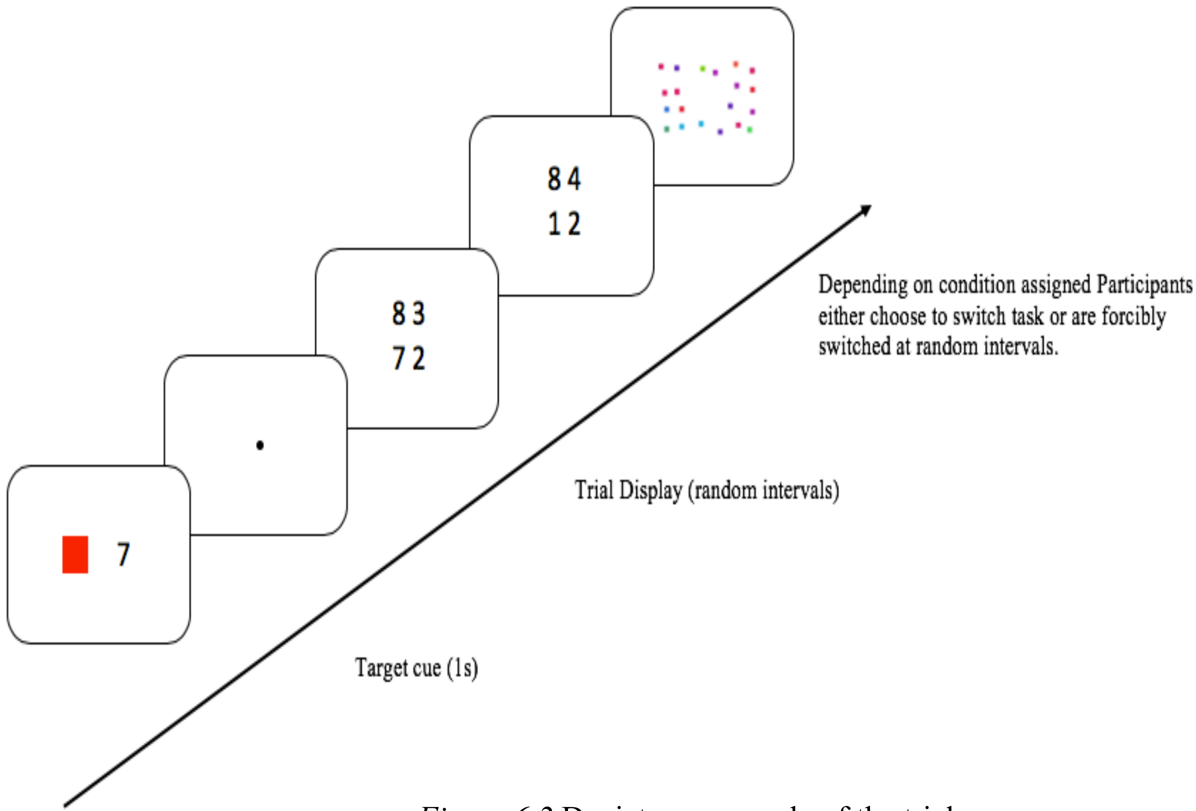

Figure 6.2 Depicts an example of the trial sequence.

Apparatus

The colour/number change target detection task was programmed by Alex Muhl-Richardson who adapted it from a previous task of his (Muhl-Richardson et al., 2018b). The task was programmed using SR Research Experiment Builder with additional custom code written in Python. Participants responded using the mouse and left-clicking on any targets they saw.

6.3 Results

There are two parts to the results. The first uses the forty-six participants who have the full fatigue measures data to ensure that the sleep manipulation was effective. The second section analyses only those sixteen participants who had full data sets to see whether the sleep manipulation induced fatigue and then tested the impact of SD on frequency of switches and time on task.

Was the manipulation effective?

Following the previously mentioned programming issues, sixteen participants (nine SD and seven Control participants) are included in the following analysis, all of which were in the voluntary switching condition.

The Fitbit data showed participants in the control condition had more sleep than those in the SD condition (M = 7.93, SD = 1.21 versus M = .14, SD = .42; $t(7.12) = 16.36$, $p < .001$). The KSS data shows the SD condition led to more fatigue than the control condition (M = 6.56, SD = 1.81 versus M = 2.57, SD = 1.13; $t(14) = -5.08$, $p < .001$).

There was no significant difference in PVT false alarms between the SD condition and the Control condition (M = 1.33, SD = 2.00 versus M = 0, SD = 0; $t(8.00) = -2.00$, p =

.08. There was no significant difference between the SD and Control conditions for the PVT lapses or PVT RT, *p* = .19 and *p* = .53 respectively.

With respect to within-group comparisons, SD led to increased KSS scores, reciprocal RT and lapses in attention on Day 2 compared to Day 1 (*M* = 6.56, *SD* = 1.81 versus *M* = 4.11, *SD* = 2.03; *t*(8) = -2.44, *p* = .04; *M* = .003, *SD* = .001 versus *M* = .004, *SD* = .001; *t*(8) = 3.67, *p* = .01 and *M* = 8.67, *SD* = 9.17 versus *M* = 1.67, *SD* = 1.66; *t*(8) = -2.49, *p* = .04 respectively). However, there were no differences false alarms between Day 1 and Day 2 (*M* = .67, *SD* = 1.00 versus *M* = 1.33, *SD* = 2.00; *t*(8) = -.89, *p* = .39 respectively).

In comparison Controls, had no differences to KSS scores, reciprocal RT, lapses in attention and false alarms on Day 2 compared to Day 1 (*M* = 2.57, *SD* = 1.13 versus *M* = 3.29, *SD* = 1.38; *t*(6) = 1.37, *p* = .22, *M* = .004, *SD* = .001 versus *M* = .004, *SD* = .001; *t*(6) = 1.59, *p* = .16, *M* = 3.29, *SD* = 5.28 versus *M* = 3.86, *SD* = 8.91; *t*(6) = .39, *p* = .71 and *M* = .00, *SD* = .00 versus *M* = .86, *SD* = 1.07; *t*(6) = 2.12, *p* = .08 respectively).

Table 6.1 Participant means for the fatigue measures (hours slept, KSS and PVT)

Measure	Controls	Sleep Deprived
	Voluntary	Voluntary
No. of Participants	7	9
Sleep Hours	*M* = 7.93, *SD* = 1.21	*M* = .14, *SD* = .42
KSS Score	*M* = 2.57, *SD* = 1.13	*M* = 6.56, *SD* = 1.81
PVT RT>500ms	*M* = 3.29, *SD* = 5.28	*M* = 8.67, *SD* = 9.17
PVT False Alarms	*M* = .00, *SD* = .00	*M* = 1.33, *SD* = 2.00
PVT Reciprocal RT	*M* = .004, *SD* = .001	*M* = .003, *SD* = .001

Task switching measures

Two 2 (Sleep condition: SD versus Control) x 2 (Task-type: Colour versus Number) ANOVAs were conducted on the number of switches and total time on task. With Sleep condition as between-participants factor and Task-type as a within-participants factor. A 2 (Sleep condition: SD versus Control) x 4 (Order: 1^{st}, 2^{nd}, 3^{rd} versus 4^{th}) ANOVA was also conducted on the number of switches and total time spent on task, with Sleep condition and order tested as between-participants factors

Greenhouse-Geisser *F* values, degrees of freedom, and *p* values are reported for repeated-measures ANOVA results wherever tests of sphericity are violated (i.e. Mauchly's test of sphericity shows a *p* value of less than .05. In the following results, any significant effects or interactions were further analysed using *t*-tests. All *t*-tests that were conducted had their *p* values Bonferroni-corrected before being reported. In all figures, error bars represent ±S.E.M.

Investigating number of switches

Mean total of switches: The main effect of sleep condition was significant, $F(1,56) = 9.57$, $p = .003$, $\eta^2 = .15$. Fewer switches made in the Control condition compared to the SD condition ($M = 15.68$, $SD = 11.79$ versus $M = 39.69$, $SD = 39.41$). All other main effects and interactions were not significant (all $F < .87$, all $p > .46$).

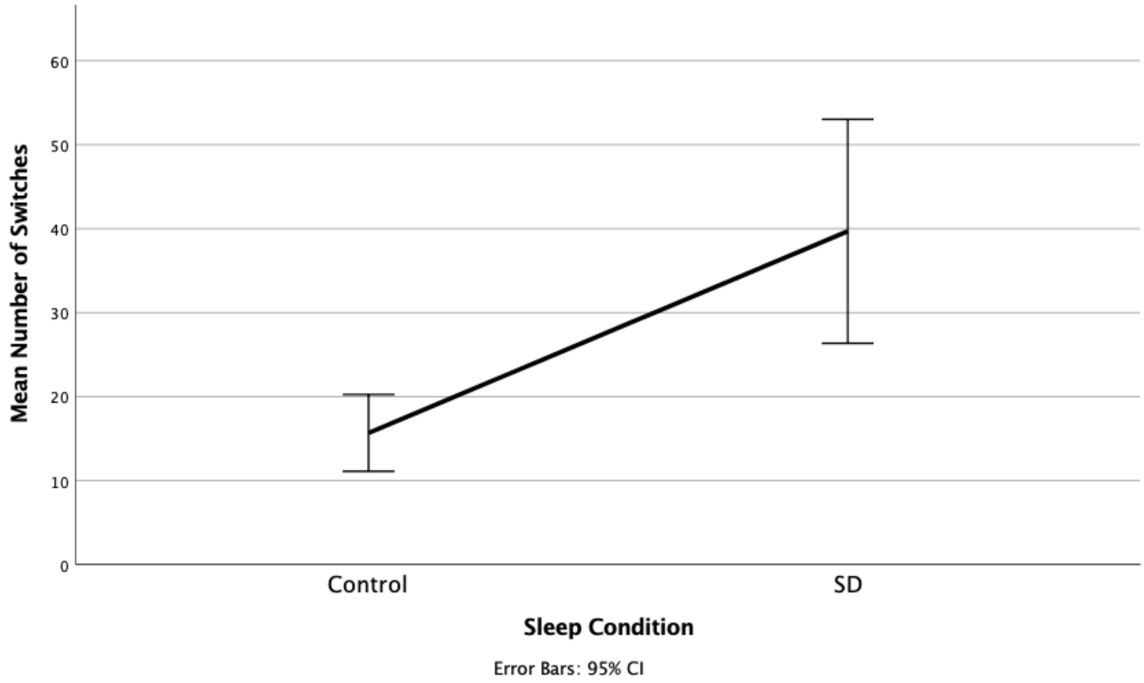

Figure 6.3 A line graph displaying the number of switches made in the voluntary switching condition across both the Control and SD participants.

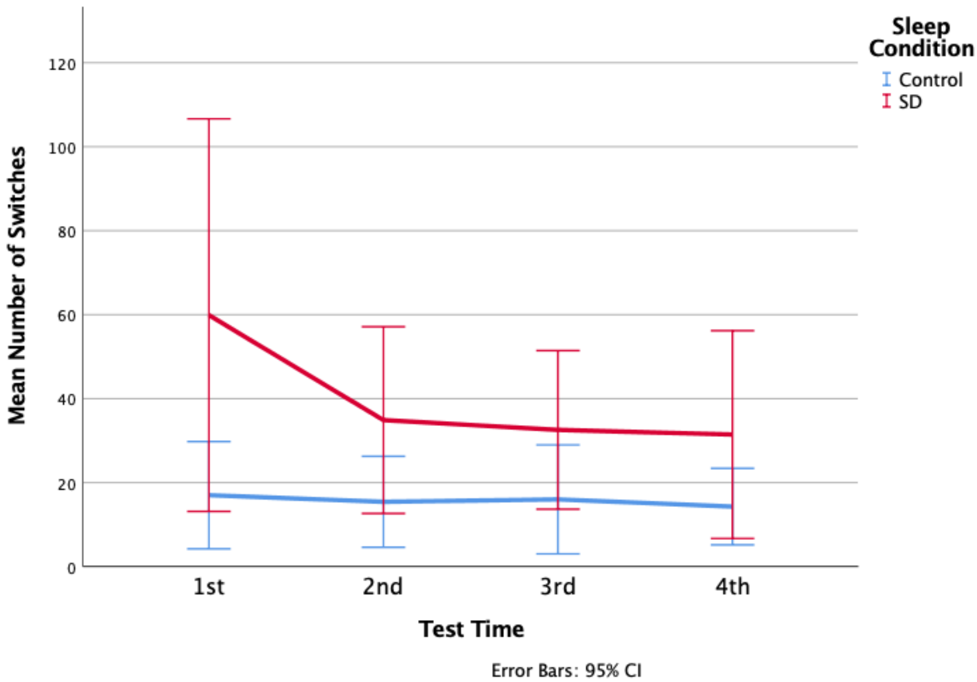

Figure 6.4 A line graph displaying the number of switches made by both the Control and SD participants in the order they completed the trials.

Investigating total time on task

Time on task (ToT): The main effect of task was significant, $F(1,62) = 5.58$, $p = .02$, $\eta^2 = .08$. With more time spent on the number task compared to the colour task ($M = 326.64$ seconds, $SD = 118.28$ versus $M = 263.35$ seconds, $SD = 115.77$). There were no significant differences between sleep conditions, $p = .35$ (Figure 6.5 and Figure 6.6). No other main effects or interactions reached significance (all $F < .66$, all $p > .42$).

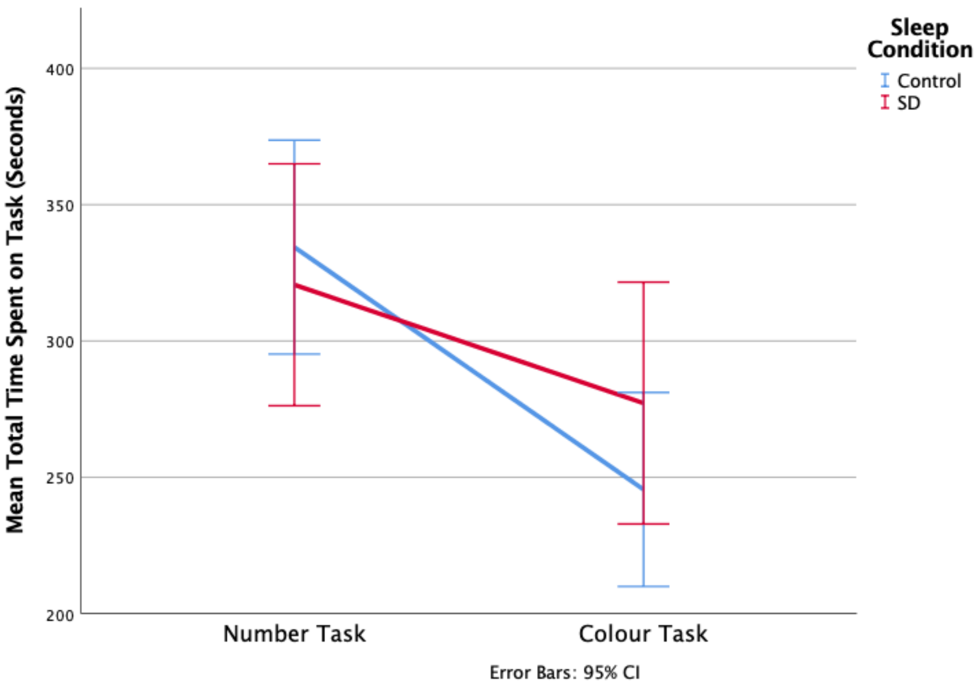

Figure 6.5 A line graph displaying the total time spent on the number and colour tasks in seconds across both the Control and SD participants.

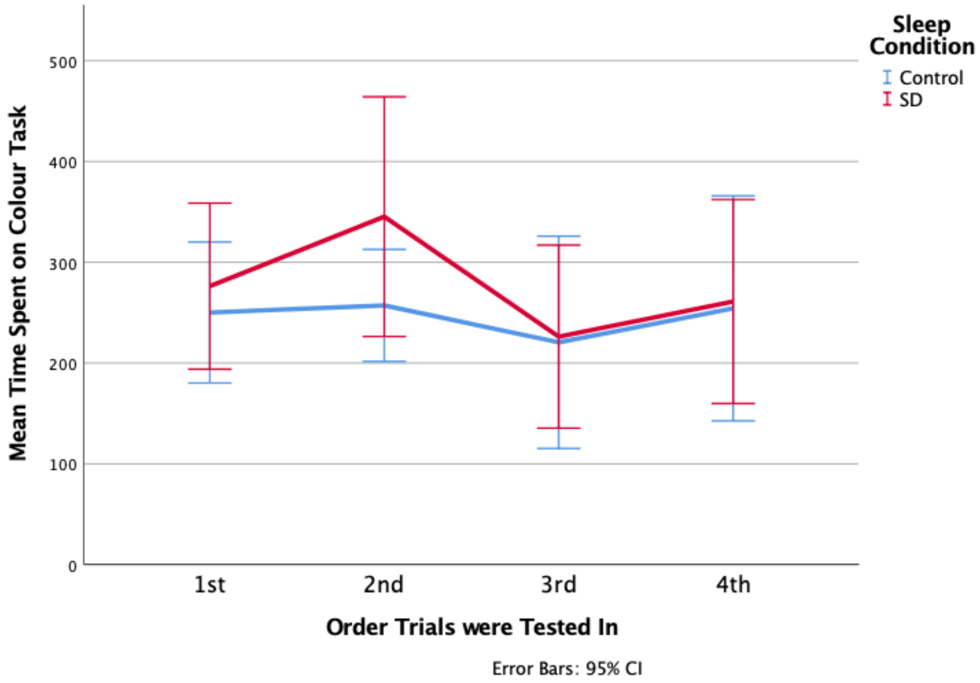

Figure 6.6 A line graph displaying the total time spent on the colour task in seconds across both the Control and SD participants in the order they completed the trials.

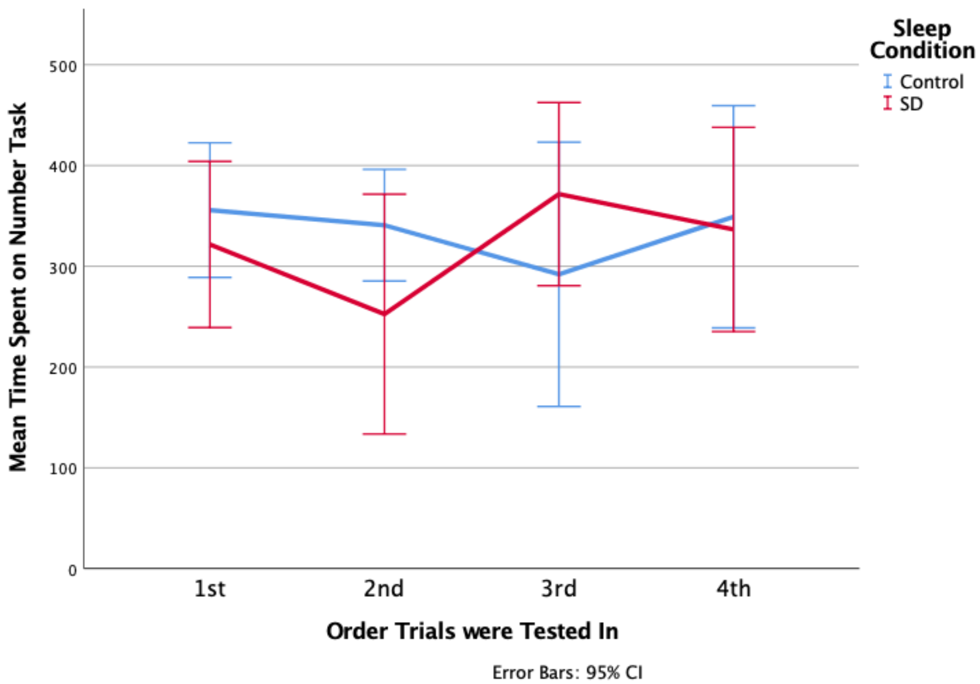

Figure 6.7 A line graph displaying the total time spent on the number task in seconds across both the Control and SD participants in the order they completed the trials.

6.4 Discussion

In the present study data, sleep deprived participants experienced less hours of sleep and reported feeling more fatigued compared to their Control counterparts. However, all PVT measures showed no differences between the sleep conditions. This could largely be explained by the limited number of participants included in the present data set. Research has highlighted the variable nature of people's susceptibility to sleep loss and subsequently more participants are needed to eradicate this variable nature of people's ability to manage sleep loss. As the same manipulation has been successful in Experiments 2 and 3 it is fair to surmise that the fatigue manipulation is still effective and that the sample size is too small to show the differences in the PVT.

Experiments 1 and 2 sought to understand different levels of sleep loss (sleep restricted and sleep deprived) and how that impacts voluntary task switching. While Experiment 3 explored how different types of task switching (voluntary and forced) are impacted by sleep deprivation. Though some key findings were observed, several new questions arose. The task used in Experiments 1, 2 and 3 had the same task goals but just differing stimuli. This led to the conclusion that the similarity in task goals allowed participants to some extent to compensate for the effects of fatigue as there was minimal conflict between active task goals for one and the reconfiguring for another. Equally, the task used also allowed for participants to respond in their own time without missing any vital task-relevant information. This meant that participants were able to spend longer recovering from a switch in task before starting the next task, again permitting a level of compensation to occur. It is the need to test these conclusions that led to the present experiment. This present experiment aimed to address these questions by including a task that involved switching between two separate different tasks with the task starting the moment the switch has occurred which could result in missed information if the participant was not attending fully.

Due to the unfortunate error during data collection, as well as, time sensitive and money dependent deadlines the present experiment only had a limited amount of useable data on this main experimental task. It is for this reason that no full conclusions can be drawn from this part of the study. Despite this the limited findings will still be discussed along with the hypotheses; SD will lead to increased number of switches and will spend longer on the colour task compared to Controls.

The main finding established in the present experiment is that the sleep deprived condition switches more frequently between the two tasks compared to their Control counterparts. This replicates a similar finding observed in Experiment 2. There has previously been mixed understanding within the literature as to how sleep deprivation changes individuals switching behaviour. Studies have observed that when fatigued people have complete choice of how frequently to switch they opted to switch less frequently putting less demand on their executive control (McGuire & Botvinick, 2010). Equally, this choice to switch less frequently is motivated by the aim to minimise costs and switching less often achieves this (McGuire & Botvinick, 2010). Additionally, the effort involved in switching between tasks might outweigh the returns the individual will receive from switching tasks and again this may serve to further decline the likelihood of switching tasks (Duggan, Johnson, & Sørli, 2013; Payne et al., 2007). More recently, research has discussed the possibility that sleep loss is understood to reduce vigilant attention and as a consequence sleep deprived individual may be inclined to switch more frequently as a means to improve and maintain their arousal and alertness on the tasks at hand (Wickens et al., 2015). A possible reason for the varied findings could relate to the extent that the individual is SD, with SD individuals requiring increased effort to maintain their alertness on the task and in doing so switch more frequently to aid their alertness, while SR participants are less fatigued and therefore less effort is needed to maintain alertness on the task therefore are more inclined to switch less. This notion is supported by the findings observed between SR and SD individuals in Experiments 1 and 2.

There was a difference observed between time spent on each of the number and colour changing tasks, with more time spent on the number task than the colour task. Although not controlled for it can be surmised that the number task is the easier of the two tasks as it has less distractors and less items to search amongst for the target. It is therefore unsurprising that all participants were found to spend more time on the number task compared to the harder colour task. Harder tasks have higher perceptual loads and as such cause an increased demand on their already limited mental resources. Therefore dealing with additional distractor items and switches in tasks is likely to cause an overload to attentional capacity (Gillie & Broadbent, 1989). It is likely that individuals in practice allocate their time so as to maximise the rewards and minimise costs (Payne et al., 2007). It would be expected given the nature of harder tasks taking up more mental resources and SD individuals having less available resources than Controls that SD individuals would be more inclined to spend even longer on the easy task. Although not significantly different SD individuals were actually observed to spend more time on the harder colour task compared to Controls. This may be a further indication of impaired decision-making in SD individuals and perhaps with a larger sample this may become significant.

An important measure addressed in the previous experiments has been that of GuT and RL. It has previously been surmised that these two measures are reflective of the disengagement/reconfiguration of task goals from one task to another. These two measures would have been of particular interest in this experiment due to the fact the task continues regardless of participants readiness and therefore would they still take the longer time to complete this process so as not to impair performance but risk missing task relevant information? Or would they feel pressured to start the task as it starts without them and subsequently not fully reconfigure themselves for the new task causing errors in performance? In Chapter 5, it was highlighted that SD participants had a longer RL time compared to Controls and this was thought to reflect the disengagement/reconfiguration process that they were unable to do prior to the switch. Even with this additional preparation time participants still had a reduction in performance producing fewer words. Therefore, it stands to reason that SD participants in this experiment will similarly require longer RL following a switch. Equally, it seems likely that when participants have no control over when the task starts there will be an increase in errors and this will be more severe in the SD participants as they would be overloaded.

Previous research has suggested that when switching between tasks with differing task goals the more interfering they will be to task resumption, therefore with both the added pressure of the task starting when the switch happens and participants having to deal with increased interference because of the differing task goals it can by theorised that this would cause all participants performance to suffer but that it would be further accentuated in participants who are SD. Unfortunately, the misfortune with the programme has prevented these measures from being examined and as such, only suppositions can be made.

6.5 Conclusion

In summary, the results of this study demonstrated the Although no full conclusions can be drawn from the main experimental task, the initial data indicates that a pattern might be emerging with the increased frequency of switching tasks for SD individuals present in both this experiment and Experiment 2.

Chapter 7

Understanding the Sensitivity of the KSS versus PVT

7.1 Introduction

The previous experiments have all studied effects of either SR or SD on the KSS and PVT. Each of the previous experiments have consistently found the KSS to be a more sensitive measure of fatigue in comparison to the PVT measures in which the effects were minimal and inconsistent. Previous research has suggested that the KSS and PVT are differentially affected by sleep loss. Specifically, with the subjective sleepiness being linearly related to the hours of sleep loss while objective measures deteriorate exponentially as levels of sleep loss increase (Jewett et al., 1999; as cited in Kaida et al., 2006). It could therefore be due to these differential effects between objective and subjective measures that the experiments in this thesis have not reached significant differences on all PVT measures. Within sleep research it is difficult to be able to directly compare findings as different experiments have different parameters they use in terms of the number of hours of sleep lost, how sleep loss is measured and the fatigue measures that are implemented. Equally, sleep research poses another challenge to overcome which is inter-individuality. Inter-individuality is a common issue within sleep research with some people able to function as normal with fewer hours sleep compared to others (Gaultney, 2010). It is for these reasons that the present experiment wishes to finally confirm whether the KSS is in fact a more sensitive predictor of fatigue compared to the PVT measures, as well as, establishing whether a larger sample is needed to overcome any inter-individual differences something that currently may be the reason for the minimal differences in the PVT measures in the previous experiments.

1) is the KSS a more sensitive predictor of fatigue?

Rationale

The present study aimed to confirm whether the KSS is in fact a more sensitive predictor of fatigue compared to the PVT measures, as well as, establishing whether a larger sample size was needed to account for individual differences that might have been causing the minimal differences in the PVT measures in the previous experiments.

Using the entirety of the dataset, fatigue measures will be explored. The KSS measure will be a more sensitive measure of sleep deprivation compared to the PVT in the SD participants. There will be no difference between the two measures in the Control participants.

7.2 Methods

This final empirical chapter investigates the fatigue measures in more depth, specifically, to establish whether the subjective fatigue measure (KSS) is a better indicator of fatigue compared to the objective measure (PVT).

Participants

Forty-three undergraduate and postgraduate students took part in Experiment 4 (28 females; *M*= 20.34*, SD* = 1.09, age range = 18 - 28 years old). The forty-three participants had all their fatigue and working memory measures fully recorded and this data will be used in the first part of the results section. In the next part of the results section, all 146 Control and SD participants (101 females; *M* = 20.07*, SD* = 1.40, age range = 18 - 28 years old) across the four experiments (see Table 7.2 for full breakdown of participants numbers from each previous Experiment) presented in this thesis will be used within the fatigue measures analysis. Some participants have had their data reused in multiple experiments, for the purpose of this analysis these participants will only have their data included once and so there will be no duplicates of participants.

All participants had normal vision or corrected-to-normal vision. All participants had normal visual acuity (at least 1.0 decimal VA at 70 cm), tested using the Freiburg Visual Acuity Test (Bach, 1996), and normal colour vision, tested using the City University Colour Vision Test 3rd Edition (Fletcher, 1998).

All participants reported no history of sleep or memory disorders and did not take any medication that may be adversely affected by a loss of sleep or may impact their usual sleep behaviour. Participants were recruited by an opportunity method of selection in which people volunteered to take part in exchange for course credits, monetary compensation or a mixture of the two. Participants were fully compensated for their time either in monetary compensation or course credits.

Design

Experiment 4 had two between-participant factors, task-switching rule (free choice of switching versus forced switching) and sleep condition (deprived versus normal).

Participants were assigned randomly to the between-participant condition with the constraint that there were equal number of participants in each. Those in the SD condition were required to have thirty hours of continual wakefulness; those in the normal sleep condition maintained their normal sleep patterns.

Participants took part in two separate computer-based testing sessions, each lasting up to 75 minutes. The two sessions were 1 day apart. During the first session the entire experiment was introduced and working memory (Ospan; Foster et al., 2015; and 3-Back; Shackman et al., 2006) and fatigue (KSS; Âkerstedt & Gillberg, 1990; and PVT; Dinges & Powell, 1986) were measured. Each participant was given a Fitbit to wear for the duration of the experiment. Sleep was tracked between the two testing sessions. Participants completed the online tests at specific times depending on their assigned condition. At the second testing session, all participants returned to complete a series of computer-based tasks. Fatigue was measured using the KSS and PVT and then they were required to complete the main experimental task; Colour/Number Change Detection Task.

Those in the sleep deprived condition had 30 hours of continued wakefulness, while those in the control condition maintained their normal sleep patterns for that night.

Testing times for both sessions were controlled and all participants were tested in the same time slots so as to control for circadian rhythm.

Due to the programming issues during the data collection period, the sixteen participants used within the data analysis were all in the voluntary switching condition only but there were still two sleep conditions. Therefore, the new Experiment 3 only had one between-participant factor; sleep condition (deprived versus normal).

Materials and Tests

Analysis Strategy

There is one main focus to the results. It addresses whether the KSS was a more sensitive measure of the effects of fatigue compared to the PVT.

7.3 Results

There are two parts to the results. The first uses the forty-three participants who have the full fatigue measures data and explored which of the PVT or KSS tests were more susceptible to the effects of fatigue. The second section analyses all SD and Control participants from the four previous experiments to establish whether a larger sample size was needed to account for individual differences that might have been causing the minimal differences in the PVT measures in the previous experiments.

Is the KSS or the PVT more susceptible to the effects of fatigue?

Using the full forty-three participants in this analysis.

Independent samples *t*-test was used to compare the hours slept, KSS score and PVT measures between control participants and SD participants. All RTs in the PVT were converted to reciprocal RT.

SD participants slept less hours compared to the control condition ($M = .22$, $SD = .73$ versus $M = 7.70$, $SD = .84$; $F(1, 34) = 843.47$, $p < .001$), and had increased fatigue as measured by the KSS compared to controls, ($M = 7.00$, $SD = 1.41$ versus $M = 3.11$, $SD = 1.52$; $F(1, 34) = 64.94$, $p < .001$,).

There was significantly shorter PVT mean reciprocal RT in the SD condition compared to the Control condition ($M = .0032$, $SD = .001$ versus $M = .0037$, $SD = .001$; $t(42) = 2.46$, $p = .02$, $d = .50$). There was no significant difference in the number of PVT lapses or false alarms in the SD condition compared to the Control condition ($M = 10.05$, $SD = 13.16$ versus $M = 5.33$, $SD = 14.66$; $t(42) = -1.11$, $p = .27$, $d = .34$; $M = 1.15$, $SD = 1.93$ versus $M = 1.13$, $SD = 1.80$; $t(42) = -.04$, $p = .97$, $d = .01$ respectively).

With respect to within-group comparisons, SD led to increased KSS scores, lapses in attention and reciprocal RT on Day 2 compared to Day 1 ($M = 7.05$, $SD = 1.43$ vs. $M = 3.68$, $SD = 1.70$, $p < .001$, $d = 2.15$; $M = 10.05$, $SD = 13.16$ vs $M = 1.55$, $SD = 1.70$, $p = .005$, $d = .91$; $M = .003$, $SD = .001$ vs. $M = .004$, $SD = .000$, $p < .001$, $d = 1.41$ respectively). But no differences in false alarms were observed ($p = .17$).

In comparison Controls, had no differences to KSS scores, reciprocal RTs, lapses in attention and false alarms on Day 2 compared to Day 1 ($t(22) = 2.02$, $p = .06$, $t(23) = 1.54$, $p = .14$, $t(23) = -.95$, $p = .35$ and $t(23) = -.25$, $p = .80$ respectively).

Table 7.1 Participant means for the fatigue measures (hours slept, KSS and PVT)

Measure	Controls		Sleep Deprived	
	Voluntary	Forced	Voluntary	Forced
No. of Participants	9	14	11	9
Sleep Hours	*M*=7.83, *SD*=1.05	*M*=7.57, *SD*=.64	*M*=.39, *SD*=.94	*M*=.00, *SD*=.00
KSS Score	*M*=2.89, *SD*=1.27	*M*=3.30, *SD*=1.77	*M*=6.82, *SD*=1.72	*M*=7.25, *SD*=.89
PVT RT>500ms	*M*=2.56, *SD*=4.80	*M*=7.21, *SD*=18.89	*M*=9.82, *SD*=8.99	*M*=10.33, *SD*=17.60
PVT False Alarms	*M*=.22, *SD*=.67	*M*=1.79, *SD*=2.08	*M*=1.36, *SD*=1.91	*M*=.89, *SD*=2.03
PVT Reciprocal RT	*M* = .004, *SD*=.001	*M* = .004, *SD*=.001	*M* = .003, *SD*=.001	*M* = .003, *SD*=.001

Was a larger sample size needed to account for inter-individual differences?

Using the full one-hundred and forty-six participants in this analysis.

Independent samples *t*-test was used to compare the hours slept, KSS score and PVT measures between control participants and SR participants. All RTs in the PVT were converted to reciprocal RT.

SD participants slept less hours compared to the control condition ($M = .29$, $SD = .79$ versus $M = 7.33$, $SD = 1.57$; $t(102.93) = 34.32$, $p < .001$, $d = 5.66$), and had increased fatigue as measured by the KSS compared to controls, (*M*=7.34, *SD* =1.29 versus *M* = 3.82, *SD* = 1.94; *t*(122.75) = -12.94, *p* < .001, *d* = 2.14).

There was significantly more false alarms and lapses in the SD condition compared to the Control condition (*M* = 1.43, *SD* = 2.53 versus *M* = .71, *SD* = 1.32; *t*(115.81) = -2.19, *p* = .03, *d* = .36; *M* = 8.49, *SD* = 12.70 versus *M* = 3.95, *SD* = 9.39; *t*(139.84) = -2.50, *p* = .013, *d* = .41 respectively). There was also a longer PVT mean reciprocal RT in the SD condition compared to the Control condition (*M* = .003, *SD* = .001 versus *M* = .004, *SD* = .001; *t*(148) = 2.63, *p* =.01, *d* = 1.00).

With respect to within-group comparisons, SD led to increased KSS scores, false alarms, lapses in attention and RT on Day 2 compared to Day 1 (*M* = 7.35, *SD* = 1.30 vs. *M* = 3.81, *SD* = 1.36, *t*(74) = -15.49, *p* < .001, *d* = 2.66; *M* = 1.49, *SD* = 2.56 vs *M* = .45, *SD* = .95, *t*(73) = -3.36, *p* = .001, *d* = .54; *M* = 8.77, *SD* = 12.88 vs. *M* = 1.82, *SD* = 4.94, *t*(73) = -4.36, *p* < .001, *d* = .71; *M* = .003, *SD* = .001 vs *M* =.004, *SD* = .00, *t*(39) = 5.47, *p* < .001, *d* = 1.41 respectively).

In comparison Controls, had no differences to KSS scores, lapses in attention and false alarms on Day 2 compared to Day 1 (*t*(63) = 1.83, *p* = .07; *t*(65) = -1.46, *p* = .15; *t*(65) = -.16, *p* = .88 respectively). There was a difference observed between reciprocal RT on Day 2 compared to Day 1 (*M* = .004, *SD* = .001 vs *M* = .004, *SD* = .001, *t*(66) = 2.81, *p* = .01, *d* = 0.00).

Table 7.2 Table of means for the fatigue measures for the 146 participants across the 4 experiments in this thesis.

Measure	Controls			Sleep Deprived		
	Exp1	Exp3	Exp4	Exp2	Exp3	Exp4
No. of Participants	27	20	24	37	18	20
Sleep Hours	*M*= 6.67 *SD*= 1.24	*M*=7.86 *SD*=2.31	*M*= 7.65 *SD*=.77	*M*=.28 *SD*=.68	*M*= .42 *SD*=1.11	*M*= .23 *SD*=.71
KSS Score	*M*= 4.89 *SD*=2.08	*M*= 3.15 *SD*=1.53	*M*=3.25 *SD*=1.59	*M*= 7.51 *SD*=1.15	*M*= 7.33 *SD*=1.50	*M*= 7.05 *SD*=1.39
PVT RT>500ms	*M*= 2.30 *SD*=3.20	*M*=4.35 *SD*=7.21	*M*=5.33 *SD*=14.66	*M*= 8.73 *SD*=13.83	*M*=6.67 *SD*=10.70	*M*= 10.05 *SD*=13.16
PVT False Alarms	*M*=.30 *SD*=.72	*M*= .65 *SD*=1.14	*M*= 1.13 *SD*=1.80	*M*= 1.54 *SD*=2.48	*M*=1.56 *SD*=3.33	*M*= 1.15 *SD*= 1.93
PVT Reciprocal RT	*M*= .004, *SD*= .00	*M*= .004, *SD*= .001	*M*= .004, *SD*= .001	*M*= .003, *SD*= .001	*M*= .004, *SD*= .001	*M*= .003, *SD*= .001

7.4 Discussion

Is the KSS more sensitive to the effects of fatigue?

Thus far, the experiments presented previously in the thesis have all produced consistent findings with the KSS measure demonstrating that when fatigued, participants rated themselves significantly higher on the scale compared to their Control counterparts. The PVT measures however, have provided inconsistent results across the experiments despite the fact that SD participants have had significantly less hour's sleep. This suggests that the KSS may be more sensitive to the effects of sleep loss compared to the PVT. This is consistent with previous findings that have suggested that subjective and objective measures of fatigue differentially change depending on the amount of sleep lost (Kaida et al., 2006).

This thesis has continually reported similar findings in these two fatigue measures and as many sleep studies have different sleep parameters and different means of measuring sleep it makes it hard for there to be direct comparisons in the findings. In Experiments 2, 3 and 4 however, the parameters and means of measuring sleep have remained constant and as such enables direct comparisons of the effects of fatigue on the KSS and PVT. In the previous experiments, a sub-set of the Control and SD participants have been reused in multiple analyses across Experiments 2, 3 and 4, therefore the present experiment collected a whole new set of participants with the aim to replicate this consistent finding and ensure that there were no other variables involved in causing that result. Results again showed the KSS to be significantly different between SD and Control participants, while it was only the mean reciprocal RT that showed differences on the PVT. This stands to further highlight the consistent finding that has emerged in this thesis that the KSS is more sensitive to the effects of fatigue compared to the PVT. However, these inconsistent findings observed in the PVT measures may also be occurring as a result of inter-individual differences.

Inter-individual differences are a common issue within sleep research. Specifically, research suggests that some people are more susceptible to the effects of sleep loss compared to others (Van Dongen et al., 2004). It is with this in mind, that the present experiment used all SD and Control participants from all four experiments in this thesis to compare the fatigue measures. It is with the reasoning that the individual experiments alone may not have had larger enough sample sizes to account for the individual differences and so by combining all participants it should alleviate these differences and effects on the PVT measures will appear. Results showed exactly this. Once all 146 SD and Control participants were counted within the analysis significant differences on the PVT were observed with SD participants having an increase in the number of lapses, false alarms and mean RT compared to their Control counterparts. This highlights that participants are more sensitive to feeling fatigued while performance on objective measures are more dependent on individual differences.

7.5 Conclusion

In summary, the results of this study demonstrated the KSS measure is particularly sensitive to the effects of fatigue and has consistently demonstrated differences between the sleep conditions. The PVT measures however, have been shown to be more dependent on individual differences and only once there is a much larger sample size do the PVT measures become significantly different between SD and Control participants. This highlights an interesting finding that individual differences only effect performance on objective measures of sleep while having no effect on people's feelings of fatigue.

Chapter 8

General Discussion

8.1 Introduction

The motivation of this thesis is to explore how fatigue affects performance on complex visuo-cognitive tasks when a switch in task is either forced or voluntarily chosen. In Chapter 1 several theories used to understand attention in task switching situations have been reviewed, as well as addressing the impact that fatigue has on the functioning of task switching. This led to the hypothesis that fatigue will cause a negative impact on performance on voluntary task switching in terms of accuracy and reaction times, and this impact will be more severe with increasing amounts of sleep lost. Furthermore, voluntarily choosing when to switch does allow for fatigued participants to overcompensate to some extent their fatigue. However, removing their control and forcibly switching them between the two tasks will impede performance greater than when the task was voluntary. Finally, when the two tasks participants are switching between differ completely in their task goals it causes more conflict and stands to cause further errors.

The work presented in Chapter 3 reworked a task (i.e. word generation task) from a previous study (Payne et al., 2007) to be in line with the goals of this research. The experiment used this voluntary task switching paradigm to measure the impact that SR has on the performance of the task. In Chapter 4, Chapter 3 was replicated but used SD participants instead of SR. The experiment aimed to examine the effects that an acute sleep loss would have on performance on voluntary task switching. Chapter 5, used the same task (i.e. the word generation task) as used in Chapters 3 and 4 but removed participants control over when they switched between the two tasks, instead forcing them to switch at random intervals. The aim was to understand whether the removal of control would impact SD participants to a greater extent than their Control counterparts. Chapter 6 reworked a task (i.e. Colour/Number changing task) from a previous study (Muhl-Richardson et al., 2018b) to be in line with the goals of this research. This chapter aimed to explore how performance changes in SD compared to Control participants when participants are required to switch between two tasks that have separate task goals. The final chapter, Chapter 7, examined whether the KSS is a more sensitive measure of fatigue compared to the PVT. A summary of the findings and implications of the empirical work presented in this thesis will be discussed in the following sections, followed by the real-world implications of this research. Finally, conclusions and directions for future research will be addressed.

8.2 Findings and Limitations

Chapter 3

In chapter 3, it initially sought to examine differences in performance on a voluntary switching task when individuals were either sleep restricted or had maintained their normal sleep. The issue was chosen because research has focused on examining forced task switching more so than voluntary task switching despite the fact that in real-world situations voluntary task switching is common, accounting for up to half of all interruptions (Czerwinski et al., 2004; González & Mark, 2004; Panepinto, 2010). This is particularly true within sleep research, with limited research focusing on how fatigue effects how people both manage voluntary task switches and the subsequent impact that it has on overall performance. With this is mind, this experiment sought to improve understanding on voluntary switching when the individuals had complete free choice or when they were restricted in some way. This resulted in voluntary and voluntary-equal conditions. Results showed that when an individual has had their sleep restricted (SR) their overall performance and the way they approach the task does not change. There is very little impact on performance as a result of their fatigue with the exception of a longer giving-up time on the hard task. This increased GuT finding is in line with the predicted hypothesis. Although originally it was posited that SR would experience an increased GuT on both the easy and hard task. These results highlight that SR does not cause a negative deficit and participants can maintain normal performance and only when the task complexity increases do they need to employ strategies to compensate (i.e. spend longer disengaging from the hard task). It was also hypothesised that SR would cause a reduction in the number of words generated and an increase in the errors produced compared to the Controls. However, results showed no such difference and this is thought to be due to the mild nature of the sleep manipulation not being severe enough sleep loss to elicit performance impairment and SR participants being able to compensate and overcome any potential influences of fatigue.

Also, of interest in this experiment was the difference in behaviour when participants had either complete control over their switching behaviour versus having certain restrictions put in place (e.g. have to spend 5 minutes on each task). The hypothesis stated that SR will lead to increased number of switches regardless of switch condition. Results should no such difference but did however observe there to be more switches in the Voluntary compared to the Voluntary-Equal condition. This makes sense as participants in the Voluntary-Equal condition know that regardless of their switches they will ultimate be forced to spend equal time on both tasks therefore there is no benefit on switching. However, results still found that in this condition participants were still inclined to switch, thus suggesting that there is some other reason for switching above and beyond simple time allocation. One particular theory is that participants regardless of sleep loss switch to maintain arousal.

Conducting a complete sleep restriction study is challenging because of the length the study is needed to get the relevant data, as well as, the stringent restrictions placed on participants. Common issues occurred with participants not adhering to the requirements of the study (e.g. not sleeping just 4 hours a night) or withdrawing their participation mid-way through the experiment which contributes to a loss of some useable data. Further getting participants to initially sign up to participate was more restrictive as many were not willing to commit to the schedule and duration of the experiment (experiment spanned over 6 days) or willing to lose sleep despite the monetary and/or course credit rewards. It is acknowledged within Chapter 3 that the sleep restricted participants ended up having a higher average number of hours sleep over the three days than originally stipulated in the study design and was due to participants not following the requirements of the study and over-sleeping. Equally, this meant that the difference in hours slept between the Control and SR participants was not as large as initially planned. This was another reason for conducting Experiment 2, to dramatically increase the difference in hours slept and eradicate any chance that participants in the sleep deprived condition would have an over-lap with the Control participants.

Nonetheless, despite the issues this study has provided an insight into task switching behaviour when SR that was not previously explored. As previously mentioned there has been limited sleep research that has explored voluntary task switching but of particular importance is the novel approach in which this study measured task switching behaviour (e.g. GuT, RL, word frequency etc.) with most task switching paradigms simply focusing on performance (e.g. errors made) and simple RTs.

Chapter 4

Continuing on from the Chapter 3, Chapter 4 sought to investigate whether there was an increased profile of performance deficits on the task switching task when individuals were SD. It is clearly understood within the research of the changing impact that different levels of sleep can cause. With SR and SD both found to result in a decline in performance (Alhola

& Plo-Kantola, 2007; Belenky et al., 2003; May & Baldwin, 2009; Pilcher & Huffcutt, 1996) but more specifically, minor SR (>4 hours of sleep per night) appears to have minimal effects while severe sleep loss (<4 hours of sleep per night) appears to cause profound effects (Wickens et al., 2015). It therefore comes as no surprise that once the sleep manipulation was increased to total SD that more behavioural differences were observed. The experiment showed that following SD, individuals produced fewer word generations compared to their Control counterparts. This is consistent with the hypothesis and highlights how increasing severity of the sleep loss, decreases performance on the same task that previously saw no differences when comparing controls with SR.

Like the experiment presented in Chapter 3, this experiment also failed to produce any differences in the number of errors sustained between the sleep conditions again opposing what was hypothesised. It was this discrepancy that led to the query of whether this lack of difference was actually simply due to the fact that SD participants were not producing as many words overall and so were likely to have no difference in errors produced. In order to establish if this was the case ratio analysis was conducted which found that the SD participants were actually producing fewer words per every error produced compared to the control participants. This suggest that SD participants are not producing enough words to highlight the difference but if they actually generated the same number of overall responses as the Control participants then they would in fact have aa higher number of errors. Another theory as to the lack of differences in errors is that by allowing participants to have complete control over the task in terms of choosing when to switch and resuming the task when they were ready without missing any vital information inhibited any potential errors and allowed the SD participants to compensate for some of their fatigue. This issue needed to be investigated further by removing participants control over the task; this was addressed in Chapter 5.

Like Chapter 3, the paradigm used in this experiment incorporated a novel approach in the way to measure impact of sleep of task switching behaviour. Additionally, one of the common issues within sleep literature is the inability to directly compare behaviours and performance changes across different studies due to various components changing. Specifically, in that sleep loss is recorded by different methods, that the level of manipulation and the way it is enforced varies, the time of day the tasks are administered and the type of tasks the participants complete are all factors that could impact the results. It was for this reason that this thesis maintained the same task and means of manipulating and measuring sleep so that comparisons across studies could be made and provide a profile of impairments following different levels of sleep loss and how it changes with different types of switching.

Chapter 5

Following on from the queries raised in Chapter 4, Chapter 5 sought to investigate differences in performance between SD and Control participants when they forcibly switched between two tasks. The experiment observed that like Chapter 4 SD participants generated fewer words compared to Control participants. Equally, when the switches were forced both Control and SD participants experienced a reduction in the number of words generated compared to their counterparts in the Voluntary switching condition. This supports what was hypothesised. This finding emphasises that with the introduction of a new added complexity in each experiment the less able individuals can compensate for effects of fatigue. This was evident in comparisons between SR and SD in Experiments 1 and 2 and then again with comparisons of Voluntary switching to Forced switching in Experiment 3.

With the introduction of forced switching, it means participants in that condition are unable to complete their disengagement/reconfiguration process prior to the switch (i.e. reflected in GuT) and so it was hypothesised that longer RL time would be observed in the Forced condition and this would be longer still in the SD participants compared to the

Control participants. Results in fact observed that SD individuals did experience a longer RL compared to Control participants. This finding supports the notion that when individuals have experienced sleep loss additional time is needed between tasks to adapt to the new task goals. Equally, it could be suggested that by having this additional time it could account for the lack of differences in errors. This idea fuelled the rational for Chapter 6. However, it was actually observed that there was a longer RL on the Voluntary condition compared to the Forced which contradicts the hypothesis. A possible reason for this discrepancy is that participants knew that they had no control over their switching and so following a forced switch, participants may have felt pressured to resume the task quickly for fear they may be switched again before completing the task. This lack of time to disengage/reconfigure on the forced switch condition could explain why there was a reduction in the number of words generated for both groups (Control and SD). When both groups (Control and SD) had control over when to switch (voluntary) and subsequently prior knowledge of an upcoming switch, they had time to prepare, and this allowed both groups of participants to perform better compared to when they had no prior knowledge (forced); this fits in with previous findings in the task switching literature (Meiran, 2000; Meiran, Chorev, & Sapir, 2000; Rogers & Monsell, 1995; Wylie & Allport, 2000).

When control over the task is removed, the effect on the number of words generated is still present, with SD participants producing fewer words compared to the Control participants. More interestingly some more subtle effects of fatigue are observed. When the task is easy SD participants do not generate as many words, but the kinds of words (i.e. frequency of words) they generate are similar to those of the Control participants – just not as many of them. When the task is hard however, Control participants respond by producing easier words (e.g. words of higher frequency) whereas SD participants do the opposite. This suggests that when the task is sufficiently hard SD individuals are no longer able to effectively adapt to a change in task complexity.

Reflecting back through Experiments 1, 2 and 3 on WM's influence on task performance it revealed an interesting pattern of effects. Initially it seems that the involvement of WM is inconsistent however, it seems that when the task difficulty is hard but not too hard that individuals are overloaded, some effects of WM are apparent. This is clear within the literature showing that when participants have free choice over when to switch tasks they will decrease the likelihood that they experience an overload in WM which is likely experienced when a switch is forced (Panepinto, 2010). This is equally why effects of WM only first emerge when participants are SD and not when they are SR as the perceived difficulty of task completion is increased. Additionally, once the task is made harder still with a forced switch being introduced, the SD participants can no longer cope and experience an overload in WM.

This chapter continued to add to the profile of behaviour and performance changes in SD individuals that occur when specific elements are manipulated. Comparisons that are currently not present within the literature.

Chapter 6

This chapter aimed to examine SD and Control participants behaviour when they were either forcibly or voluntarily switched between two tasks that both have separate task goals. This followed on from the issues discussed in the previous two chapters about the similarity of the task goals in the word generation task inadvertently cueing one another, whilst also allowing for participants to respond to the task at their leisure without missing vital task-relevant information. These two components could be unintentionally reducing potential costs that would otherwise be associated with SD. Unfortunately, due to some errors during data collection and the subsequent limited data, full conclusions cannot be drawn but will still be briefly discussed below. The first component that this chapter is investigating remains untouched by this error and so can still be investigated to the full extent.

Before discussing the results of this chapter's investigations, the issues during data collection need to be addressed. The program was modified from a previous study and contained a number of complex requirements that needed to be included to the adapted script. During the initial testing phases, it appeared that the voluntary switching condition was working correctly and so aware of the impending money and time deadlines, data collection began. Meanwhile, attention was giving to the forced switching condition which was not switching automatically between the tasks at the specified times remaining on one task throughout. It was only then that it became apparent that the responses were not consistently recorded on all trials, with some participants having half of their trials recording correctly while others had no trials recording correctly. Data collection continued whilst trying to address the problem despite the obvious flaw in the program with the knowledge that useable data was still being collected in order to address the first component of the chapter's investigations. In future, a more stringent check needs to be completed when testing whether the experiment runs completely on all conditions and for all counterbalances before undertaking any data collection and time and money permitting it would have been possible in the present thesis. Nonetheless, it was still imperative that the data continued to be collected so as to address the first query.

Although no conclusions can be firmly drawn from the findings in this chapter, it can discuss some initial patterns that may pave the way for further investigations to be conducted. The experiment observed that SD participants switched significantly more compared to Control participants. This replicates the same finding observed in Experiment 2 and is in line with the hypothesis. This increased switching has been theorised to occur as a result of SD participants either switching more frequently to help maintain arousal on the task or that it is an indicator of their impaired decision-making; with switching between tasks known to generate associated negative switch costs so by switching more frequently, SD participants could be seen to be less efficient in their approach to the task. Additionally, although not significantly different, SD participants were observed to spend more time on the hard task (colour task) compared to Controls and this could again be another indicator of their impaired efficiency and decision-making toward the task.

Chapter 7

The final experimental chapter wished to address the consistent findings amongst the fatigue measures observed in the previous 3 chapters. Specifically, aiming to investigate whether the KSS is a more sensitive measure of fatigue compared to the PVT measures which has been the observation in the previous chapters.

Throughout each of the 4 experiments presented in this thesis fatigue measures taken remained the same. A consistent finding occurred across all experiments showing that the KSS was a more sensitive measure of fatigue following both SR and SD while the effects on the different PVT measures varied. Initially, it was thought that perhaps the sleep manipulation itself was not severe enough to elicit behavioural effects of fatigue on the PVT. This comes from the research that states that the KSS and PVT change differentially with the amount of sleep lost, with the KSS linearly increasing with the amount of hours SD while the PVT measures change exponentially with the increasing sleep loss (Kaida et al., 2006). However, another possibility of the differences between the KSS and PVT measures could be a result of individual differences commonly found with people's ability to perform normally on less hour's sleep compared to others. Further investigations of this relationship between the KSS and PVT to SD were conducted in Chapter 7. This investigation included all SD and control participants collected throughout the duration of the thesis. Results supported the hypothesis and showed strong significant differences in all PVT measures and KSS scores between SD and Control participants. This highlights an important finding that the KSS is more sensitive to the effects of fatigue regardless of individual differences, whereas the performance on the PVT although impacted by fatigue it was observed that individual differences will obscure these findings until a larger sample is included.

8.3 Real-world Implications

Although this thesis is not an applied piece of research, it has provided a basis in which future applied research can adhere to. This research has a number of practical inferences to real-world situations and of specific interest to the funders of the thesis, the maritime industry. While the tasks completed in the thesis were not maritime specific and the participants were not mariners the general principle of switching between complex visuo-cognitive tasks in both a forced and voluntary manner while experiencing varying levels of fatigue is of great likeness to the maritime industry.

Many real-world activities require the monitoring of complex dynamic displays for changes. Often this type of task also frequently requires the individuals to switch between monitoring of two independent displays, interleaving between the two. An example of this is monitoring multiple marine radars on board a ship. Specifically, individuals stationed on the bridge of a ship will be required to carefully monitor multiple displays namely radars, in addition to maps detailing ships position, direction, and speed (Muhl-Richardson et al., 2018). Therefore, to successfully detect any changes on the displays, sustaining attention is vital (Muhl-Richardson et al., 2018; Warm, Parasuraman, & Matthews, 2008; Warm, Finomore, Vidulich, & Funke, 2015). It is for this reason that switching between tasks can cause vital information to be missed and even more so when individuals are fatigued.

In recent years the introduction of automated ships brings a change in the behaviour and tasks performed on board a ship. It aims to reduce seafarer's workload, with for example automation now aiding navigation on most ships (Hadnett, 2008, as cited in Hillstrom, Pugh, & Clark, 2015). Despite the intention to reduce workload, automation has now simply resulted in a change of task demands. Rather than actively completing the task themselves, seafarers are now required to monitor an automated system; a navigator for example is no longer required to plot a safe course but must monitor the automated system to ensure the path is safe (Lützhöft & Dekker, 2002). In addition to this change in task demands the automation also emits alarms periodically, therefore producing forced interruptions (Motz, Hockel, Baldauf, & Benedict, 2009). Thus, with an increase in automated tasks on board ships, individuals are now required to continually switch back and forth between monitoring different displays or attending to alarms when they sound. As a result of this seafarers are exposed to immense attentional demands (Cook & Smallman, 2013).

It is for this reason that exploring task switching behaviour is of vital importance. Even more so exploring this task switching behaviour when individuals have experienced sleep loss much like many mariners and commonly, people in their daily lives often experience. The word generation task used in this thesis aimed to reflect the immense attentional demands often experienced on board a ship. To do this in needed to be a task that incorporated both basic executive functions; reflects a number of cognitive processes that would be reflected in task mariners do, such as attentional control, inhibitory control, working memory and cognitive flexibility; as well as, higher order executive functions that involve multiple brain regions, combining basic cognitive functions alongside more complex ones like planning, reasoning and problem solving. Alongside the type of task used the level of sleep loss also aimed to replicate similar scenarios that can be present on board; firstly, sleep restriction which is common place and reflective of shift work and secondly, sleep deprivation which could occur in a scenario where all mariners need to be on alert and at their stations for a prolonged period (e.g. due to bad weather).

8.4 Conclusions and Future Directions

The research presented in this thesis answered some important questions regarding the impact of fatigue on performance of complex tasks. It can now firmly be concluded that mild SR (4 hours a night for 3 nights) only produces minor impairment to performance. Once the sleep loss is much more severe (1 night of total SD) the profile of impairments becomes more widespread, including a reduction in the number of words produced. Nonetheless, despite the interference that SD causes while participants still maintain control over the task (i.e. voluntary switching) they are able to compensate for some of the effects of fatigue evidenced by the lack of errors observed in the first three empirical chapters. When this control has been removed (i.e. forced switching) the same performance impairments remain (e.g. reduction in the number of words generated) but some more subtle effects appear. Control participants adapt to changes in difficulty when the task is hard and the control has been removed by producing easier words (i.e. words of higher frequency), this relationship fails in SD participants.

The primary inference of this work is that prior studies have provided limited and incomplete research into individuals behaviour when voluntarily switching between tasks and this is specifically the case when exploring the differential levels of sleep loss on voluntary switching behaviour. Previous sleep studies have put a lot of emphasis on task switching paradigms that force the switches despite the knowledge that real-world switching is most commonly associated with voluntary switching. Equally, previous research has neglected to provide direct comparisons of voluntary versus forced types of task switching whilst seeing how this compares with SD and Control participants. Further, sleep research has used standard task switching paradigms that simply measure performance and RT and as a result cannot draw any deeper conclusions on how sleep loss impacts behaviour and strategies employed to task switch. This thesis has bridged that gap, by incorporating additional measures (e.g. GuT, RL, word frequency etc.) and as a result has allowed for insight to the subtler effects of sleep loss. This was based upon the measures set in Payne et al's (2007) study. Although this paradigm is closely in line with that of Payne et al's some important distinctions remain, namely the inclusion of sleep loss as a condition. Payne et al's study provided an important bench mark but this thesis broadened it investigating how performance and behaviours changed as their sleep loss changed. Additionally, the thesis furthered the analysis, beyond what Payne et al did, and investigated the types of response (e.g. word frequency) participants gave as well not just the basic performance measures.

Likewise, unlike previous research this work has enabled a direct comparison between forced and voluntary switching and as such has produced an understanding of the specific differences that occur between these two types of switching and to what extent sleep deprivation furthers these differences. Finally, it has provided evidence of the sensitivity of the KSS as a measure of fatigue, while highlighting the variable nature of people's performance on the PVT when fatigued, something again that has not directly been investigated.

Despite providing answers to a number of important questions the findings in this thesis have led to more questions, of which they are noted below. Firstly, this thesis has discussed the issues of the variable nature of sleep loss and people's ability to differentially compensate for its effects, it would therefore be beneficial to re-run these experiments but use a within-participant design. This will allow for inter-individual bias to be controlled for whilst also giving a more accurate understanding of an individual's susceptibility to sleep loss. This in turn may highlight the range of impairment between those who are particularly susceptible to sleep loss compared to those who are better able to manage it.

The second issue is with the external validity of the research. The tasks performed were relatively short compared to real-world tasks. Other research has discussed issues with time on task effects being particularly impaired by sleep loss (Lim & Dinges, 2008), as well as, impaired alertness during sustained attention tasks. Currently in the literature sleep loss and sustained attention tasks have been investigated but only with short tasks such as the PVT and so it would be of interest to understand how complex tasks are impaired over prolonged periods equivalent to that of a full day's work. Do individuals who have experienced a loss of sleep experience time on task effects at a quicker rate?

The final question is regarding simultaneous multitasking something that is of equal prevalence to task switching in day-to-day situations. Research has shown that simultaneous tasks switching and sequential task switching are different (see Muhl-Richardson et al., 2018.; Ravizza & Carter, 2008) but this has not been expressed in terms of SD's impact on it. One way to test this would be to use the same experimental design presented in Muhl-Richardson et al., (2018) and extend it to include a SD condition. This would provide a further, more comprehensive overview of SD's effects on task performance in different situations and add to the portfolio of behaviours that this thesis has already provided.

In conclusion, this thesis has provided an experimental and novel approach to investigating the effects of fatigue on performance of complex visuo-cognitive tasks. A number of developments have been made, revealing the specific nature of effects on performance on different types of tasks. As previously highlighted, there are still a number of areas that require further investigation to provide a more comprehensive understanding of SD's effects on cognitive tasks. Ultimately the goal, will be to have a full overview of the effects of SD on different cognitive task in different situations and examine how this can be related to real-world situations

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Appendix 1 – Consent Forms, Information Sheets, Instruction Sheets and Debriefing

Example Consent Form

PARTICIPANT NUMBER: ________

CONSENT FORM

UNIVERSITY OF Southampton

Study title: Task switching and Alertness

Researcher names: Gemma Hanson and Rob Chan Seem
ERGO Study ID number: 25468
Please initial the box(es) if you agree with the statement(s):

I have read and understood the information sheet and have had the opportunity to ask questions about the study. ☐

PLEASE READ CAREFULLY.
I agree to the following terms, and understand that if the following conditions are not met my participation in the study may be discontinued. ☐

- I will not swim during the duration of the experiment (across 5 days).
- I will not consume alcohol from 11.30pm on Day 2 until after the lab session on Day 6 lab.
- I will not exceed my usual caffeine intake throughout the study (Days 1 to 6).
- I will not drive (or operate heavy machinery) on Days 4, 5 and 6, and the day after the experiment has been completed.
- I will not partake in any important events that might suffer from reduced cognitive capability, such as assignments, exams, interviews, etc. on Days 4, 5 and 6, and the day after the experiment has completed.
- I am responsible for returning the activity monitor as soon as my participation in this experiment stops, otherwise I will be charged for the equipment at a cost of £100.
- I will participate in the tasks as described on the information sheet (subject to be being able to withdraw from the study at any time).
- I will note down the time of going to bed and getting up for each of the five nights.
- I will only remove the activity monitor when it is in danger of getting wet (e.g., bath, shower, washing up), and will only remove it for up to 30 minutes per day.
- I understand that an accuracy of 75% must be achieved in both the practise test on Day 1 and the online quizzes (Days 3 to 6) for my participation to continue. These accuracy levels have been chosen through piloting and have been chosen as reasonable to achieve when engaging with the tasks.

I agree to take part in this research project and agree for my data to be used for the purpose of this study. ☐

I confirm I do not have any medical conditions that might be adversely affected by sleep deprivation. ☐

I understand my participation is voluntary and I may withdraw at any time without my legal rights being affected. ☐

Name of participant (print name)..

Signature of participant.. Date...............................

Example Information Sheet

Participant Information Sheet (v4GI, 29/01/2018)

Study Title: Task Switching and Alertness 3

Researcher names: Gemma Hanson
ERGO Study ID number: 31722

Please read this information very carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.

What is the research about?
The data will be used to understand the effects of fatigue on individuals' ability to successful switch tasks. Results will be reported to the TK Foundation-funded MARTHA project and Leverhulme Trust "Understanding Maritime Futures" project, and applied to fatigue in mariners.

Why have I been chosen?
You volunteered to take part as part of a convenience sample.

What will happen to me if I take part?

Once participants have consented to participation. Participants will be ***RANDOMLY*** *assigned to one of two conditions. One condition requires participants to be sleep deprived without any sleep for 29 hours (not allowed to sleep from the start of the experiment on Day 1 until after the end of the experiment on Day 2), while the other requires participants to maintain their usual sleep behaviour for that night. Unfortunately, you cannot opt to be in one condition over another, so please be prepared to take part in any of the conditions. Payment is £6/hour or Research Participation Credits are 3 credits per 15 minutes. Payment is usually received within three weeks, but can take up to four weeks to be received.*

The total study will involve 60 minutes of lab-based tasks on Day 1 and another 60 minutes on Day 2.

Day 1 Lab session starting at 9.30am/9.45am/10.30am/10.45am and ending at 10.30am/10.45am/11.30am/11.45am as follows:

- *Pick up activity monitor and start wearing the activity monitor on the wrist of your non-dominant hand for 29 hours. You will receive 6 credits or £3 (included in study total).*
  - *Data from the activity monitor includes estimates of the following: number of steps taken per day, distance walked per day, number of flights of steps climbed per day, number of calories burned per day, time of going to bed and getting up, duration of sleep, restless and wakeful periods during sleep.*

- *You will also be asked to fill out a questionnaire about your normal sleep patterns.*

- *You will be asked to fill out a questionnaire about your fatigue levels at that moment in time (KSS).*
- *You will be asked to fill out a questionnaire about your uncertainty levels (IUS-12).*
- *You will be required to complete a test to measure your working memory capacity (OSPAN and 3-back).*
- *You will be required to complete a test to measure your alertness (PVT).*

Days 1 and 2:

- *Please do not exceed your usual caffeine intake throughout the study.*
- *No swimming.*
- *No alcohol to be consumed during the experiment until after lab session on Day 2.*

- *Complete 6 x 30-minute on-line quiz to evidence being awake, starting at different times of the day.*

Day 2 Lab session starting at 2.30pm/2.45pm/3.30pm/3.45pm and ending at 3.30pm/3.45pm/4.30pm/4.45pm as follows

- *You will be asked to fill out a questionnaire about your fatigue levels at that moment in time (KSS).*
- *You will be asked to fill out a questionnaire about your uncertainty levels (IUS-12)*
- *You will be required to complete a test to measure your alertness (PVT).*
- *You will be required to complete 4 blocks of word generation.*
    - *You will need to complete a practise test of the task. All participants must achieve a reasonable level of accuracy (levels of accuracy have been informed by a pilot study, ERGO number: 19343) to be included in the study.*

- *Given that this study is about fatigue, long breaks cannot be given, but you can take a 2-minute break at any time between the word generation trials.*

<u>Are there any benefits in my taking part?</u>

You will receive a monetary compensation or Research Participation Credits (or a mixture) for taking part in the complete study, at a rate of £6/hour or 3 credits per 15 minutes for the tasks you take part in (as detailed below).

If you opt for the payment option, you will be required to sign at the end of the experiment to confirm the number of hours involved, and may need to supply bank account information. The payment is usually received within three weeks, but can take up to four weeks to be received.

Overview of the payment for the experiment:

- ***Day 1 (1 hour - £6 or 12 credits):***
    - *PVT (10 minutes - £1 or 2 credits)*
    - *KSS and Questions on Sleep Pattern (5 minutes – 50p or 1 credit)*
    - *3-back task (20 minutes - £2 or 4 credits)*
    - *OSPAN (20 minutes - £2 or 4 credits)*
    - *Breaks In between task (total 5 minutes – 50p or 1 credit)*

- ***Day 1 and 2 (3 hour - £18 or 36 credits):***
    - *6 Online surveys (30 minutes each - £3 or 6 credits)*

- ***Day 2 (1 hour - £6 or 12 credits):***

  - *PVT (10 minutes - £1 or 2 credits)*
  - *KSS (5 minutes – 50p or 1 credit)*
  - *4 block of word generation task (40 minutes - £4 or 8 credits)*
  - *Breaks In between task (total 5 minutes – 50p or 1 credit)*

- ***Additional compensation (total - £3 or 6 credits):***
  - *Wearing the Fitbit for the duration of the experiment (29 hours) (£3 or 6 credits)*
  - ***Sleep Deprived group only: to compensate for no sleep (8 hours - £48).***

Please keep this information sheet in a safe place, so that you have a record of the process and requirements.

IMPORTANT SECTION: Are there any risks involved?

You should not drive or operate heavy machinery on Days 1 and 2, and the day after the experiment. Nor partake in any important events that might suffer from reduced cognitive capability, such as assignments, exams, interviews, etc. on Days 1 and 2 and the day after the experiment. Please see the consent form for details.

Very occasionally the activity monitor can cause irritation to the skin. If you experience irritation, you should stop taking part in the experiment, remove the activity monitor and wash irritated skin with soap and water.

If you need to stop the study for any reason, please contact the experimenter to arrange your withdrawal from the experiment and return of the activity monitor.

Are there any restrictions to my taking part?

Yes by signing the consent form you have agreed to the following terms:

- *I have not previously taken part in a study titled "Task switching and alertness".*
- *I will not swim during the duration of the experiment (across 2 days).*
- *I will not consume alcohol for the duration of the experiment, until after the lab session on Day 2.*
- *I will not exceed my usual caffeine intake throughout the study.*
- *I will not drive (or operate heavy machinery) during the experiment and the day after the experiment has been completed.*
- *I have a grade C or above in GCSE English or equivalent.*
- *I will not partake in any important events that might suffer from reduced cognitive capability, such as assignments, exams, interviews, etc. during the experiment and the day after the experiment has completed.*
- *I am responsible for returning the activity monitor as soon as my participation in this experiment stops, otherwise I will be charged for the equipment at a cost of £100.*
- *I will participate in the tasks as described on the information sheet (subject to be being able to withdraw from the study at any time).*

- *I will only remove the activity monitor when it is in danger of getting wet (e.g., bath, shower, washing up), and will only remove it for no more than 30 minutes per day.*

Will my participation be confidential?

- *All data will be anonymised using a participant number key, which will only be available to the researchers on the project.*
- *Computer task data will be stored on a computer in a locked lab/office and/or a password-protected computer.*
- *Data from the activity monitor will be checked online, behind a password-protected login, and stored on a password-protected computer when downloaded. In addition, participant names or number identifiers will not be stored alongside the online activity-monitor data.*
- *Data from the quizzes will be stored on a password-protected online system, and stored on a password-protected computer when downloaded.*
- *Completed questionnaires will be kept safely by the researcher whilst being coded, and then stored in a locked filing cabinet.*
- *Questionnaires will be anonymised using participant ID numbers.*

What happens if I change my mind?

You have the right to withdraw from the study at any time without your legal rights being affected. Please contact the experimenters if you choose to withdraw. If you choose to withdraw from the study, any data that has already been collected will be destroyed.

What happens if something goes wrong?

In the unlikely case of concern or complaint, you may contact the Chair of the Ethics Committee, Psychology, University of Southampton, Southampton, SO17 1BJ. Phone: +44 (0)23 8059 3856, email fshs-rso@soton.ac.uk

Where can I get more information?

If you have any questions please contact Gemma Hanson on g.hanson@soton.ac.uk.

Example of specific instructions for Control participants

UNIVERSITY OF Southampton

Participant Instruction Sheet (v4C, 29/01/2018)

Study Title: Task switching and Alertness 3

Researcher names: Gemma Hanson
ERGO Study ID number: 31722

Please read this instruction sheet very carefully.

Instructions for taking part

You have been randomly assigned to one condition. This instruction sheet applies only to your condition.

The total study will involve wearing a FitBit activity monitor, 60 minutes of lab-based tasks on Day 1, 6x30 minutes of online surveys, and another 60 minutes of lab-base tasks on Day 2.

Day 1 Lab session starting at 9.15am/9.30am/10.30am/10.45am and ending at 10.15am/10.30am/11.30am/11.45am as follows:

- *Pick up activity monitor and start wearing the activity monitor on the wrist of your non-dominant hand for 29 hours. You will receive 6 credits or £3 (included in study total).*
    - *Data from the activity monitor includes estimates of the following: number of steps taken per day, distance walked per day, number of flights of steps climbed per day, number of calories burned per day, time of going to bed and getting up, duration of sleep, restless and wakeful periods during sleep.*

- *You will also be asked to fill out a questionnaire about your normal sleep patterns.*
- *You will be asked to fill out a questionnaire about your fatigue levels at that moment in time (KSS).*
- *You will be asked to fill out a questionnaire about your uncertainty levels (IUS-12).*
- *You will be required to complete a test to measure your working memory capacity (OSPAN and 3-back).*
- *You will be required to complete a test to measure your alertness (PVT).*

Days 1 and 2:

- *Please do not exceed your usual caffeine intake throughout the study.*
- *No swimming.*
- *No alcohol to be consumed during the experiment until after lab session on Day 2.*

- *Complete a 30-minute on-line quiz to evidence being awake, starting at the following times or as close to these times as possible:*

- *Day 1 at 2pm, 4.30pm, 6.30pm, 9pm*
- *Day 2 at 10.30am and 12.30pm*
- *You will need your participant number to complete the quizzes.*
- *An experimenter will email the links to the quizzes to you on during the testing session on Day 1.*

Day 2 Lab session starting at 2.15pm/2.30pm/3.30pm/3.45pm and ending at 3.15pm/3.30pm/4.30pm/4.45pm as follows

- *You will be asked to fill out a questionnaire about your fatigue levels at that moment in time (KSS).*
- *You will be asked to fill out a questionnaire about your uncertainty levels (IUS-12).*
- *You will be required to complete a test to measure your alertness (PVT).*
- *You will be required to complete 4 blocks of word generation.*
    - *You will need to complete a practise test of the task. All participants must achieve a reasonable level of accuracy (levels of accuracy have been informed by a pilot study, ERGO number: 19343) to be included in the study.*

- *Given that this study is about fatigue, long breaks cannot be given, but you can take a 2-minute break at any time between the word generation trials.*

Once you have completed the experiment you will receive a monetary compensation totalling £33 or 66 Research Participation Credits (or a mixture) for taking part in the complete study, at a rate of £6/hour or 3 credits per 15 minutes for the tasks you take part in (as detailed below).

Example of specific instructions for SD participants

UNIVERSITY OF Southampton

Participant Instruction Sheet (v4SR, 29/01/2018)

Study Title: Task Switching and Alertness 3

Researcher names: Gemma Hanson
ERGO Study ID number: 31722

Please read this instruction sheet very carefully.

Instructions for taking part:

You have been randomly assigned to one condition. This instruction sheet applies only to your condition.

The total study will involve wearing a FitBit activity monitor, 60 minutes of lab-based tasks on Day 1, 6x30 minutes of online surveys, and another 60 minutes of lab-base tasks on Day 2.

Day 1 Lab session starting at 9.15am/9.30am/10.30am/10.45am and ending at 10.15am/10.30am/11.30am/11.45am as follows:

- *Pick up activity monitor and start wearing the activity monitor on the wrist of your non-dominant hand for 29 hours. You will receive 6 credits or £3 (included in study total).*
    - *Data from the activity monitor includes estimates of the following: number of steps taken per day, distance walked per day, number of flights of steps climbed per day, number of calories burned per day, time of going to bed and getting up, duration of sleep, restless and wakeful periods during sleep.*

- *You will also be asked to fill out a questionnaire about your normal sleep patterns.*
- *You will be asked to fill out a questionnaire about your fatigue levels at that moment in time (KSS).*
- *You will be asked to fill out a questionnaire about your uncertainty levels (IUS-12).*
- *You will be required to complete a test to measure your working memory capacity (OSPAN and 3-back).*
- *You will be required to complete a test to measure your alertness (PVT).*

Days 1 and 2:

- *Please do not exceed your usual caffeine intake throughout the study.*
- *No swimming.*
- *No alcohol to be consumed during the experiment and until after lab session on Day 2.*

- *Complete a 30-minute on-line quiz to evidence being awake, starting at the following times:*
    - *Day 1 at 10pm*
    - *Day 2 at 12.30am, 3am, 5.30am, 8am and 10.30am*
    - *You will need your participant number to complete the quizzes.*
    - *An experimenter will email the links to the quizzes to you during the testing session on Day 1.*

NOTE: If periods of sleep are record on the Fitbit, then you may not receive the full participation payment. The Fitbit monitors movement, therefore during the night it is your responsibility to periodically be active to ensure the Fitbit registers that you are awake.

Day 2: Labs tasks starting at 2.15pm/2.30pm/3.30pm/3.45pm and ending at 3.15pm/3.30pm/4.30pm/4.45pm as follows

- *You will be asked to fill out a questionnaire about your fatigue levels at that moment in time (KSS).*
- *You will be asked to fill out a questionnaire about your uncertainty levels (IUS-12).*
- *You will be required to complete a test to measure your alertness (PVT).*
- *You will be required to complete 4 blocks of word generation.*
    - *You will need to complete a practise test of the task. All participants must achieve a reasonable level of accuracy (levels of accuracy have been informed by a pilot study, ERGO number:19343) to be included in the study.*

- *Given that this study is about fatigue, long breaks cannot be given, but you can take a 2-minute break at any time between the word generation trials.*

Once you have completed the experiment you will receive a monetary compensation totalling £81 or 162 Research Participation Credits (or a mixture) for taking part in the complete study, at a rate of £6/hour or 3 credits per 15 minutes for the tasks you take part in (as detailed below).

Example Debrief Sheet

UNIVERSITY OF Southampton

ERGO study ID Number: 31722

Total Sleep Deprivation and Alertness 3 (v4) Debriefing Statement

The aim of this research was to better understand the effects of fatigue on task switching performance. Previous research has found that switching tasks can cause a slowing in task performance, as well as an increase in errors. This study used a computer programme to test whether fatigue affects people's ability to successfully switch tasks and whether how people allocate their time between the easier and harder tasks differs when individuals are fatigued. Your data will help our understanding of effects of tiredness and will be used for my PhD thesis, as well as the TK foundation-funded MARTHA project and Leverhulme funded "Understanding Maritime Futures" project to help increase safety in mariners.

The results of this study will not include your name or any other identifying characteristics. The research did not use deception.

If you would like a summary of the research findings, once complete, please send your name and email address to Gemma Hanson (g.hanson@soton.ac.uk).

Please remember that you should not partake in any important events that might suffer from reduced cognitive capability, such as assignments, exams, interviews, etc., today or tomorrow. Nor should you drive or operate heavy machinery today or tomorrow, or indeed until you get a good night's sleep.

If you have any questions please contact Gemma Hanson (g.hanson@soton.ac.uk).

Thank you very much for your participation in this research.

If you have questions about your rights as a participant in this research, or if you feel that you have been placed at risk, you may contact the Chair of the Ethics Committee, Psychology, University of Southampton, Southampton, SO17 1BJ. Phone: +44 (0)23 8059 3856, email fshs-rso@soton.ac.uk

References:

Banks, S., & Dinges, D. F. (2007). Behavioral and physiological consequences of sleep restriction. *J Clin Sleep Med*, *3*(5), 519-528.

Payne, S. J., Duggan, G. B., & Neth, H. (2007). Discretionary task interleaving: heuristics for time allocation in cognitive foraging. *Journal of Experimental Psychology: General*, *136*(3), 370.

Appendix 2 – Questionnaires

Karolinska Sleepiness Scale (KSS)

Participant Number ________________

SUBJECTIVE SLEEPINESS

Please, indicate your sleepiness during the 5 minutes before this rating by circling the appropriate description

1=extremely alert
2=very alert
3=alert
4=rather alert
5=neither alert nor sleepy
6=some signs of sleepiness
7=sleepy, but no effort to keep awake
8=sleepy, some effort to keep awake
9=very sleepy, great effort to keep awake, fighting sleep

Sleep Pattern Questionnaire

UNIVERSITY OF Southampton

ERGO Number: 25468

PARTICIPANT NUMBER: ________

Sleep Pattern Questionnaire (v5)

1. How many total hours do you sleep a night, on average?

   0-4 hours   4-6 hours   6-8 hours   8-10 hours   10+ hours

2. Do you usually sleep in one solid sleep-period?

   Yes   No, I typically wake up ____ times during the night.

3. How consistently do you sleep this many total hours?

   ____ My total hours of sleep varies a lot

   ____ This is typical, but my total sleep varies a few times a week.

   ____ I almost always sleep this many hours a night

4. Do you often take naps during the day?   Yes   No

   a. If yes, how many and for how long?______________________________

5. How frequently is your sleep good quality?

   Never   Sometimes   Frequently   Always

Example of sleep diary for Experiment 1

Experiment: Task Switching and Alertness,
March 2016 to November 2016.

ERGO Number 19968

Participant number ___________________

Day	Date	
1		Time went to sleep =
2		Time woke up =
2		Time went to sleep =
3		Time woke up =
3		Time went to sleep =
4		Time woke up =
4		Time went to sleep =
5		Time woke up =
5		Time went to sleep =
6		Time woke up =

Example of sleep diary for Experiment 2, 3 and 4

Experiment: Task Switching and Alertness,
January 2018 to June 2018

ERGO Number 31722
Participant number ___________________

Day	Date	
1		Time went to sleep =
2		Time woke up =

Appendix 3 – Words Generated in the Normative Study

Participant No.	LEOXBWH	CYAHLIT	SIPERLM	DJMKILL	PBVWONV	TORRLPB	OAEWXPF	EMTGPEA
1	Box Whole Hole Bowl Owl Howl Web Hex Lobe Leo	Hat Chat Hail Tail Halt Yacht Hay Latch Thai Latch Lay Lit Hit	Lime Mile Sip Prime Primes Miles Rip Rips Sperm Perm Perms Spire Ripe Rip Smile Smiler Simpl e Sip	Kill Lid Mid Milk Kid Mild Mill Dill	Won Bow Own	Rot Pot Lot Bot Orb Lob Lop Rot Rob Port Tor Pot	Axe Wax Fax Pew Few Axe Paw Pax	Gap Pat Pet Met Get Pea Meet Meat Team Tame Mat Page Gape Gate Mate Peat Game Tame
2	Box Hole Whole Hex Web Bow We Ox He Be	Hit Lit Lay Halt Hay Italy Chat It At Hat Cat Latch	Sperm Miser Rise Ripe Rips Rip Lip Lips Me Is Sip Per Sim Prime Primes ,	Kill Dill Ill Jim Dim Mill Lid Kid Milk Jill Mid Mild	Won On Now Bow No	Top Port Lot Rot Or Bolt Blot Rob Plot Pot	Wax Axe Fox Ox Fax Ape Ex Paw We Foe Few Pew Awe,	Pea Gem Tea Team Gape Game Gate Tape Mate Meet Tag Ape Peg Page Meat Tame Gap At Map Mat Tame Tap,
3	Leo Who	Hilt Halt	Perm Sip	Kill Milk	Won Vow	Pop Or	Pop Wax	Team Pea

	How Blow Howl Box Hex Web	Cat Tilt Chat Hat Lit	Slim Lips Sperm Slip Peril	Dill Jill Ill	Wow Now	Bob Top	Wow Awe Fox Weep	Tea Meet Meat Gape Gate
4	Ox Whole Hole Bowl Howl Ex Box Leo Who We Bow	Halt Lit Chat Yacht Hat Cat Hay Lay Clay Hail Tail It Tic At Hi	Sip Rip Rips Ripe Me Peril Mile Miles Pie Pies Perm Perms	Kill Mill Jill Dill Dim Jim Kim Milk Mid	Won On Vow Now Bow	Plot Blot Rot Rob Top Or	Awe Pew Few Axe Wax Fax Fox Pox Ex Owe	Pea Pet At Get Peg Met Meet Meat Game Mate Team Tea Apt Teem Gate Gap Gape
5	Box Hole Owl Bowl Lobe Web Whole Below Elbow Ox Hex Blow Low Who We Be He How Bow Low Leo Bowel	Cat Hat Lit Hail Chat Halt Hay Lay Yacht Hilt At It	Sip Lip Rip Rep Miser Pile Prise Mile Miles Smile Rise Rims Slim Spire Ripe Pier Piers Lips Rips Lisp Lime Semi Mire	Kill Mill Dill Jill Ill Milk Kid Mid Lid Mild	Won Own Vow Bow Now Pow On No	Pot Rot Lot Port To Blot Plot Or	Wax Fax Axe Foe Fox Pox Ox Woe Paw Few Of Awe We Ape	Pee Pea Get Met Pet Ape Tape Mate Ate Eat Meet Meat Gate Game Gem Peat Tea Team Peg Gape Map Gap Tap Me Ma Pa

								Tag Age Page Meg
6	Box Hole Whole Leo Below Web Hex	Halt Lit Hilt Clay	Slim Pile Piles Pliers Spire Prime Primes Rip Rips Ripe Slime	Mill Dill Kill Lid Jill Kid Mid Ill I'd I'm	Won Bon Bop Now Pow Vow	Pot Rot Lot Port Plot Pro	Paw Of Few Foe Poe Pew Axe Fax Fox Wax	Met Get Pet Peat Team Peg Meet Meat Tag Pea
7	Ox Box Whole Hole Web Hex Owl Bowl Bowel Hob Ex Low How Who Lobe	Lit Lay Hit Cat Chat Hail Hilt Tail Halt Chat Hay Hi Latch Hat Thy	Miles Sip Pier Piers Mile Lip Lips Slip Ripe Lie Lies Spire Mire Slim Lisp Piles Pile Sim Rim Lime Limes Rile Rip Pie Pies Me Is	Kill Mill Jill Dill Lid Jim Dim Mid Kid	Won Vow Pow Now Bow	Port Pot Top Lot Rot	Wax Ox Fax Few Axe Ape Fox Paw	Get Met Pet Peat Pat Map Gap Gape Tame Team Meet Game Age Page Peg Tape Mat Mate Tap Pat Gem
8	Hob Web Hex Box Bowl Howl	Hit Lit Hat Lay Hay Chat It	Sperm Rim Ripe Sip Rip Rips Perm	Kill Dill Mill Milk Lid Mid Kid	Won On Now Bow Vow Own No	Lot Bot Pot Rot Bolt Port Or	We Pox Fox Wax Fax Axe Woe	Pea Pet Get Pat Mat Met Meat

	Hole Whole Low How Bow Hoe Woe Owl Lobe Ox We He Be	Tail Hail Latch Yacht Thai Cat Hi	Perms Pie Pies Pier Piers Prim Prism Lip Lips Sir Sire Slime Slim Lime Limes Prime Primes Mile Miles Pile Piles Rile Is Isle	Dim Ill	Nob	Top Rob To	Foe Ape Awe Owe Paw Few Pew	Meet Peat Gape Gap Tap Map Tape Team Peg Tag Game Tame Eat Tea Ate Mate Gate Pate
9	Box Leo Hex Owl Howl Below Ox Blow Web	Lit Hat Cat Hay Tail Thai Halt	Sip Perm Sperm Mire Pier Lip Rip Slip Sir Miser Rise	Kill Mill Dill Jill Lid Kid Kim Ill Mid Mild	Won No Now Nob	Lot Pot Rot Top	Fox Pew Few Wax Fax Axe	
10	Leo Box Hob Ox Bowl Hole Whole Bow How Hoe Who	Lit Hit Hail Yacht Cat Hay Lay Tail Latch Halt	Sip Rise Lip Pile Piles Ripe Lime Mile Me Sim lips slip slim	Kill Mill Milk Mild Lid Jill Dill Mid Dim Jim kim	Won Now On Bow Vow Nob	Rot Rob Plot Top Pot Lot Bolt	Wax Fox Fax Axe Woe Foe Owe	Tea Eat Peg Get Meat Ate Pet Gate Game Ape Pea Gem Gap

	Owl Web		sir sperm pier perm					Gape Team Teem Meet Met Bate Bat Mat Pat Mate Tame
11	Box Web Hoe Leo Hob	Hay Clay Lit Lay Hail Tia Cilt Hat	Sperm Spire Mire Rem Slip Ripe Pie Pies Perm Lie Slim Sip Pier Piers	Kill Mill Lid Dill Jill Dim Mid	Won On No Pow Wop Nob Con Von Now Vov Bop Bow Bon	Tor Rot Pot Top Lop Bop Port Lot Bot Torp Bort	Pow Pew Wax Pea Pox Fox Weap Pax Wex Ape	Pea Peat Meet Meat Team Eat Ate Me Met Peg Tea Pet Gem Ape Get Peet Gate Gape Tame Map Mat
12	Leo Bow Hoe Web Elbow Box How	Yaht Clit Chil Hay Lay Clay Tail Hail	Sip Sperm Simer spire Peril Rim Rise Lie Lies Limp Rip	Kill Milk Mild Dim DJ Jill Mill Jim Kim I'll Ill	Won Pow Bow Now	Trop Top Bot Rob Lot Rot	Wax Pea Fox Oxe Few Paw Of Pew	Pea Pet Tea Meet Met Meg Peg Temp Peat Pete Mag Gap Pat Get Gem Tag Tap

artici pant No.	LNOIE T	ESIFL CE	BYTI APJ	IRCDE OE	HRTUQ SF	STAU NRO	GAR KTIX	MTSHO EL
1	Toil Atone Tone Loan Lane Tea Teal Nail Oat Note Tan Lone Line Tail Tale Eat Neat Lean Oil	Lice See Feel Feels Life	Pat Put Bat Bit Tip Pity	Cried Creed Doe Ice Iced Rice Code Deer Dire Reed Core Ride Ode Rode Code Cord	Shut Rust Rush Rut Hut Turf Hurt Shut	Rust Run Ran Rant Runt Star Roast Oast Our Tour Sour Nut Nuts Rats Rat Saturn Out	Tar Kart Tag Rat It Kit	Shoe
2	Tone Toilet Late Tile Line Lane Let Tonal Toe Lot Ant Tan Lone lent Nail Tole Toil Not Tin Note Oil Eat Ate	Slice Flee Files File See Fee Lice Self Is If Life feel fees	Tip Tap Bat Pat Apt Pity Tab It At Bap	Doe Cod Rod Reed Ride Cried Creed Ore Dire Code Rice Dice Ode Deer Core Rode Do Ere	Hurt Surf Rust Hurts Thus Shut Fur Furs	Rants Runt Star Nuts Nut Ant Ants Rant Urn Urns Stun Sat Ran Turn Turns Run Runs Aunt Tar Roast Rust	Rat Kit Ark Rag It At Gait Tax Art Irk	Shoe Stole Mole Moles She Hole Holes Stem Melt Melts Most Host Lost Home Homes Toe Toes Lose Shot Hot Tole

	Teal							
3	Late Lot Lit An It To Tone Toilet Let Tile Line Lane Tonal Toe Ant Lone Lent Loan Nail Tole Toil Not Note Tin Tan Teal Eat Ate Oil	Face Lace Lice Mice Mace Slice Faces File Feel Feels Files Fee Flies Self Is If Fees Life Isle Flee Flees	It At Bat Pat Pit Pity Bit Tip Tap Apt Tab	Deer Creed Reed Rid Dire Doe Do Cod Rod Ride Ore Cried Code Rice Dice Ode Core Rode	Hurt Surf Rust Hurts Thus Shut Fur Furs Rut Hut Huts Turf Turfs	Saturn Ran Run Tan Turn Torn Turn Runs Ton Stun At To So Rants Rant Runt Nut Nuts Ant Ants Urn Urns Aunt Tar Sat Roast Rust Rots	Grit Rat Kit Ark Rag It At Gait Tax Art Rig Irk	Shoe Stole Mole Moles She Hole Holes Stem Melt Melts Most Host Lost Home Homes Toe Toes Lose Shot Hot Tole
4	Tail Tale Lane Line Tile Toil Loan Tone Ton Tan Not Net	Lice Ice Self Elf Life File Selfie Flies Files See Flee Slice	By Pat Pit Bat Bit Pay Bay Pity Tip Tap	Creed Ice Rice Dice Doe Core Ore Dire Rode Rod Cod Code	Hut Shut Rust Rush Fur Rut Turf Surf Us Hurt Hurst	Rant Tan Ran Tans Urn Turn Aunt Aunts No On At Rat	Rag Rat Ark Tag Tar It At Kit Art Grit	Shoe Toe Toes Mole Moles Shot Those Them The Let Lot Slot

	Let Lot Ant Note Teal Late Ate Nail Ale Oil Line In On An At It No Tin Lint			Reed Deer Ride Ide Ode Cried Red Die Erode		Sat Nut Rut Stun Not Rot Our Tour Sour Turn Runt Star Tar Rats Ton Tons Snot Tor Tors Ant Ants Or Snout Stan Roast Torn		Hotel Hotels Motel Motels Mesh Lose Lost Host Most Home Lest Stole Hole Sole She He
5	Lane Tale Nail Tone Lint Tonal Ale Tile Not Note Ton No On At It	Slice Lice See Feel Feels Flee	Bit Pit Pat Bait Bat	Rice Doe Dire Ride Rode Cried Creed Deer Dice	Shut Rut Ruts Rush Rust Hurt Hurts	Tan Tans Star Rots Rat Rats Rot No On An Run Runs Rants Rant Runt	Ark Tar Rat Rag Tag Grit	Lot Lots Shoe Shot Mesh Slot Melt Melts Stem

	Line					Runts Stun Stuns		
6	Lane One Ten Tone Tonal Tin Tile Lean On No At To Tan Not Note Late Latin Lent Toil Noel Alone Lone Toe Tie Eat Teal	Lice See Lies Lie File Files Flies	Tip Pat By Bit Bay Pay Bat Pit	Doe Deer Do Rid Rode Ride Reed Creed Cried Rice Cod Code Die Dice Core	Hurt Hurts Rust Rush Shut Fur	Run Runs Stun Ton Tons Rust Rat Rats Ran Rot Rots On No Not Roast Runt Runts Rant Rants Star	Rat Tag Ark Kit Tax Kart Rag	Shoe Shot Hotel Hotels The Host Most Mole Me Lose Lost Toes Toe Let Lets Melt Melts Mesh Moles Home Homes Lot Lots Let Lets
7	Lane Line Tin Tie Lie Nail Net Ten Tan Lone One On It	Lice Ice Is Life File Feel Eel Flee Elf	By It Tip Pit Pat Tap Pay At Bay Bat Tan	Ice Iced Dice Rice Ride Red Deer Reed Decor Deed Code	Hut Hurt Turf Rut Surf	Stun Run Nut Tan Torn Sat To Ton Not Rot Star Rat	Kit Tar Rat Rag Ark Tag It Kart Art	Shoe Hoe Toe To Hotel Hot She He Met Shot Hose Motel

	Lot Late Ate Tea Eat			Ode Dire Rod Creed		Turn Tar Tour Nuts		Let Lot Toes Set Lots Lets Set Hole Holes Moles Mole
8	Tea Lane To Toe Nile Note Tan Tin Line Let Tale Ale No It Ten Net Tie Ton Not Eat On One Note Tone Lone Toil	Lice Life Slice File Self Elf Feel Lie	By Tap Bay Bait Pit Tip Pay Pat	Ride Doe Rice Deer Dire Reed Ore Red Rod Rid	Hurt Hut Surf Rut Fur Turf	Stun Nut Run Ran Rot Rat Tan Not Ton Tons Rats Star Nut Tar Turn Runt Soar	Ark Rag Kit Tar Rat Kart Tag Art	Shoe Toe Shot Lot Lots Met Let Lets Hoe Hotel Hot Hots Home Hostel Lost Most Toes Moth Moths

Appendix 4 – Sleep Diary Data

Experiment 1

P's	Condition	Day 1-2	Day 2-3	Day 3-4	Day 4-5	Day 5-6
2	SR	23.30-10.30	02.45-11.00	03.05-07.00	03.00-07.00	03.05-07.00
3	SR	23.16-08.06	01.44-10.30	03.00-7.05	05.03-07.05	03.00-07.05
4	Control	22.00-09.00	24.00-08.30	24.00-08.30	24.00-08.30	23.45-08.10
8	SR	22.30-07.00	23.00-08.45	02.45-07.00	02.45-07.00	03.00-07.00
10	Control	01.00-10.30	02.00-12.15	02.00-09.00	04.00-09.00	03.00-07.15
12	Control	02.00-10.00	24.00-09.00	24.00-08.30	03.00-10.30	23.00-08.00
13	Control	00.43-08.30	00.31-09.00	01.00-11.41	23.00-08.00	24.00-08.00
14	SR	23.49-08.55	23.28-09.05	03.00-07.00	03.00-07.00	03.05-07.00
15	Control	23.08-09.11	00.00-08.45	00.00-08.00	23.10-06.40	00.30-07.34
16	Control	02.00-08.45	03.00-09.00	02.30-10.30	00.30-08.30	00.30-06.30
17	Control	23.45-08.30	00.10-08.10	23.20-08.50	00.15-08.45	23.40-08.00
18	SR	22.00-07.30	00.00-08.30	03.00-07.00	03.00-07.00	03.00-07.00
19	SR	02.30-11.30	03.20-09.40	03.40-08.10	03.40-10.10	03.00-07.00
20	Control	02.39-09.15	02.32-08.30	23.30-06.45	03.30-08.30	00.30-02.30
21	SR	23.40-07.04	22.00-05.30	03.00-07.00	03.00-06.45	03.00-07.00
22	SR	23.30-07.30	23.45-07.30	03.00-07.00	03.00-07.00	03.00-07.00
23	SR	23.49-07.00	23.45-07.05	03.00-07.00	02.58-07.00	03.00-07.00
24	Control	01.00-08.00	03.00-10.00	02.00-09.00	02.30-08.30	23.00-8.00
25	SR	01.45-10.20	23.45-10.40	03.00-07.00	03.00-07.00	03.00-07.00
26	Control	04.30-12.06	02.30-10.50	00.15-07.45	01.30-09.40	00.50-07.50
28	Control	01.45-10.30	01.00-09.15	00.30-09.45	01.45-08.25	01.30-08.50
29	SR	22.40-04.50	22.15-05.20	03.00-06.52	03.00-07.00	03.00-07.00
30	Control	01.30-08.40	04.15-09.33	01.15-07.34	01.20-08.50	01.46-08.00
32	Control	01.40-11.10	02.30-11.10	00.00-11.30	1.20-13.00	2.30-9.00
33	SR	01.15-07.15	01.40-10.20	03.00-07.00	03.00-07.00	03.00-07.00
34	Control	04.00-11.30	02.00-10.40	02.00-08.00	2.30-9.40	2.00-8.00
35	SR	04.20-12.00	03.12-11.57	03.00-07.05	03.00-07.00	3.10-7.00
36	Control	02.45-08.53	01.29-08.00	00.20-11.20	5.30-12.50	3.40-8.40
37	SR	00.00-10.00	03.00-10.00	03.00-07.00	03.00-07.00	03.00-07.00
38	Control	02.00-10.15	00.30-10.00	3.00-11.00	02.00-08.00	03.30-09.00
39	SR	00.20-10.45	23.25-07.50	02.50-07.00	02.50-07.00	02.45-07.00
40	Control	00.15-08.30	04.15-07.20	01.10-10.30	02.15-09.30	03.20-08.30
41	SR	02.00-11.00	23.00-09.00	03.20-06.50	03.30-07.15	03.30-07.20
42	Control	22.40-07.00	23.05-08.45	23.30-08.30	22.40-08.20	22.20-07.00
45	SR	00.00-09.00	01.00-09.30	03.00-07.00	03.00-07.00	03.00-07.00
47	SR	02.00-10.30	01.00-11.30	03.00-07.00	03.00-07.00	03.00-07.00

48	Control	03.00-12.00	00.00-09.45	01.30-09.17	00.00-09.00	23.30-08.15
49	SR	00.00-11.00	02.00-09.00	02.30-07.00	02.00-07.00	02.00-07.00
50	Control	01.50-10.50	04.00-11.35	04.10-11.30	02.30-11.45	01.30-08.00
51	SR	03.00-10.30	02.00-10.30	03.00-07.00	03.00-07.00	03.00-07.00
52	SR	01.30-10.30	00.30-07.30	03.00-07.00	03.00-07.00	03.00-07.00
53	Control	00.50-07.35	01.00-08.00	01.55-09.00	01.40-06.00	02.25-09.00
54	SR	02.15-10.15	01.00-09.30	03.00-07.00	03.00-07.00	04.00-07.00
55	Control	00.30-07.15	00.25-08.40	01.45-09.50	00.50-07.20	01.00-08.45
56	SR	02.30-08.30	01.00-08.30	03.00-07.00	03.00-07.00	03.00-07.00
57	Control	23.30-07.21	23.40-08.00	23.50-08.30	23.30-07.45	22.20-07.00
58	SR	03.00-01.30	03.00-01.00	03.00-07.00	03.00-07.00	03.00-07.00
59	Control	01.30-08.30	00.50-07.00	00.12-08.00	02.10-09.00	19.30-07.00
60	SR	23.00-09.00	01.00-10.00	03.00-07.00	03.00-07.00	03.00-07.00
61	Control	01.50-09.00	02.00-08.30	02.30-09.00	01.40-09.15	02.15-06.45
62	SR	00.00-09.30	00.30-09.15	03.00-07.00	03.00-07.00	03.00-07.00
63	SR	02.00-08.00	00.00-09.00	03.00-07.00	03.00-07.00	03.00-07.00
64	Control	01.00-10.50	00.00-08.30	22.00-10.30	23.30-12.15	01.45-07.50
67	SR	05.00-13.50	02.45-10.00	03.00-07.00	03.00-07.00	03.00-07.00
68	Control	23.00-09.00	23.30-12.00	01.30-11.30	01.30-10.45	23.30-07.50
69	SR	02.00-10.50	02.00-10.00	03.00-07.00	03.00-07.00	03.00-07.00
70	Control	23.45-09.00	00.30-10.30	00.45-09.00	00.45-8.45	00.50-08.00
73	SR	03.00-09.30	02.30-08.00	03.00-07.10	02.50-07.00	02.45-07.00
74	Control	23.45-09.30	02.30-09.30	23.30-07.45	00.30-08.45	23.00-08.00
75	SR	01.30-11.00	12.20-08.30	03.05-07.00	03.00-07.00	03.00-07.00
76	Control	00.00-07.30	01.30-08.30	01.30-08.30	01.30-08.30	01.30-08.30
77	SR	06.00-11.40	02.50-13.40	03.00-07.00	03.00-07.00	03.30-07.00
78	Control	23.45-07.30	23.45-09.30	00.30-07.30	23.45-08.00	00.40-07.30
80	Control	01.00-08.30	01.00-08.30	03.00-08.45	00.00-09.00	01.00-07.15
81	Control	23.55-08.10	23.50-09.40	23.50-10.55	23.50-10.00	00.15-06.40

Experiment 3 – Control participants only

Participant	Condition	Day 1-2
1	Control	01.30-10.30
2	Control	03.00-09.30
8	Control	01.00-07.30
9	Control	00.00-11.15
10	Control	00.45-10.00
14	Control	23.00-07.00
15	Control	00.00-09.45
20	Control	00.00-07.15
21	Control	00.30-10.00
22	Control	00.50-08.00
23	Control	01.00-09.30
32	Control	03.00-10.30
33	Control	23.00-09.30
34	Control	00.30-09.00
35	Control	00.30-10.00
36	Control	04.00-12.11
37	Control	01.53-09.25
38	Control	00.45-07.45
39	Control	00.14-09.17
40	Control	02.00-12.30

Experiment 4 – Control participants only

Participant	Condition	Day 1-2
1	Control	01.30-09.45
2	Control	00.30-07.30
3	Control	01.00-10.00
4	Control	00.00-08.00
5	Control	00.00-9.00
12	Control	23.02-08.24
17	Control	01.00-10.20
18	Control	01.30-09.30
20	Control	02.30-07.30
22	Control	23.50-09.00
23	Control	00.30-09.00
28	Control	00.30-09.00
29	Control	00.30-10.00
32	Control	04.00-12.11
33	Control	01.00-09.30
35	Control	01.30-09.30
36	Control	23.00-10.00
39	Control	23.45-09.30
40	Control	00.45-11.00
42	Control	2.00-08.30
44	Control	00.30-10.45