The Effects Of A Brief Recuperative Nap On Vigilance And The Speed-Accuracy Trade-Off

By
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Abstract

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Abstract: Sleep deprivation can impair a number of cognitive faculties. Daytime napping has been proposed as way to remediate the negative consequences of sleep deprivation. Yet the evidence that short naps improve cognitive performance is limited. The goal of the current work was to examine the potential recuperative effects of a nap on alertness using a Psychomotor Vigilance Task (PVT) and perceptual decision-making in a speed-accuracy trade-off (SAT) task while recording magnetic fields from the cortex with magnetoencephalography (MEG). Two groups received 3 hours of sleep, but only one had a 20-min nap prior to testing. The nap appeared to have a small improvement on reaction time in the PVT. However, the nap had no apparent effect on performance in the SAT task, nor did it affect a perceptual index of information processing as measured by MEG. These findings suggest that a short-term nap might improve alertness but not necessarily decision-making processes.

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List Of Abbreviations And Symbols Used

ACC	Accuracy
ANOVA	Analysis of variance
EEG	Electroencephalography
EOG	Electrooculogram
FA	False alarm
fMRI	Functional Magnetic Resonance Imaging
LPFC	Lateral Pre Frontal Cortex
MEG	Magnetoencephalography
PRE-SMA	Pre-Supplementary motor area
PSG	Polysomnography
PVT	Psychomotor Vigilance Task
RT	Reaction time
SPD	Speed
SAT	Speed accuracy tradeoff
c	Criterion
d’	Sensitivity

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Introduction

Engineers on duty at the Chernobyl disaster were working more than 13 hours when the biggest recorded nuclear explosion occurred, leading many to believe that sleep deprivation could have been a contributing factor (Summary Report on the Post-accident Review Meeting on the Chernobyl Accident, 1986). Researchers such as Brooks and Lack (2006) sought ways to offset the negative neurocognitive impacts of sleep deprivation. Sleep deprivation has been linked to life threatening incidences such as motor vehicle accidents by falling asleep at the wheel or having a lower level of alertness. In terms of economic cost, it has been estimated in the United States that $50 billion is spent on work related accidents due to lack of sleep, and up to $150 billion when considering other factors such as productivity lost (Leger, 1994).

Objective measures have been used to measure the psychological impact of sleep restriction. The impact of sleep restriction on performance has become of increasing interest as several fields of work require long periods of sustained attention without sleep such as paramedicine, nursing, firefighting and military operations (Billings, 2014; Neufield, Carney, Dolezal, Boland, & Cooper, 2016). Objective measures of sleep debt include neural measures such as EEG, MEG and PSG and specific tests such as the Maintenance of Wakefulness Test (MWT) (Harma, Suvantom, Popkin, Pulli, Mulder & Hirvonen, 2002) and behavioral measures such as reaction time and impact on decision making processes (Lim & Dinges, 2008). There are also subjective measures of the impact of sleep restriction (e.g., feelings of alertness and mood; Carskadon & Dement, 1979; Mikulincer, Babkoff, Caspy & Sing, 1989).

The effect of sleep deprivation on cognition

In humans, among many other organisms such as plants and animals, circadian

(*circa* latin for "around," *diem* meaning "day") rhythms exist which are part of an internal biological process that regulates different functions such as sleep or hormone levels. Human circadian rhythms go through cycles of approximately 24 hours and originate in the nerve cells of the suprachiasmatic nuclei (SCN) in the anterior hypothalamus (Aschoff, 1960). Sleep patterns are part of the circadian rhythms, although external stimuli such as light or temperature can impact them (Klein, Moore & Reppert, 1991).

Circadian rhythms impact sleep and wake times which are also interrelated to the duration and frequency of time spent sleeping. Healthy individuals generally experience rapid eye movement (REM) sleep and four stages of non-REM (rapid eye movement) sleep and REM sleep (Hartmann, 1968). The stages of sleep can be measured in sleep clinics using polysomnography (PSG). PSG incorporates electrooculography (EOG), electromyography (EMG), and electroencephalography (EEG; Othmer, Hayden & Segelbaum, 1969). Feinberg and Floyd (1979) discussed the features that generally characterize the different stages of sleep. Stage one sleep is characterized by fast, sporadic EEG and eye movements. During stage one sleep the person is easily wakened. Alpha waves are rare and theta waves become prevalent. In stage two, EEG slows and eye movements are uncommon. Sleep spindles (bursts of brain activity) tend to occur in the second stage. In stage three, the waves become increasingly slower and larger in amplitude (i.e., delta waves). Stages three and four are considered slow-wave sleep (SWS). Stage four is comprised almost exclusively of delta waves. People in SWS may be disoriented if woken up. The last stage of sleep is REM. Paradoxically, EEG and eye movements increase in frequency and amplitude such that it looks like waking EEG. Following REM sleep, if the person is still asleep, the cycle typically goes back through stages 1-4 and then REM for approximately 90 minutes each time until the person wakes

up. Therefore, an individual will typically experience several cycles of stages of sleep throughout one night of rest.

Most people generally get 7 to 8.5 hours of sleep per night (Carskadon and Dement, 2005). Many researchers have focused on the effects of sleep restriction on several different facets. For attention (focusing on a particular stimulus for a certain amount of time), Cote, Jancsar and Hunt (2015) found that participants focused their efforts on emotional stimuli, in particular negative emotion. This could have negative implications for people who may have poor emotional regulation techniques.

Other objective measures of sleep deprivation include research conducted by Cain, Silva, Chang, Roda, and Duffy (2011) that failed to find an effect of sleep deprivation on the Stroop effect. The Stroop effect refers to the performance advantage for identifying the color of a word that is either neutral (e.g., "XXX" in red) or congruent (e.g., "RED" in red) versus identifying the color of a word that is incongruent (e.g., "RED" in blue). However, Gevers, Deliens, Hoffmann, Notebaert, and Peigneux (2015) noted an effect based on sequential effects in a Stroop task. Specifically, performance on incongruent trials was improved when the preceding trial was congruent rather than when it was incongruent following normal sleep. No such difference was observed following sleep deprivation. According to Gevers et al. (2015), this finding suggests that sleep deprivation selectively impairs top-down processes that rely on a specific network of cognitive resources (e.g., Botvinick, Matthew, Braver, Barch, Carter & Cohen, 2001). Pilcher and Huffcutt (1996) performed a metanalysis across 19 research studies to describe the effects of sleep loss. They found negative effects of sleep deprivation on cognitive function and mood. Unexpectedly, partial sleep deprivation had a greater effect on cognitive or motor performance than full sleep deprivation. Thus, it is important to

distinguish between total sleep deprivation and partial sleep restriction because while they share some similarities, they may have effects on different cognitive mechanisms. This has ramifications for understanding the potential recuperative effects of short-term napping.

Maintaining attention to stimuli over long periods (e.g., driving a car) is often required to perform tasks successfully. The psychomotor vigilance task (PVT) is a sustained-attention task that measures the amount of time it takes a subject to respond to a stimulus. The PVT is particularly sensitive to partial sleep restriction, which is why the PVT is frequently used to measure cognitive effects due to lack of sleep (Doran, Dongen & Dinges, 2001; Dorrian and Dinges, 2005; Graw, Kräuchi, Knoblauch, Wirz-Justice, & Cajochen, 2004; Griffith and Mahadevan, 2015; Jewett, Dijk, Kronauer, & Dinges, 1999). There are a number of PVT outcome measures that are sensitive to sleep restriction (Basner & Dinges, 2011). The most common outcome measures are false starts, lapses, and reaction time (RT). A false start is a premature response in anticipation of a stimulus. Lapses occur when there is no response to the stimulus within a given timeframe. RT is simply measured as the time it takes to make a response to the stimulus. Previous researchers (e.g., Doran, Dongan & Dinges, 2001) have found that PVT performance generally worsens with sleep deprivation. However, Doran et al. observed that performance on only some trials on the PVT suffered from sleep deprivation. Performance on other trials were unaffected by sleep deprivation. Accordingly, Doran et al. noted that there is a strong relationship between mean and standard deviation of RT in the PVT task. They suggested that as sleep pressure mounts (as would occur with prolonged sleep deprivation), that there is an increase in the variability of sustained attention. According to this “state instability” hypothesis, sleep deprivation leads to a

general decrement in performance which can, on occasion, be offset by compensatory (e.g., Drummond et al., 2000) and motivational (Horne & Petit, 1985) factors. Therefore, the effects of sleep deprivation may be difficult to observe and limited to a portion of the trials on some tasks.

While most of the research on sleep deprivation has focused on deficits and decreases in performance, some neuroimaging research (e.g. Drummond et al., 2000) has found an increase in activity in prefrontal regions associated with sleep deprivation. This has been taken to suggest that frontal regions may be recruited to compensate for the decreases in cognitive performance and hemodynamic activity in other parts of the brain. This *compensation hypothesis* has been challenged by other researchers due to findings in reduction of activity in those brain regions (e.g., Thomas et al., 2000). Thomas et al. used positron emission tomography (PET) to assess absolute changes in cerebral blood glucose levels associated with full sleep deprivation in a serial addition/subtraction task. Performance on this task decreased with increased sleep deprivation. Thomas et al. also observed decreases in cerebral blood glucose levels in many regions of the brain (e.g., temporal cortex [in particular, the fusiform and parahippocampal gyri], anterior cingulate, thalamus, amongst others). Notably, the prefrontal cortex also demonstrated reduced activity, suggesting that increases in this region may not be the norm. This decrease of activity in the prefrontal cortex may be associated with general decreases of attention and alertness.

Different stages of sleep serve unique, and perhaps interdependent, functions (Rauchs, Desgranges, Foret & Eustache, 2005**).** The interdependence highlights the importance of all four stages and REM during a regular night of sleep. In particular, researchers found that memory has a relationship with task performance (Genzel et al.,

2012). Memory consolidation is an important function that occurs during non-REM and REM sleep. The consolidation of memory helps with performance on a range of tasks, including memory recall tasks and researchers emphasize that procedural, perceptual representation, semantic and episodic memory benefit from different stages of sleep.

The recuperative effects of napping

There have been several methods suggested to counteract the effects of sleep restriction. Solutions to reverse the effects of sleep restriction include stimulants (caffeine and amphetamines; Penetar et al., 1993; Newhouse, Belenky, Thomas, Thorne, Sing & Fertig, 1989), short-term periods of sleep (power naps; Brooks and Lack, 2006; Hayashi, Chikazawa, & Hori, 2004; Hayashi, Fushimi, & Iizuka, 2014; Hayashi, Motoyoshi, & Hori, 2005; Tietzel and Lack, 2002), exercise (Leproult, Van Reeth, Byrne, Sturis & Van Cauter, 1997) or change of diet (Grassi et al., 2016). Here we will focus on the potential recuperative effects of napping.

There is empirical evidence that the negative effects of sleep restriction can be reversed with a short-term nap (Brooks and Lack, 2006; Hayashi, Chikazawa, & Hori, 2004; Hayashi, Fushimi, & Iizuka, 2014; Hayashi, Motoyoshi, & Hori, 2005; Tietzel and Lack, 2002). For instance, Brooks and Lack (2006) assessed cognitive performance following partial sleep deprivation. In their study participants received five hours of sleep at home with short naps ranging from 5min to 30min. The naps largely comprised of stage two sleep, with some stage 1 and some SWS with longer (20-30min) naps. None of the volunteers reached REM sleep with the short nap. Following a 20min nap, they observed performance improvements on a simple-RT and a digit-symbol substitution task at about 35min following the nap. The authors suggest that the onset of delta activity, and

the presence of stage two sleep, in the nap are critical to observing task-related benefits from a nap.

Different durations of naps have been studied by researchers to examine the potential effects on alertness and decision-making processes (Tietzel and Lack, 2002; Hoddes, Zarcone, Smythe, Phillips & Dement, 1973). Naps of approximately 10 mins have shown the greatest improvement on alertness (e.g., as measured with RT) and cognitive performance (Tietzel and Lack, 2002). Subjective measures of alertness, such as the Stanford Sleepiness Scale (SSS; Hoddes, Zarcone, Smythe, Phillips & Dement, 1973), also improve 35min or so after a brief nap, but tend to show impairments shortly (15min) after the nap (Brooks & Lack, 2006). This early impairment is likely the result of *sleep inertia* (e.g., see Tietzel & Lack, 2001), a temporary period of grogginess and confusion that generally follows lengthy naps.

In addition to different durations of naps, the actual amount of time spent sleeping during the nap has also been researched. Gillberg, Kecklund, Axelsson and Åkerstedt (1996) found, following only 4 hours of restricted sleep, that a 30min nap yielded mean sleep time of 19.8 mins. Most of this time was spent in stage one (7.1min) and stage two (9min) sleep. Gillberg et al. (1996) assessed performance on a simple vigilance task after a 7.5 hrs of sleep (baseline), after 4 hrs of sleep, and after 4 hrs of sleep with a 30min late morning nap. The nap improved the number of "hits" (i.e., responses to targets) in the vigilance task to levels that approached baseline. This finding is important given that vigilance tasks have been shown to be sensitive to partial sleep restriction (Yeo, Tandi, & Chee, 2015). Gillberg et al. (1996) also found that other measures of sleepiness (e.g., EEG and subjective reports) suggested a general improvement in the nap condition. These findings demonstrate that a short nap can bring performance back to normal levels

without compensating for all of the lost sleep.

Varying times of sleep restriction and duration of naps can impact performance in different ways. Takahashi and Heihachiro (2000) found that a 15min nap improved the latency, but not the magnitude of the P300 (an event-related potential, putatively related to alertness) to an infrequent, brief tone. They also made fewer errors on a logical reasoning task following a nap, but the response time to make a decision on this task was unaffected by the nap. The authors (e.g., see Tietzel and Lack, 2002; Gillberg et al., 1996) suggest that napping generally benefits alertness and performance on a range of tasks.

Decision-making, the speed-accuracy trade-off, and sleep

It is clear from the current review that napping seems to offset some of the performance detriments in a variety of tasks associated with sleep restriction. Yet, the outcome measures that improve with napping (or are impaired with sleep deprivation) vary across studies. This is difficult to interpret, given the well-known trading relationship between the speed and accuracy of a response (e.g., Wickelgren, 1977). However, despite the variability of methods and results, there appears to be a difference in performance of tasks post nap (within a certain time frame, sleep inertia being considered) compared to groups that did not nap. Most cognitive tasks have two key outcome measures: response time (RT) and accuracy. In a meta-analysis of sleep deprivation studies, Lim and Dinges (2010) noted, across a range of tasks, that sleep deprivation generally affected both RT and accuracy measures. However, there is

substantial variability across studies that possibly obfuscates any meaningful interpretation.

Errors become more frequent when responses are fast or decrease when the responses are slower (e.g., Lange, 1888; Woodworth, 1899). This speed-accuracy trade-off (SAT) has been demonstrated across a variety of species including honeybees, ants, rats, and humans (Chittka, Dyer, Bock, & Dornhaus, 2003; Franks, Dornhaus, Fitzsimmons, & Stevens, 2003; Rinberg, Koulakov & Gelperin, 2006). It is ubiquitous in both thought (Wickelgren, 1977) and action (Fitts, 1966). SAT tasks have been used in many studies to study the effect of strategies on decision-making (Baldwin & Shaw, 1895; Carrasco & McElree, 2001; Cattell, 1893; Dambacher, Hübner, & Schlösser 2011; Fitts, 1966; Forstmann et al., 2008; Ivanoff, Branning & Marois, 2008; Lange, 1888; Pachella, 1974; Wenzlaff, Bauer, Maess, & Heekeren, 2011; Wickelgren, 1977; Woodworth, 1899). Sequential accumulator models (Pachella, 1974; Ratcliff, Smith, Brown & McKoon, 2016) describe the mathematical relationship between evidence accumulation and processing time. These models generally hold that information begins from a starting point to a threshold with the activity between reflecting both signal and noise. The speed at which evidence advances towards the threshold is referred to as the drift rate. The SAT is typically ascribed to a change in the decision threshold (Ratcliff, 1978; Ratcliff & Rouder, 1998), although others have suggested that it is equally plausible that a shift in the starting point may account for the data equally well (Ivanoff et al., 2008; see also Link, 1975).

Ratcliff and van Dongen (2011) used a formal model of the decision process (e.g., the diffusion model) to explore the effects of sleep deprivation on RTs in the PVT. The model accounted for the change in PVT performance to a reduction in the drift rate and

the variability in the drift rate across trials. There were no effects on the decision threshold, nor were there any effects on processes that occurred prior to the diffusion process. Thus, Ratcliff and van Dongen ascribe the effect of sleep deprivation to the same mechanism that is affected by difficulty in a brightness discrimination task: the quality of evidence used to make a decision. The implication of this finding is that sleep deprivation has a very specific effect on the temporal dynamics of decision-making.

There are other approaches to studying the temporal dynamics of information-processing. SAT instructions have long been used to study the transition from fast and erroneous responding to slow and accurate responding (Wickelgren, 1977). Bogasz, Wagenmakers, Forstmann, and Nieuwhuis (2010) suggest that there are three key neural regions involved in changing the emphasis between accurate and hasty responding: the striatum (Forstmann et al., 2008; Wei, Rubin, & Wang, 2015), the pre-supplementary motor area (pre-SMA; Ivanoff et al., 2008), and the lateral prefrontal cortex (LPFC; Ivanoff et al., 2008; van Veen, Krug, & Carter, 2008). Interestingly, no study has found evidence that regions associated with sensory or perceptual processing is directly associated with the SAT. For instance, in a motion discrimination task with fMRI, Ivanoff et al. (2008) found that the motion-sensitive area MT+ selectively responded to the onset and offset of stimulus movement, but was unaffected by SAT instructions when the data was time-locked to the onset of the response. This finding is consistent with the idea that regions associated with higher-order perceptual processing are uninfluenced by speed-accuracy instructional task-sets. However, hemodynamic responses are notoriously sluggish as the temporal resolution of fMRI is slow (i.e. on the order of seconds). It is possible that higher-order perceptual processing is influenced by SAT instructions but that it is undetectable with fMRI.

Face-Selective Perceptual Processing and the M170

Several researchers have found that regions of the fusiform gyrus exhibit activity associated with face processing between 100ms and 170ms after the presentation of the face (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Bruce & Young, 1986; Liu, Harris, & Kanwisher, 2002). Liu et al. (2002) examined the M100 and M170 face-related components with a categorization (versus non face stimuli) and recognition face tasks. They found that the amplitude of the M100 was sensitive to the categorization of faces, but the M170 was not. The M100 amplitude was also greater when participants made correct choices. This could suggest that the M100 and M170 are sensitive to two different underlying perceptual processing mechanisms associated with the processing of faces.

There is limited research on the effects of sleep deprivation on facial processing. Cote, Mondloch, Sergeeva, Taylor, and Semplonious (2014) assessed whether the N170 (an electrophysiological marker of face processing) is sensitive to sleep deprivation in a task in which the goal was to categorize different emotional faces. The identification of sad faces (but not angry, fearful or happy) was reduced following sleep deprivation. The amplitude of the N170, however, was greater following sleep deprivation than it was for a rested control condition. According to Cote et al., this finding suggests sleep deprivation impacts the processing of emotional faces, perhaps by affecting the detection of particular features associated with emotional faces. It is not known whether napping improves neural markers of face processing in other tasks. The current study incorporated faces into the SAT task and used MEG as the neural measurement to observe activity in different regions of the brain as a face was presented.

The Current Study

The goal of the present research was to examine the potential recuperative effect of a brief nap on the behavioural and neural correlates of alertness and decision-making. To accomplish this goal, the current experiment was comprised of two groups. Both groups were partially sleep deprived (receiving 3 hours of sleep), but only one group was given the opportunity to have a 20-min nap in mid-afternoon (2:40PM). The PVT was administered twice prior, and once after, the nap opportunity. The SAT task was only administered once after the nap opportunity. According to *motivational theories* of sleep deprivation (Horne & Pettitt, 1985; Wilkinson, 1961), it is expected that napping will improve performance in any simple, long, and uninteresting tasks following partial sleep deprivation. Accordingly, the effect of the nap should be greater on PVT performance than the SAT task because the SAT has greater complexity and differing levels of control. As motivation is not expected to impact perception, there should not be an effect of the nap on magnetoencephalographic markers of face processing (e.g., M170). According to *vigilance theories* (e.g., Doran, Van Dongen, & Dinges, 2001), on the other hand, partial sleep restriction impairs task performance more generally and a nap should improve performance on both tasks, as both require sustained attention to complete**.** It is also anticipated that the nap will increase the magnetoencephalographic markers of face processing because alertness improves the amount of evidence used to make a decision (e.g., Ratcliff & van Dongen, 2011).

Methods

Design

Day 1

On the first day of the experiment, participants arrived at 11:00PM at the Chronolab in the Abbie J. Lane Hospital. The participant was instructed to prepare for bed just before the lights to the private bedroom were turned off at 12:00AM. This first night in the laboratory was intended to allow participants to become familiar with the surroundings of the sleep lab to ensure a better quality of sleep for the following night (Agnew, Webb & Williams, 1966).

Day 2

Lights were turned on at 7:00AM for wake up. Participants left for the entire day, were instructed not to consume any caffeine above 150 mg, alcohol, or illicit drugs, and returned to the Chronolab at 11:00PM that night. Once participants arrived at the lab on the second night, they completed the PVT at 11:10PM for practice. Following the PVT, participants stayed awake. During this time, participants were instructed to do quiet activities such as reading or watching Netflix in their room. Participants were told to prepare for bed just before the room lights were turned off at 4:00AM. Participants were woken at 7:00AM.

Day 3

After waking at 7:00AM, participants were provided with breakfast at 8:00AM by purchasing food of their choice from the hospital cafeteria. At approximately 10:00AM,

participants completed another PVT. Following the task, participants were given quiet time and then provided with lunch of their choice at 12:00PM (healthy food was encouraged). Participants had quiet time from 1:00PM-3:30PM. During that time, participants were provided with the instructions for the SAT task that they would later perform in the magnetoencephalography (MEG).

In the nap group, instructions were given at 2:00PM to prepare to nap. PSG was recorded from 2:40PM-3:00PM for those in the nap group to provide a recording of sleep stages. Volunteers performed a third and final PVT task at 3:30PM and were then escorted by the researcher to the MEG lab at the IWK Health Centre for 4:00PM. Upon arrival to the IWK, the actigraphy was removed. From 4:00PM-4:30PM, participants were prepped for the MEG. At 4:30PM, subjects performed the SAT Go/No-Go task in the MEG to obtain a neural and behavioral data. The SAT Go/No-Go task took approximately 28 minutes to complete with four runs and was followed by a brief 5-minute resting-state (eyes closed) in the MEG. Following the task in the MEG, participants were escorted home.

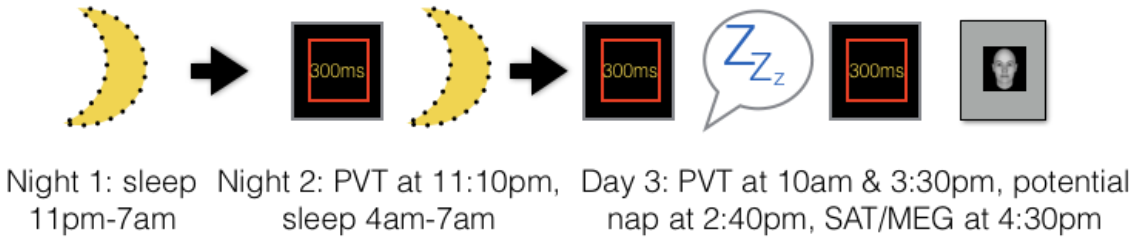

Figure 1. Study design for entire duration of study (two nights and one day). The first night participants stayed the night in the hospital and were able to have a regular night sleep to adjust to the settings from 11pm-7am. On the second night, participants performed a PVT task and only slept 4am-7am. On the third day, participants performed a PVT at 10am, had a potential nap at 2:40pm, performed another PVT task at 3:40pm and completed the SAT task in the MEG scanner at 4:30pm.

Participants

Preliminary Testing- Screening and Consent Form

The research was approved by Saint Mary's University, IWK Health Centre, and Nova Scotia Capital District Health Authority Research Ethics Boards. A consent form was provided and signed before participants began the study. All participants had to self-report any ineligibility and were encouraged to consult with a medical professional and family to verify they met the requirements to partake in the study. Volunteers were screened to ensure they were eligible to participate. During the screening process many factors were controlled (listed below) that may have impacted either their safety, performance or the integrity of the data. We *excluded* volunteers with any of the following:

- previous surgery involving metal, such as: clips, rods, screws, pins, wires;
- heart pacemaker;
- implanted electrodes, pumps or electrical devices;
- cochlear (inner ear) implants;
- intraocular lens (eye) implants (cataract lens allowed except for brain imaging studies);
- any metallic foreign body, shrapnel or bullet;
- intrauterine contraceptive device (IUD) or contraceptive diaphragm;
- dental work held in place by magnets;
- non-removable dental braces and retainers;

- metal dental work, unless it was composed predominantly of precious or semiprecious alloy or amalgam;
- Tattoos (if within six months they were excluded)
- Non-removable metal jewelry (body piercing)
- Heart and circulatory problems, seizure disorders, anxiety disorders, mental or psychiatric disorders
- Had a Body-Mass Index (BMI) greater than 30 or less than 18 (large deviations in BMI can be associated with sleep disordered breathing)
- If they were, or might have been, pregnant
- Females were excluded from participating unless (1) they were taking oral contraceptives and (2) participated 10 days after the end of menstruation (and before the start of the next menstrual period; circulating hormones might impact cognition; Genzel et al., 2012; Hatta & Nagaya, 2009)
- Nicotine, nitroglycerin and/or contraceptive patches
- Claustrophobia

The following were identified as things that may have impacted sleep patterns. Participants were excluded from participating if they had the following:

- A chronic serious illness (e.g. asthma, diabetes, hemophilia)
- A history of neurological disease or impairments (e.g., epilepsy, migraines)
- Sleep complaints
- Used street drugs during the past year
- Smoked cigarettes or other tobacco products
- A pattern of alcohol misuse (>14 drinks a week) during the past year

- Weight loss greater than 5% in the past month
- Regularly slept less than six hours or more than ten hours daily
- Took regular naps
- Had a history of shift work in the last six months
- Had taken an airplane flight in the last month crossing more than two time zones
- Took large amounts of caffeine daily. Caffeine users may have been included if their daily intake from all sources is not more than the equivalent of one cup of coffee, or three cups of tea, daily (approximately 150 mg of caffeine)

Any additional medications, which included over-the-counter drugs, that were known to have an effect on sleep-wake cycles and consumed recently or regularly prohibited participation in the study. Participants also had to be available for the entire duration of the study that took place over two nights and one full day consecutively beyond the first week of preliminary testing.

Demographics

Eighteen participants (n=18) took part in the study for pay ($125). There were eight volunteers in the nap condition. One participant withdrew mid-way through the study and the MEG data from another was of very poor quality so it was excluded from the analysis. The data from six participants remained in the analysis (3 female and 3 male) in the nap condition. Ten participants (5 female and 5 male) took part in the no nap group. Participants were 18-35 years old to control for age-related effects on sleep (Carroll et al., 2016).

Apparatus, Stimuli and Procedure

Actigraphy

One week prior to participating, potential participants wore an actigraph (Ambulatory Montoring, Ardsley, NY). The actigraph looked like a watch and was worn on the wrist of the participant. It provided a rough measurement of sleep/wake cycles via a sensor that detects motion. Sleep patterns were monitored with the actigraph to determine eligibility. Those with less than six, or more than ten, hours of sleep per night were deemed ineligible to participate in the study. See Appendix (Figures A1-A12) for actigraphic records of the sleep deprivation night and the second day of testing.

Psychomotor Vigilance Task (PVT)

The PVT task was performed on an Apple Mac Mini computer with an Apple keyboard and an ACER monitor. Testing took place in the Abbie J. Lane hospital in a room free from distractions. The task was programmed using MATLab (Natick, MA) with the Psychophysics Toolbox (Brainard, 1997). The PVT is a sustained-attention task and performance on this task is well-known to be sensitive to sleep deprivation (Basner & Dinges, 2011; Graw et al., 2004; Jewett et al., 1999).

Participants sat approximately 60cm away from the monitor. Instructions appeared on the screen informed participants to “Press G to start the task. Press the B key when the counter appears”. Once they pressed the “G” key, subjects awaited a counter that appeared against a black screen. A red box (427 x 256 pixels**)** was presented at the center of the screen. It remained on the screen while they waited for the counter target. The counter target appeared randomly between 2s to 10s. The counter appeared in yellow

(Arial font, size 64 pts) and it counted up from 0 to 30 seconds (in ms) or until the participant made a response. Participants responded to the onset of the counter as soon as possible by pressing the 'b' key on the keyboard. If a participant responded to the counter within 30 seconds (correctly), the counter stopped and the reaction time appeared on the screen for one second. If a response was made before the counter appeared, the words "false start" appeared in blue (Arial font, size 64 pts). If a response was not made within 30 seconds, the word "overrun" appeared in the same font. The key outcome measures were reaction time (RTs<30000ms), lapses (if no response within 500ms) and false starts (i.e., responses made in absence of the counter target) were recorded. There were 100 trials presented to participants within approximately 12 minutes.

Polysomnography (PSG)

Those in the nap condition were instructed at 2:00PM on the third day to prepare to nap. Preparation included changing in to clothing that they would normally sleep in and make any other preparations to sleep as they normally would. Once the participant was ready to sleep, the primary researcher and the research assistant placed electrodes on the participant. Electrolytic paste was used to secure the electrodes. The signals from the electrodes were fed into an amplifier that leads to a computer with the Embla Sandman software (version 9.3; Natus, Middleton, WI). If there was difficulty receiving optimal conductance, sigmoid gel was used to increase conductivity between the skin and electrode. AgCl electrodes were used to measure galvanic skin response (GSR), echocardiography for heart rate (ECG), electromyography (EMG), and electrooculography (EOG). The electrodes were placed on the scalp [C3, C4, CZ (ground), O1, O2] behind the ear (M1, M2), chin (EMG), above and below the eyes [E1

(LOC), E2 (ROC)], and one on each side of the face for the masseter muscle for EMG (to record jaw movement). Once the electrodes were placed in a way that provided satisfactory conductance, the light was shut off in the participant's room and the recording was started[1].

Speed Accuracy Tradeoff (SAT) Go/No-Go Task

The task was created using Presentation software (Version 0.70; Neurobehavioral Systems, Berkley, CA) on a desktop computer with a monitor that was set up outside of the shielded chamber. Images were projected through a series of mirrors onto a screen placed in front of the participant. The screen was placed approximately one meter in front of the subject, and the projector screen was 27 centimetres tall to ensure a consistency for all participants.

The avatar face images were created using FaceGen (Singular Inversions, Toronto, ON). The images were randomly-generated, grey-scaled, and bald. All other images were created using Paint (Microsoft, Redmond, WA). The task itself was approximately 28 minutes long and was run on the third day of the study at 4:30PM.

There were a series of four alternating blocks of trials within the task of the present study that instructed participants to focus on their response speed or the accuracy of their response. At the onset of a block of trials, the word "Ready" appeared in white on a black background at the centre of the screen. After the volunteer was prompted by the researcher (and a button was pressed in another room to initiate the task), the instruction for speed ("Please be as fast as possible") or accuracy ("Please be as accurate as

[1] Unfortunately the coded PSG data was not available from the technicians at the time of writing. For this reason, it cannot be determined with absolute certainty that participants in the so-called "nap condition" actually fell asleep given the opportunity to nap.

possible") was presented for 3.0s in the same font and coordinates as the "Ready" signal. Following the instruction cue, 20 trials were presented. Each instruction (speed or accuracy) was repeated twice in a run, with 4 blocks per run in total. Each participant completed 4 runs in a session.

A single trial within a block proceeded as follows. First, a fixation cross was presented for 0.5 s (a white cross, 48 pts, centre of the screen). Participants were instructed to look at the cross and try not to move their eyes. It was then replaced with the presentation of a face for 0.1 s, followed by a fixation cross that appeared for 1.9 s (long duration, 16 times per block) or 0.8 s (short duration, four times per block). Following the presentation of the face, the participant was encouraged to prepare, but not execute, a left or right key-press response with their left or right index finger. If the face was perceived as masculine, participants were instructed to prepare a left key-press response, whereas if the face was feminine, a right key-press was prepared. Following the presentation of the face and cross, a box appeared that was either completely white or checkered with black and white boxes (boxes were 400 x 400 pixels). The prepared response was to be executed when a completely white box (*go* target) appeared or withheld for a checkered box (*no-go* target). Both sorts of targets were presented for 1.5 s and were followed by the return of a fixation point (a blue cross, font 48 pts, centre of the screen) for 0.1 s. The feedback image was then provided for 0.1 s (images used for feedback were 300 x 300 pixels created in Paint). The positive feedback image was a smiling, light yellow cartoon face with black eyes and lips. The negative feedback face was similar, but frowning.) The nature of the feedback dependent on the instruction the participant received before the block of trials, and the consequent response. See Figure 1 for a depiction of trial events.

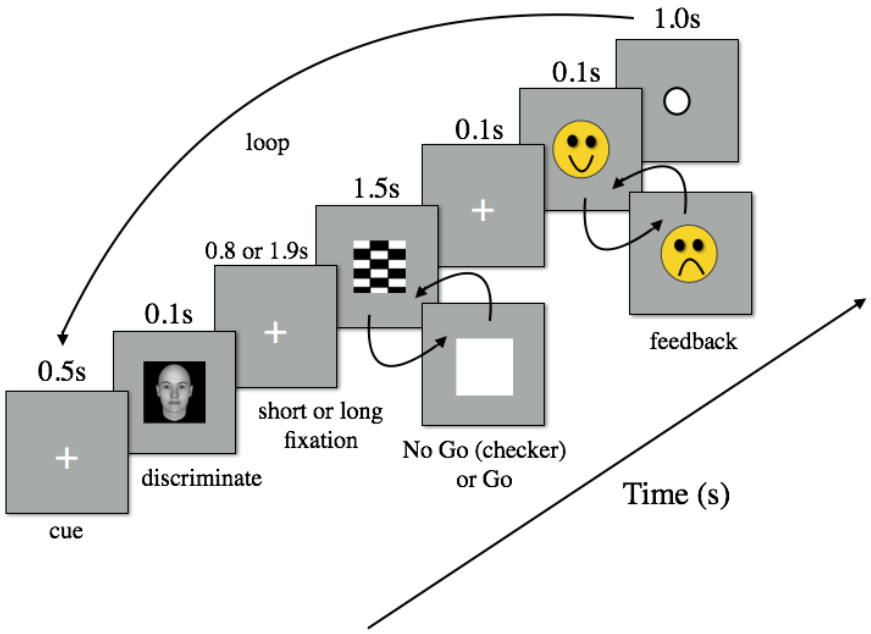

Figure 2. Trial events for speed-accuracy trade-off task performed in the MEG. Following the speed or accuracy instruction (not shown) and the fixation cross, participants had to prepare a response by discriminating between a masculine face (left button press) or a feminine face (right button press). Next, there was a long or short fixation, followed by a go stimulus (white square) in which they would execute the prepared response, or a no-go stimulus (checker) to withhold any button press. A brief fixation appeared, followed by feedback- positive (happy face) or negative (sad face) based on participants' response (see text for further details). A circle appeared indicating that trial was over.

In the accuracy condition, positive feedback was contingent only on the response choice. If the appropriately prepared response was executed to the *go* white square target, or withheld to the *no-go* checkered square target, participants were given positive feedback (happy face). However, if they did not respond to a *go* stimulus (white square) within 1.0 s, the response was still deemed incorrect. Likewise, if a response was executed to the *no-go* (i.e., the black and white checkerboard square) target, participants were given negative feedback.

In the speed condition, the participants were instructed to respond as quickly as possible and feedback was contingent on the timing of their response. At the onset of the block, participants were given an arbitrary response deadline (0.4 s). In the first three trials, they were given positive feedback if their response (to either a *go* or *no-go*) was faster than the initial deadline. After the first three trials were presented, the response deadline became a rolling average of the next three responses. The rolling average took an average of all of the response times that the participant made, and the feedback was positive if they were faster than the average of their previous responses, and negative if they were slower than the average of their previous responses. This latter feedback criterion was to encourage sustained attention to the square targets.

Feedback was followed by a central white circle for 1.0 s to communicate to the participant that the trial was over. Half of all trials included feminine faces as cues. Ten of the 16 long SOA trials were *go* white square targets and the other 6 were *no-go* checkered square targets. The remaining four trials were short SOA trials that included 2 feminine face cues, 2 masculine face cues, 2 *go* targets and 2 *no-go* targets. The inclusion of the short duration trials was intended to prevent participants from predicting the onset of the square target and was not analyzed.

A single run consisted of 4 blocks with 20 trials, and each trial lasted approximately 4 s. There were 4 runs of 4 blocks (2 speed and 2 accuracy) and 320 trials lasting approximately 28 minutes. Following the SAT task, participants conducted a 5 min resting period with eyes closed. They were instructed to relax, but not sleep, while they closed their eyes for five minutes.

Magnetoencephalography (MEG)

Magnetoencephalography (MEG; 306 channel Elekta Neuromag system, Elekta AB, Stockholm, SE) was used in the IWK Health Centre MEG lab to measure magnetic fields produced by the neurally-sourced activity while performing the SAT task. Before participants entered the MEG, they were told to remove any metal objects and an artefact check (raised into the MEG helmet for 30 seconds) was performed to ensure that anything that might interfere with data acquisition was removed.

If the artefact check was completed, and the data was ready to be collected, participants were escorted to a wooden chair and their skin was prepped with NuPrep Skin Gel (Weaver and Company, Aurora, CO) and alcohol wipes for electrode placement. The electrodes (EasyCap GmbH, Herrsching, Germany) were placed on the face (above and below eyes, vertical electro-oculogram, VEOG), collarbone (ground), on the inside of each bicep (electrocardiogram; ECG) and hands (one on the knuckle of each index finger and another approximately two centimeters apart) to record the electromyogram (EMG). Electrodes were held in place using transparent film (3M Tagaderm Transparent Film, London, Ont).

In addition to the electrodes, two head position indicator (HPI) coils were placed on the forehead (on either side) and two were placed behind each of their ears. Three

anatomical positions (nasion and right/left pre-auricular points) and a 200-point head shape was recorded with a Polhemus digitization device (Polhemus Incorporated, Vermont, USA).

The HPI coils were active during the entire task and resting state in the MEG to monitor head movement. After volunteers were prepped and seated in the MEG scanner, the light was dimmed and MEG, EMG (left and right hand), ECG, EOG and behavioral data was collected during the scan. Total prep time and time spent in scanner was approximately 1 hr.

Data Analyses

PVT Data

The data collected from the second night was considered practice data and was not included in any further analysis. The following dependent variables were used in the PVT analysis: mean RT, lapses and false starts. PVT data was collected at 10:00AM on the third day (block 1) and at 3:30PM on day 3 (block 2).

SAT Go/No-Go Data

The following dependent variables were measured: proportion of correct response directions (i.e., when a participant correctly made a left or right button press and correct RTs to the *go* targets. The signal detection measures *c* and *d′* (MacMillan & Creelman, 2005) were also included in the analysis. The criterion (*c*) is a measure of response bias (i.e., positive scores indicate a relative to respond, while negative scores reflect response impulsiveness), while sensitivity (*d′*) is a measure of the participant's ability to discriminate Go from No-Go targets.

MEG Data

To preprocess the neural data, visual inspection was performed to remove any data that could not be used. Data was downsampled by a factor of four (to 250Hz). The MEG data was filtered with a lowpass of 70Hz and a highpass of 4Hz. Head position estimations were completed to control for excessive head movement (no more than 3mm in rotation and 5mm within translation). If the participant moved their head beyond the given limit for the majority of the run, the data was discarded. However, if there were only small segments of head movement, further coding was used to remove those bad time segments and the remaining data was used. Furthermore, eye blinks detected by the EOG were removed due to noise in the data. To remove the eye blinks, an absolute minimum and maximum value of 150 mV was selected from the time of the presentation of the face to the go/no-go stimulus. If the data exceeded those values, the epoch was removed from further analysis. Table A2 presents the number of trials that were removed due to noisy data.

Post-processed files were saved as .fif and a MATLab script was created to further organize and view the data and some FieldTrip functions were used. In MATLab, the script isolated the sensors and data epochs for the analysis of the components associated with perceptual processing of the face (i.e., the M100, M170, M210 and M270). The sensors of interest were identified using a face localizer from a previously published study (Henson, Mouchlianitis, & Friston, 2009).Only magnetometers were analyzed in the following analysis.

We focused on the neural signals responsible for the perceptual processing of the face stimuli. Peak activity was identified for each trial within the following windows: 88ms-124ms (M100), 136ms-172ms (M170), 180ms-240ms (M210) and 244ms-296ms

(M270). The windows were selected because they were largely separable across individual time courses and guided by mean data. These sensor amplitudes were analysed using a mixed measures ANOVA with condition (ACC v. SPD) as a within-subject factor and group (Nap v. No Nap) as the between-subject factor.

Results

PVT

A 2 x 2 Mixed Measures ANOVA was run with group (nap versus no nap) and block (1 versus 2) as factors. Recall that block 1 was at 10:00AM on day 3 and block 2 was following the potential nap at 3:30PM. The dependent variables were false starts (pressed a button when they should not have), lapses (took longer than 500ms to respond or did not respond at all), and mean RT (average reaction time). The descriptive are provided in Table 1.

The results of the 2 x 2 mixed measures ANOVAs revealed an interaction between group and block [$F(1,15) = 5.023$, $p=0.041$, $\eta^2 = 0.203$] for mean RT**.** Mean RTs in the nap group improved by 20.2ms between blocks 1 and 2 (341.7ms versus 321.5ms, respectively) whereas the performance of the no nap group was virtually unchanged (346.1ms versus 346.5ms, respectively).

SAT Go/No-Go Task

Mean RTs, d', c, hits (%) and false alarms (%) were included in the analysis (Table 2).

Table 1

Contrast of PVT at Block 1-2 for False starts, Lapses and Mean RT for Nap versus No Nap Groups

	Block 1		Block 2		
Measure	*M*	*SD*	*M*	*SD*	*Cohen's d*
False starts (%)					
Nap	2.86	3.50	3.29	5.31	-0.112
No Nap	3.30	1.95	3.20	2.60	0.04
Lapses (%)					
Nap	6.43	8.66	6.14	11.92	0.046
No Nap	5.40	4.90	7.0	4.83	-0.516
Mean RT (ms)					
Nap	341.7	54.58	321.5	46.98	0.819
No Nap	346.1	32.66	346.5	34.65	-0.028

Note. Sample size for behavioral data (which varies from MEG data) Nap is n=7 and No Nap is n=10. Block 1 is 10AM on day 3 and Block 2 is 2:40PM on day 3. *All Block 1 versus Block 2 contrasts were non-significant, except for the Mean RT for the Nap group (p = .047).

Table 2

Speed Accuracy Tradeoff (SAT) Task Contrast for Nap Versus No Nap

	Speed			Accuracy		
Measure	*M*	*SD*	*Cohen's d*	*M*	*SD*	*Cohen's d*
p(response direction)						
Nap	0.902	0.032		0.900	0.045	
No Nap	0.855	0.128		0.865	0.111	
Both			-0.458			0.394
RT Go No-Go Correct (ms)						
Nap	414.31	74.15		475.78	97.72	
No Nap	427.22	119.19		567.99	155.18	
Both			0.125			0.682
d'						
Nap	2.82	0.740		3.297	0.689	
No Nap	2.74	1.15		3.44	0.953	
Both			-0.075			0.173
c						
Nap	-0.042	0.342		0.101	0.344	
No Nap	-0.051	0.350		0.141	0.310	
Both			-0.025			0.124
RT All (ms)						
Nap	411.32	72.05		475.03	102.01	
No Nap	422.22	114.24		565.72	154.75	
Both			0.109			0.67
Proportion of Hits						
Nap	0.899	0.080		0.907	0.090	
No Nap	0.923	0.086		0.920	0.064	
Both			0.278			0.164
Proportion of False Alarms						
Nap	0.098	0.062		0.056	0.052	
No Nap	0.087	0.048		0.037	0.029	
Both			-0.198			-0.458
RT All Correct (ms)						
Nap	408.40	71.71		471.68	100.36	
No Nap	424.16	116.80		568.39	154.50	
Both			0.156			0.714

Note. Sample size for Nap is *n*=7, and No Nap is *n*=10. Two different instructions in task: focus on Speed or Accuracy. For further details on task, see Figure 2.

The behavioral dependent variables were analyzed with a 2 (group: nap v. no nap) x 2 (instruction: speed v. accuracy) mixed measures ANOVA (Table 2). In the *d′* analysis, instruction (speed or accuracy) had the only significant effect [$F(1,15) = 6.61$, $MSe = 0.43$, $p<0.05$, $\eta^2 = 0.303$]. The *d′* score was greater following an accuracy instruction ($M = 3.38$, $SD = 0.78$) than it was following the speed instruction ($M = 2.77$, $SD = 0.98$). The effect of instruction was also the only significant effect in the analysis of *c* [$F(1,15) = 11.14$, $MSe = 0.02$, $p<0.005$, $\eta^2 = 0.42$]. The decision criterion was more conservative in the accuracy condition (M=0.12, SD=0.31) than it was in the speed condition ($M = -0.05$, $SD = 0.34$). In the analysis of RTs (overall for go/no-go and correct responses)**,** the only effect that was statistically significant was instruction, [$F(1,15) = 15.33$, $MSe = 5494$, $p<0.005$, $\eta^2 = 0.47$]. Correct go responses following the speed instruction (M=442ms, SD=101ms) were faster than those following the accuracy instruction (M= 530ms, SD = 139ms). There were no significant effects of group, nor any interaction between group and instruction, on any of the dependent variables.

Face Processing: MEG

For the perceptual component of the neural data associated with face processing, peak activity around 100ms, 170ms, 210ms and 270ms for speed and accuracy were observed (Figures 2 and 3) at right temporal sensor sites previously identified by other researchers with a similar apparatus (Henson et al., 2009).

Mixed measures ANOVAs, again with group (nap v. no nap) as a between-subject factor and instruction (speed v. accuracy) as a within-subject factor, were conducted for each individual component peak. The only significant effect was for instruction was within the analysis of the M270 [$F(1,14)=15.75$, $MSe = 797.6$, $p=0.001$, $\eta^2=0.524$]. The M270 was greater following accuracy instructions than it was for speed instructions (see Figure 3). No other effects were significant.

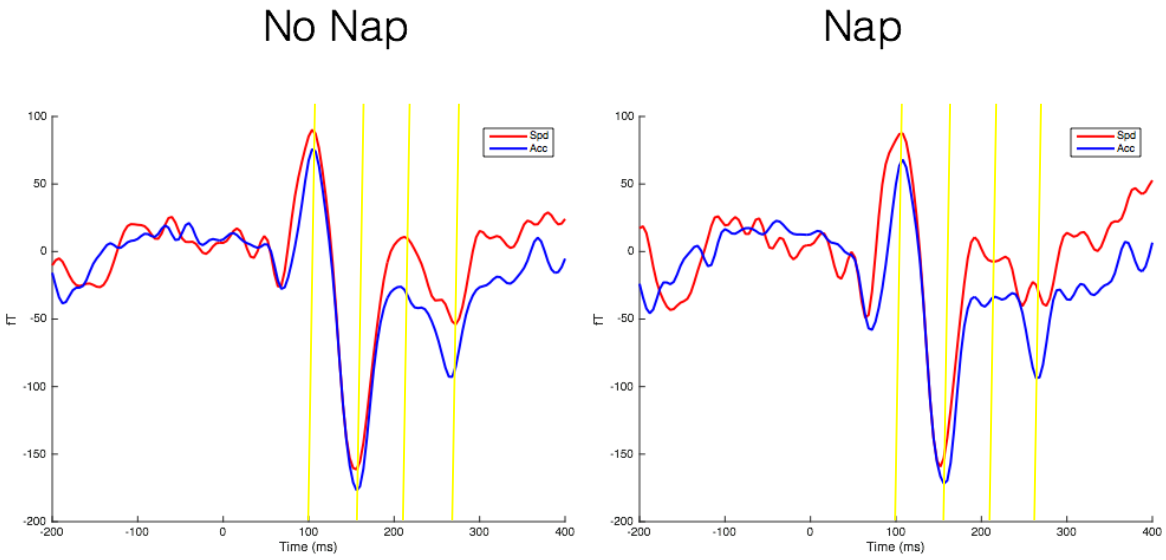

Figure 3: Activity in right temporal region sensors of interest (sensors 97 and 100) for speed (Spd) versus accuracy (Acc) instruction across both experiments. Time 0 is the presentation of the face stimulus. The yellow lines highlight peaks of amplitude.

General Discussion

The objective of this investigation was to examine the effect of a recuperative nap on alertness and decision-making. Alertness was assessed using the PVT and decision-making was assessed in a SAT task. For the PVT, there was a small RT difference (~20 ms) before and after the nap, suggesting that a short-term nap improves alertness. In the SAT task, RTs were faster (and errors were more frequent) under speed than accuracy instructions. There was no effect of napping on the performance of the SAT. The M270 component was also larger under accuracy instructions than it was under speed instructions. Again, none of the MEG sensors analyzed that surrounded the M170 were significantly affected by napping.

Many other researchers have found that the PVT is sensitive to sleep restriction (Basner & Dinges, 2011; Jewett, Dijk, Kronauer, & Dinges, 1999; Doran, Dongen & Dinges, 2001; Dorrian and Dinges, 2005; Graw, Kräuchi, Knoblauch, Wirz-Justice, & Cajochen, 2004; Griffith and Mahadevan, 2015). Napping in this study improved mean RT in the PVT, but not lapses or false starts. These findings are different from those of Basner and Dinges (2011) who found that lapses and false starts, along with Graw et al. (2004) that found lapses and slowest RTs (90^{th} percentile) were most sensitive to the PVT following sleep restriction. However, Doran, Dongen and Dinges (2001) did find that a nap increased RT and standard deviation compared to total sleep deprivation. These findings suggest that (1) sleep deprivation impairs vigilance differently than a short nap improves it, or (2) the absence of an effect of napping on lapses (and false starts) is the result of poor statistical power.

The difference in mean reaction time for the nap group versus no nap group was 20ms faster for the timeframe before and after the nap for the PVT. This may seem trivial,

but the consequences of even the tiniest delay can be profound. For example, if a driver travelling at 100km/hr tries to stop, then a 20ms delay translates approximately into a 55cm distance before the brakes are even applied. Therefore, even short naps are beneficial and should be encouraged when alertness is considered to be an important prerequisite of the job.

Many other researchers have found that people easily trade response speed for accuracy in a range of tasks (Lange, 1888; Cattell, 1893; Baldwin & Shaw, 1895; Woodworth, 1899; Fitts, 1966; Pachella, 1974; Wickelgren, 1977; Carrasco & McElree, 2001; Ivanoff, Branning & Marois, 2008; Forstmann et al., 2008; Wenzlaff et al., 2011; Dambacher et al., 2011). Although speed-accuracy instructions did impact performance, as expected, napping did not significantly modulate this difference. Some researchers (e.g., Horne & Pettitt, 1985; Wilkinson, 1961) claim that the effects of sleep deprivation are more pronounced when a task is not overly complex. In the current study, the lack of an effect of napping on performance on the SAT task may be the result of inexperience (i.e., it was unpractised before testing), an arousing environmental context (i.e., the MEG lab), or a task with multiple stimuli and varying instructions (i.e., speed versus accuracy task-settings). The PVT was practiced the night before the study, it was performed in a familiar environment (i.e., the chronobiology lab where the participant slept and rested), and task had one imperative stimulus (the counter) with a simply set of instructions. Accordingly, participants may have been less motivated to perform the PVT as optimally as the SAT task. Therefore, there is reason to believe that the recuperative effects of a nap depend on motivational factors and the complexity of the task.

In the SAT task, there was activity in the right temporal area after the presentation of the face with noticeable peaks around 100ms, 170ms, 210ms and 270ms. Those peaks

of activity were expected, as they are thought to be related to face-selective perceptual processing (Bruce & Young, 1986; Bentin, Allison, Puce, Perez, & McCarthy, 1996; Henson et al., 2009; Liu et al., 2002). Consistent with motivational accounts of sleep deprivation, there was no evidence that any peak was affected by napping. However, it is not clear whether the effects of napping on information quality would be evident in a less-arousing task, like the PVT (e.g., Ratcliff & van Dongen, 2011). It is important that future research explore the boundary conditions of a nap's effect on information quality.

The only neural difference observed between speed and accuracy instruction occurred with the M270. In most tasks, it would be difficult to interpret activity within this time range because of the temporal proximity to responding. In the current study, responses occurred 2s after the presentation of the face, so the activity around 270ms is unlikely to be contaminated by response processes. Given that the effect of speed-accuracy instruction occurred after the M170, it may owe to sustained attention to the face when accuracy is stressed. Other researchers have observed attentional effects in similar locations at a similar time (e.g., Martínez, Di Russo, Anllo-Vento, & Hillyard, 2001). However, given that other studies have not studied the M270 component closely, these predictions are speculative and future research is necessary.

Limitations

It is unclear how much sleep each person actually got during the nap or what sleep stages they experienced. Actigraphy was recorded one week before the study up to thee MEG session. The actigraphy (Appendix, Figures A1-A12) shows trends in movement that could be used as markers to estimate whether or not each participant was sleeping during the nap. . It is worth nothing that in two cases the actigraphy was not successfully recorded due to equipment malfunction, so self-recorded sleep diaries from participants

were collected. Neither sleep diaries nor actigraphy are considered a proper substitute for PSG (the gold standard for assessing sleep quantity and quality). PSG was recorded, but the data was not analyzed in time for this paper. It could be used in future publications to determine what stages of sleep were experienced by those participants in the nap group. Nonetheless, given the short period of time that the nap group had to sleep, the actigraph recordings showed very little movement during the 20min period in which the lights were turned out and participants were in bed. This suggests that they may have slept for some of the 20min nap (Appendix, Figures A1-A12). Those who did nap likely experienced stage one or stage two sleep **(**Hayashi, Motoyoshi, & Hori, 2005).

Conclusions

A short 20min nap improved performance on a PVT task, but did not reveal any impact on a more complex SAT task. These results support *motivational theories* (e.g., Wilkinson, 1961) suggesting that short naps do not directly improve performance, but rather alter the level of effort deployed for uninteresting tasks.

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Appendix

Table A1

Participant ID's and notes

PARTICIPANT	DATE (of MEG scan)	SUBJECT ID #/NAP/DATE	SEX	NAP(2)/NO NAP(1)	NOTES
1	September 9th, 2016	01010809	M	NO NAP	
2	September 24th, 2016	03010924	F	NO NAP	Data discarded.
3	October 27th, 2016	02011027	M	NO NAP	
4	November 18th, 2016	04021118	M	NAP	
5	November 19th, 2016	05011119	M	NO NAP	
6	November 25th, 2016	06021125	M	NAP	
7	November 26th, 2016	07021126	M	NAP	Actigraphy malfunction (self-reported)
8	December 3rd, 2016	08021203	F	NAP	
9	January 28th, 2017	09010128	M	NO NAP	
10	January 29th, 2017	10010129	M	NO NAP	
11	February 3rd, 2017	11010203	F	NO NAP	
12	February 4th, 2017	12010204	F	NO NAP	
13	March 24th, 2017	13010324	F	NO NAP	
14	May 5th, 2017	14020505	M	NAP	
15	May 12th, 2017	15020512	F	NAP	
16	May 24th, 2017	16020524	F	NAP	Actigraphy malfunction (self-reported)

17	September 30th, 2017	17010930	F	NO NAP	
18	November 17th, 2017	18021117	F	NAP	Behind schedule, data ok.

Note. Data was collected on 18 people for both experiments but 2 sets of data could not be used so the final sample size was 16: 10 in the no nap experiment and 7 in the nap experiment (7 for the behavioral data but only 6 for the neural data due to excessive head movement which created noisy data).

Table A2

Participant trials removed due to noisy data for MEG analysis

PARTICIPANT	RUN
3	All 4
7	3, 4
14	1
15	All 4
18	2

Note. Data was removed for the neural data completely (participant 3 and 15) due to excessive head movement which created noisy data. These sets of data were still used for behavioral analysis.

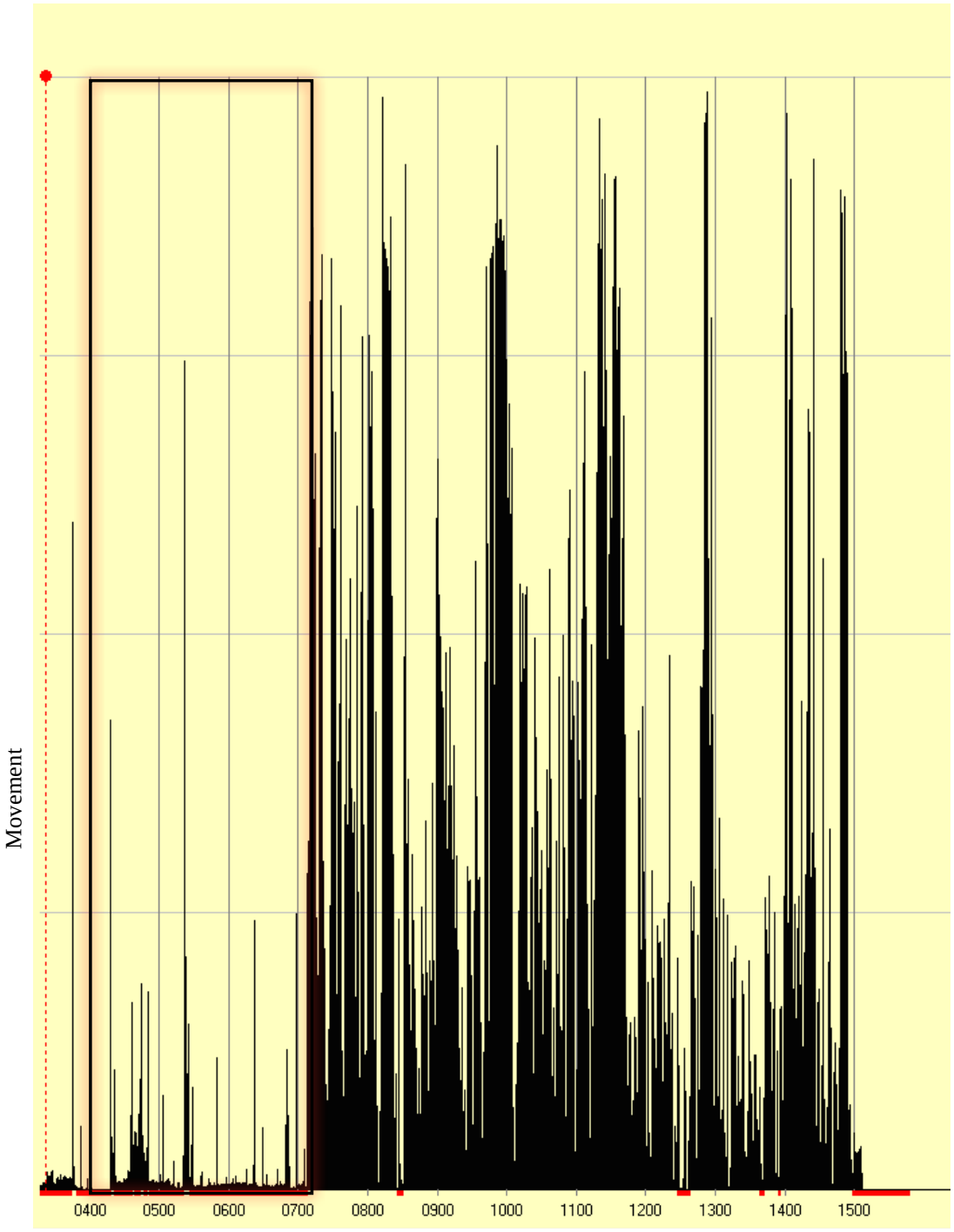

Figure A1. Actigraphy for participant four in napping group, activity versus time of day. Sleep period activity highlighted in red/black box from 4:00AM-7:00AM.

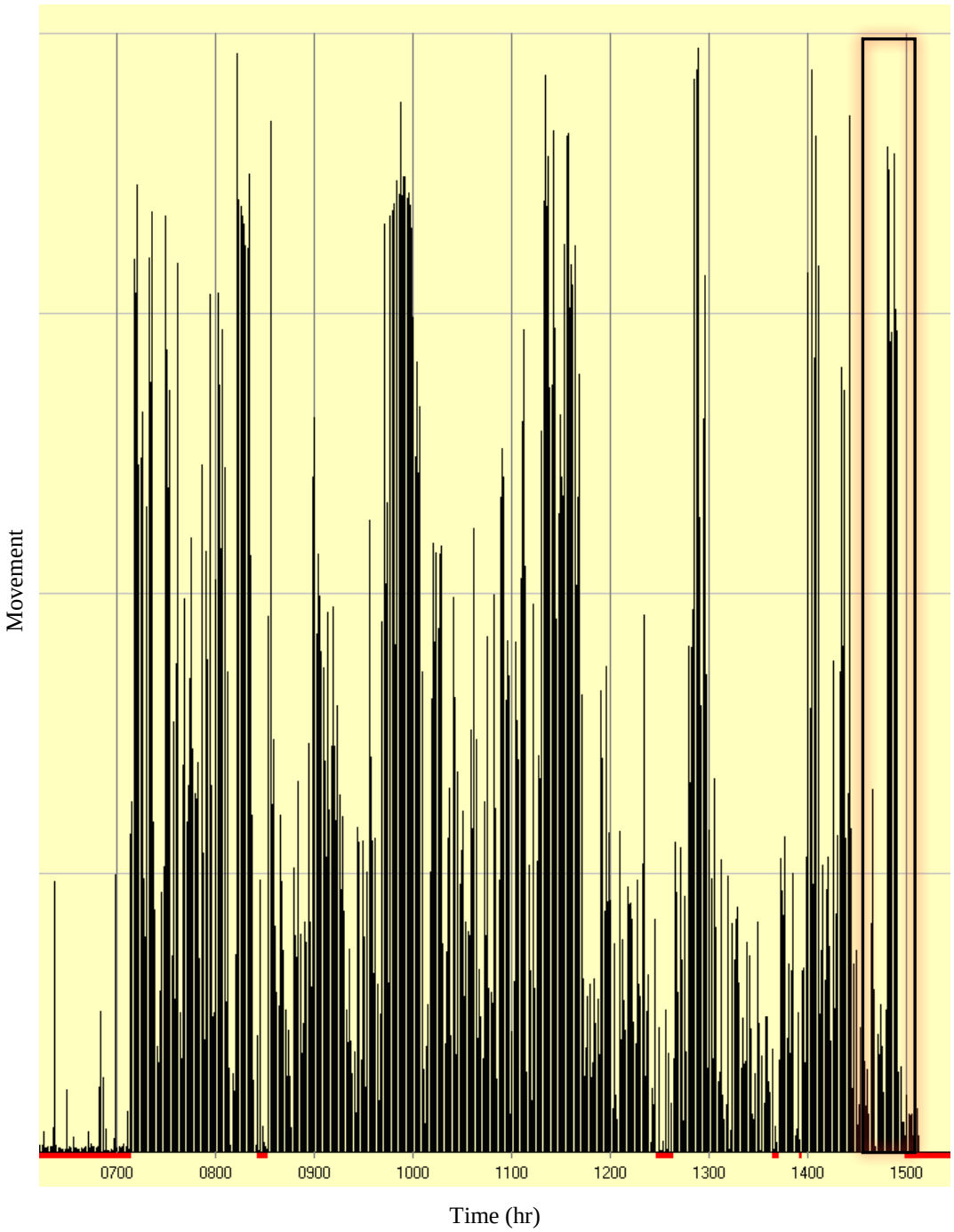

Figure A2. Actigraphy participant four in napping group, activity versus time of day. Napping period activity highlighted in red/black box from 2:40PM-3:00PM.

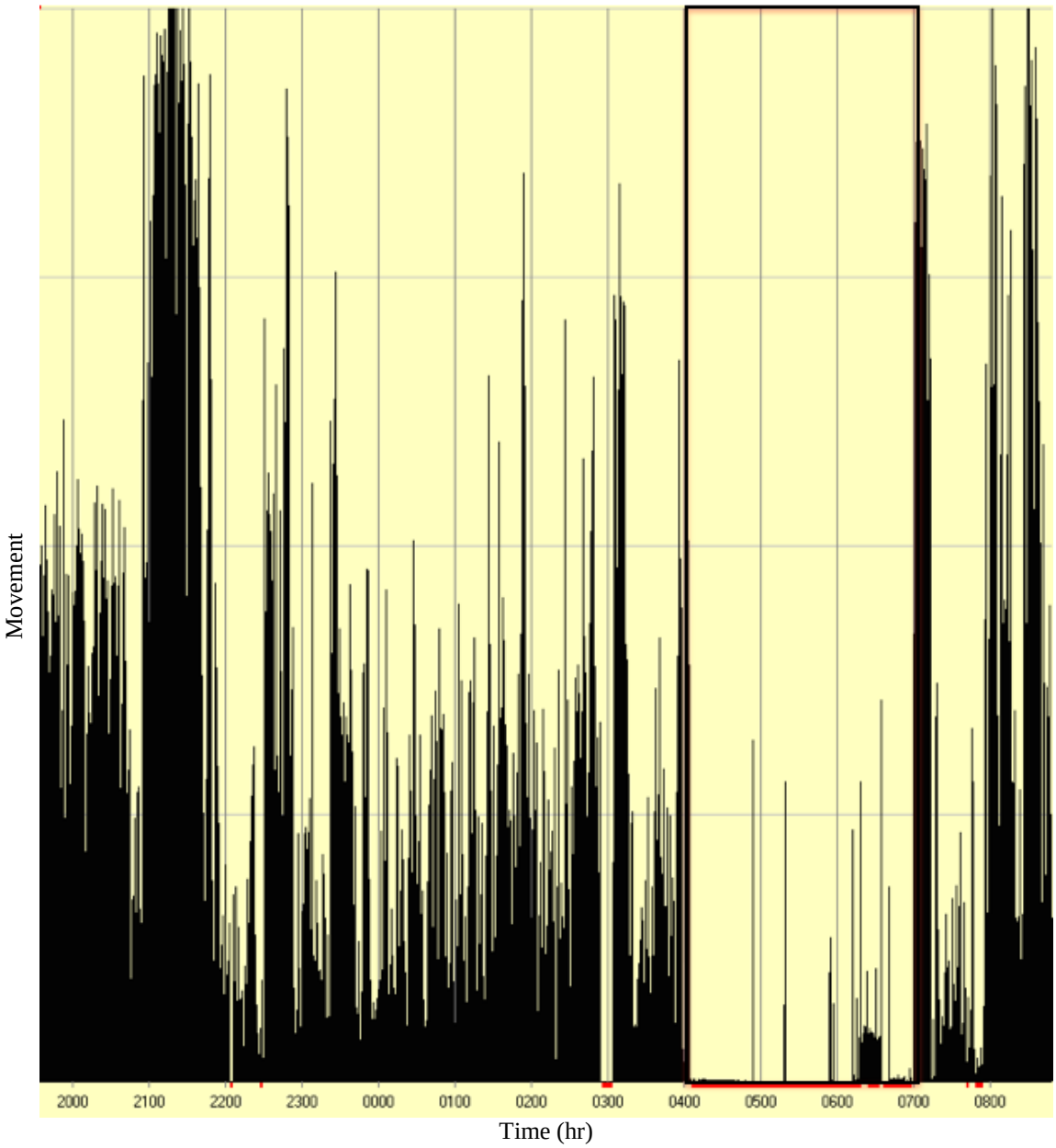

Figure A3. Actigraphy for participant six in napping group, activity versus time of day. Sleep period activity highlighted in red/black box from 4:00AM-7:00AM.

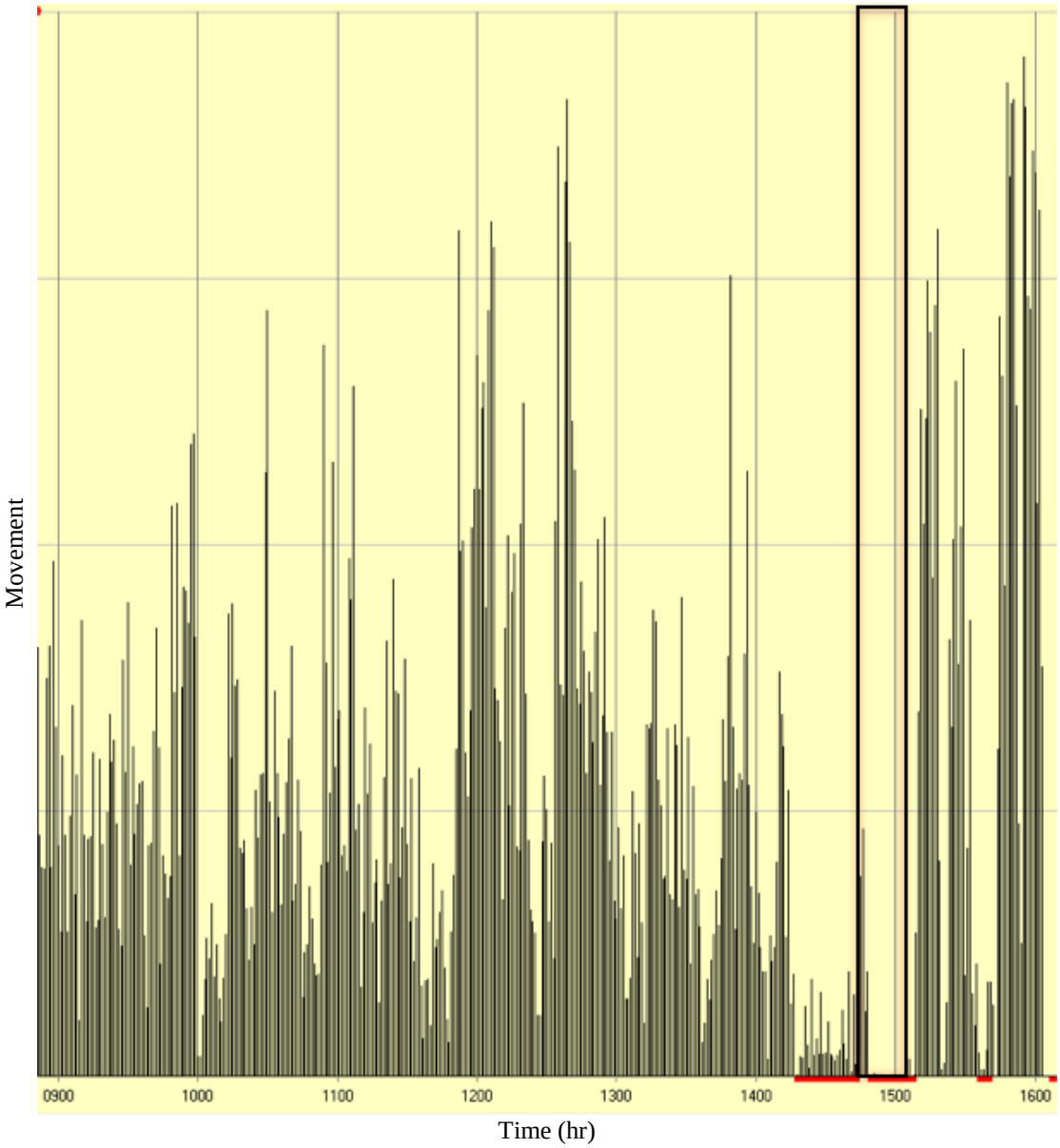

Figure A4. Actigraphy for participant six in napping group, activity versus time of day. Napping period activity highlighted in red/black box from 2:40PM-3:00PM.

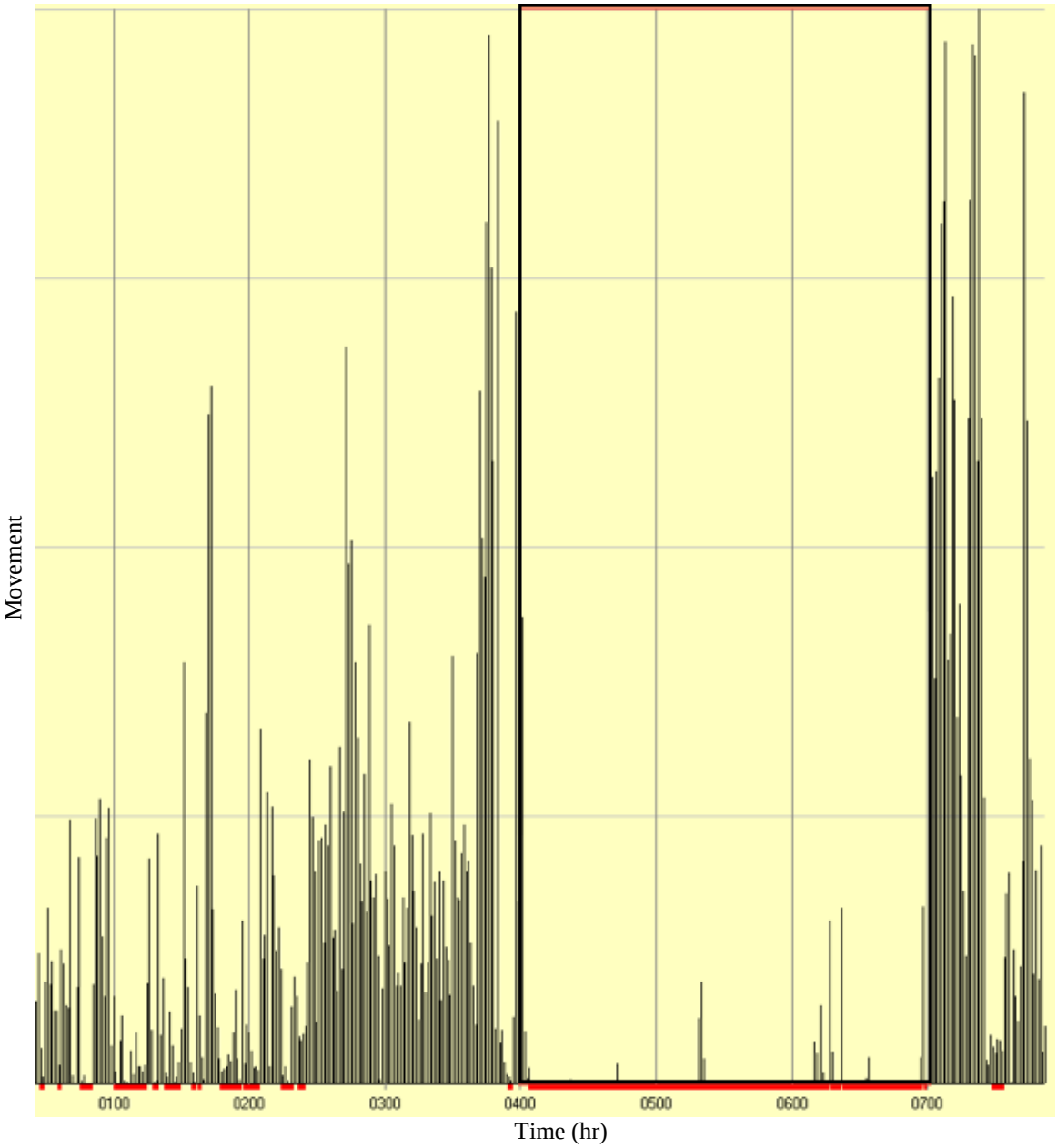

Figure A5. Actigraphy for participant eight in napping group, activity versus time of day. Sleep period activity highlighted in red/black box from 4:00AM-7:00AM.

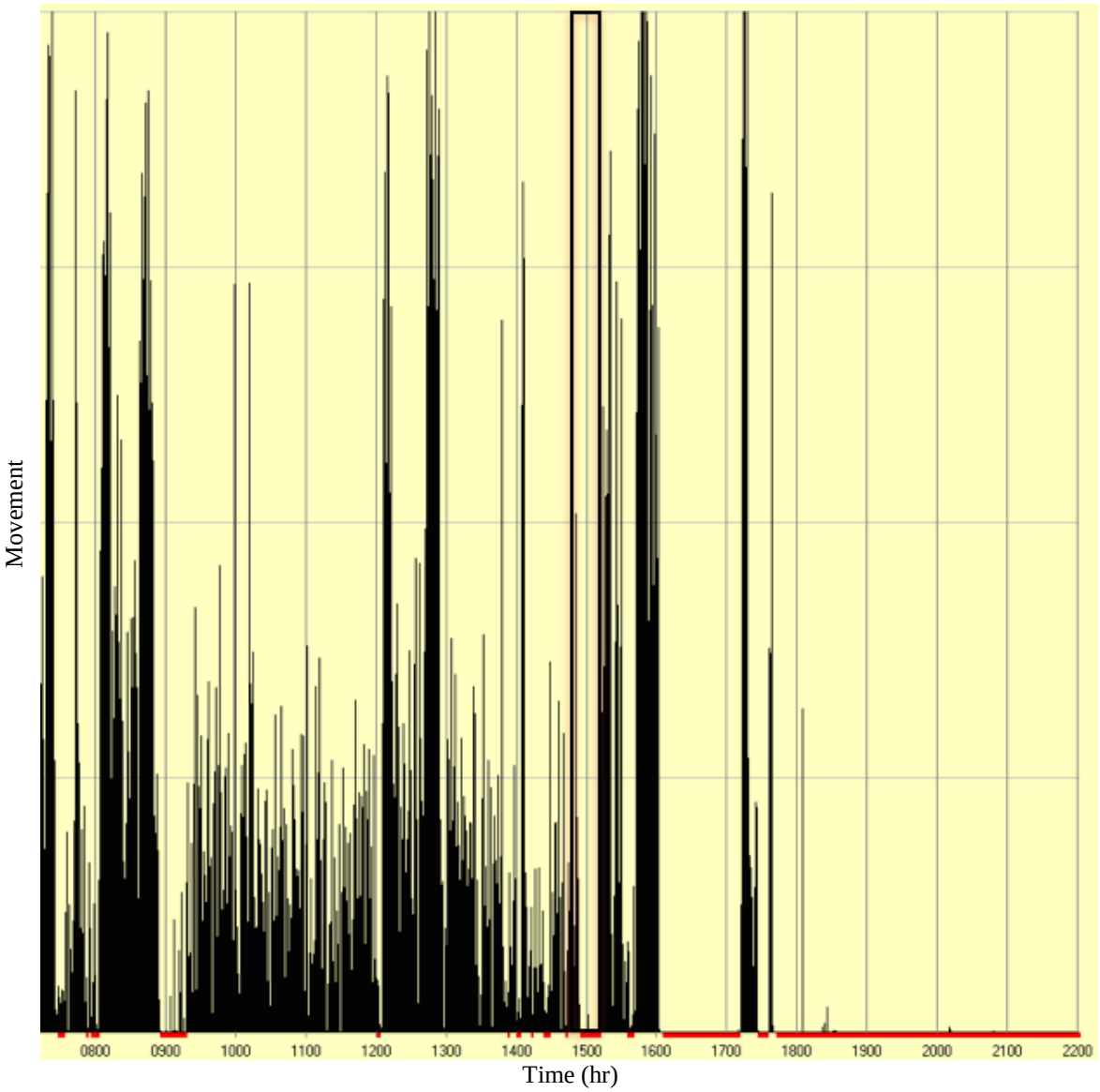

Figure A6. Actigraphy for participant eight in napping group, activity versus time of day. Napping period activity highlighted in red box from 2:40PM-3:00PM.

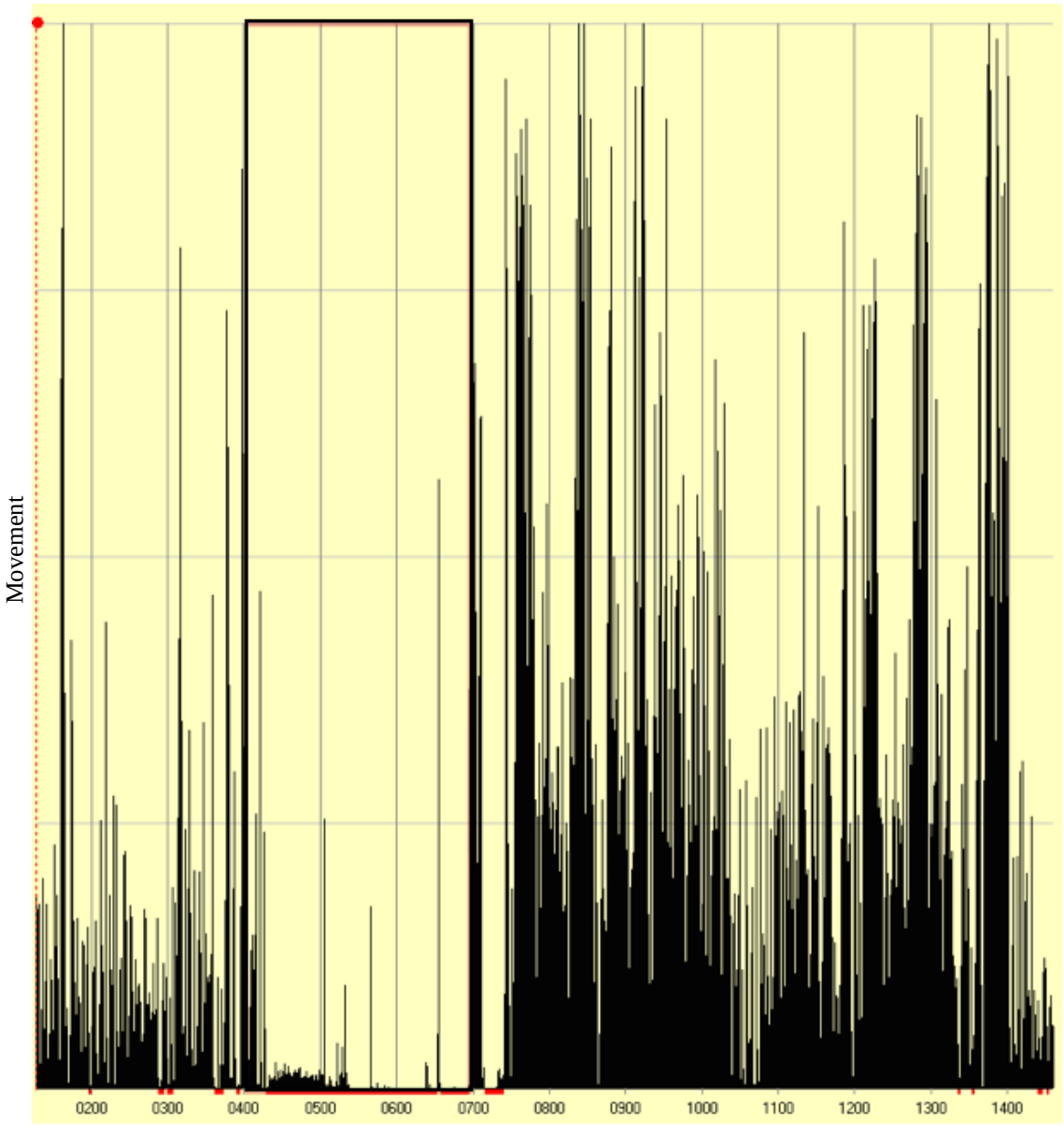

Figure A7. Actigraphy for participant 14 in napping group, activity versus time of day. Sleep period activity highlighted in red/black box from 4:00AM-7:00AM.

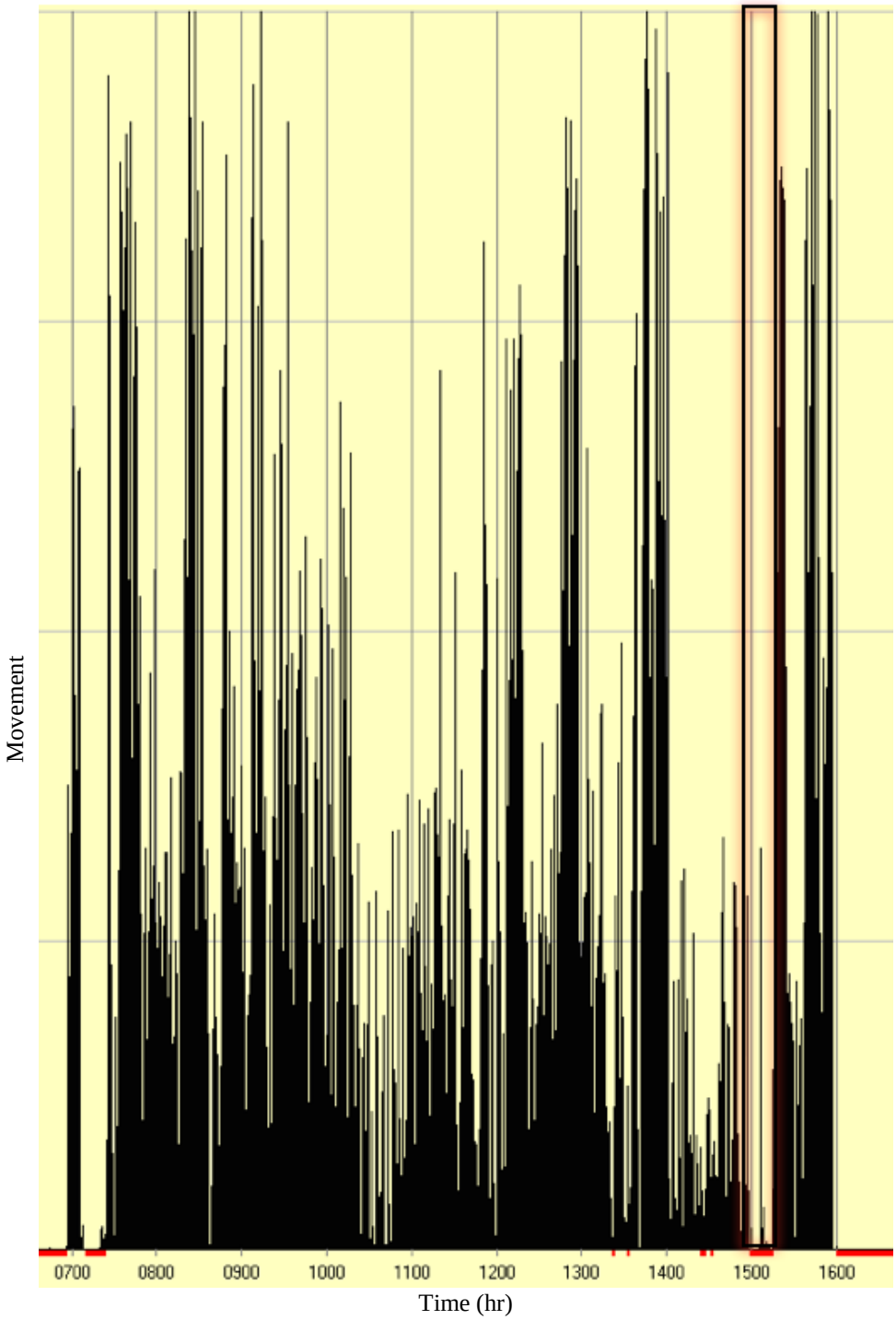

Figure A8. Actigraphy for participant 14 in napping group, activity versus time of day. Napping period activity highlighted in red box from 2:40PM-3:00PM.

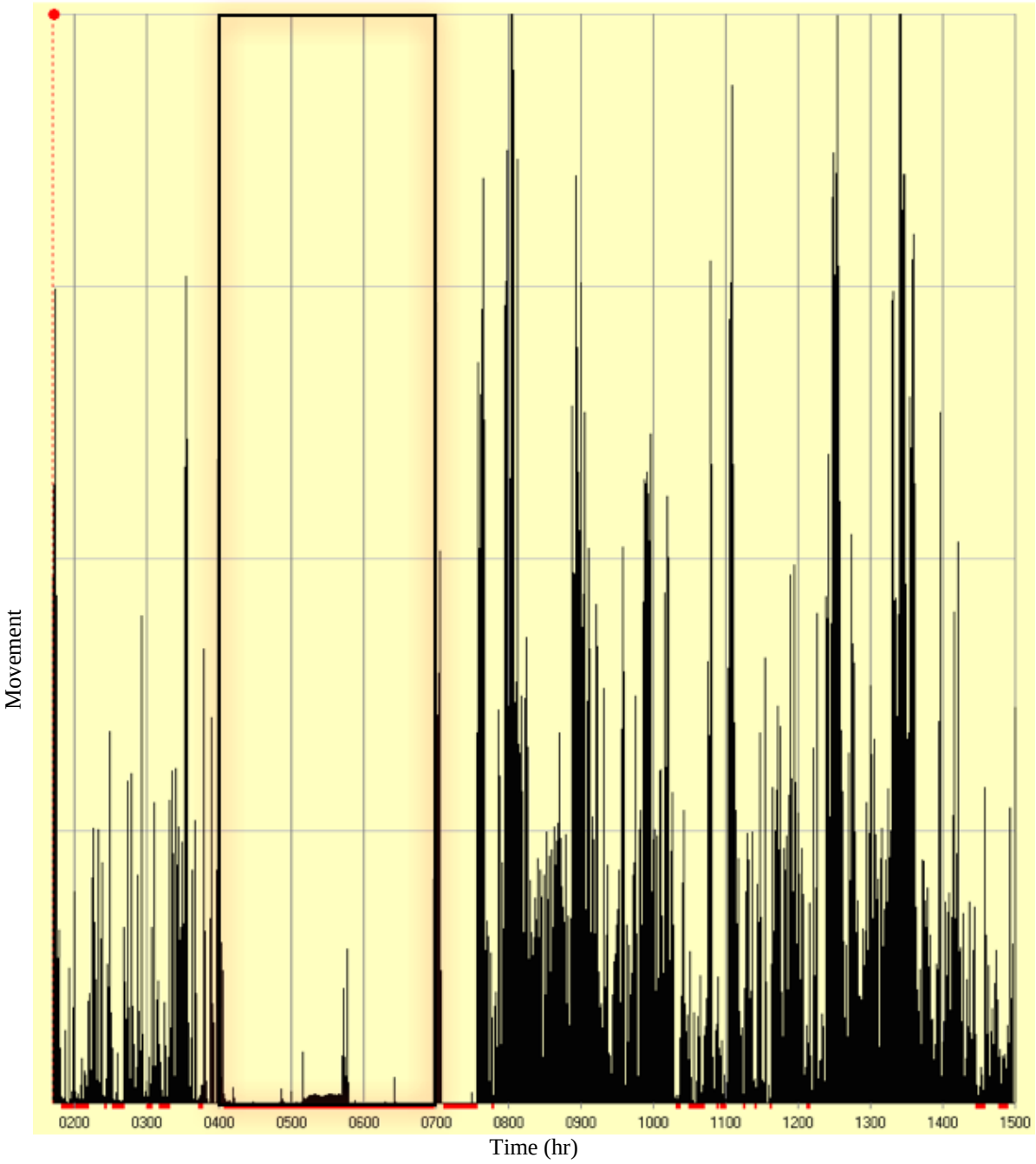

Figure A9. Actigraphy for participant 15 in napping group, activity versus time of day. Sleep period activity highlighted in red/black box from 4:00AM-7:00AM.

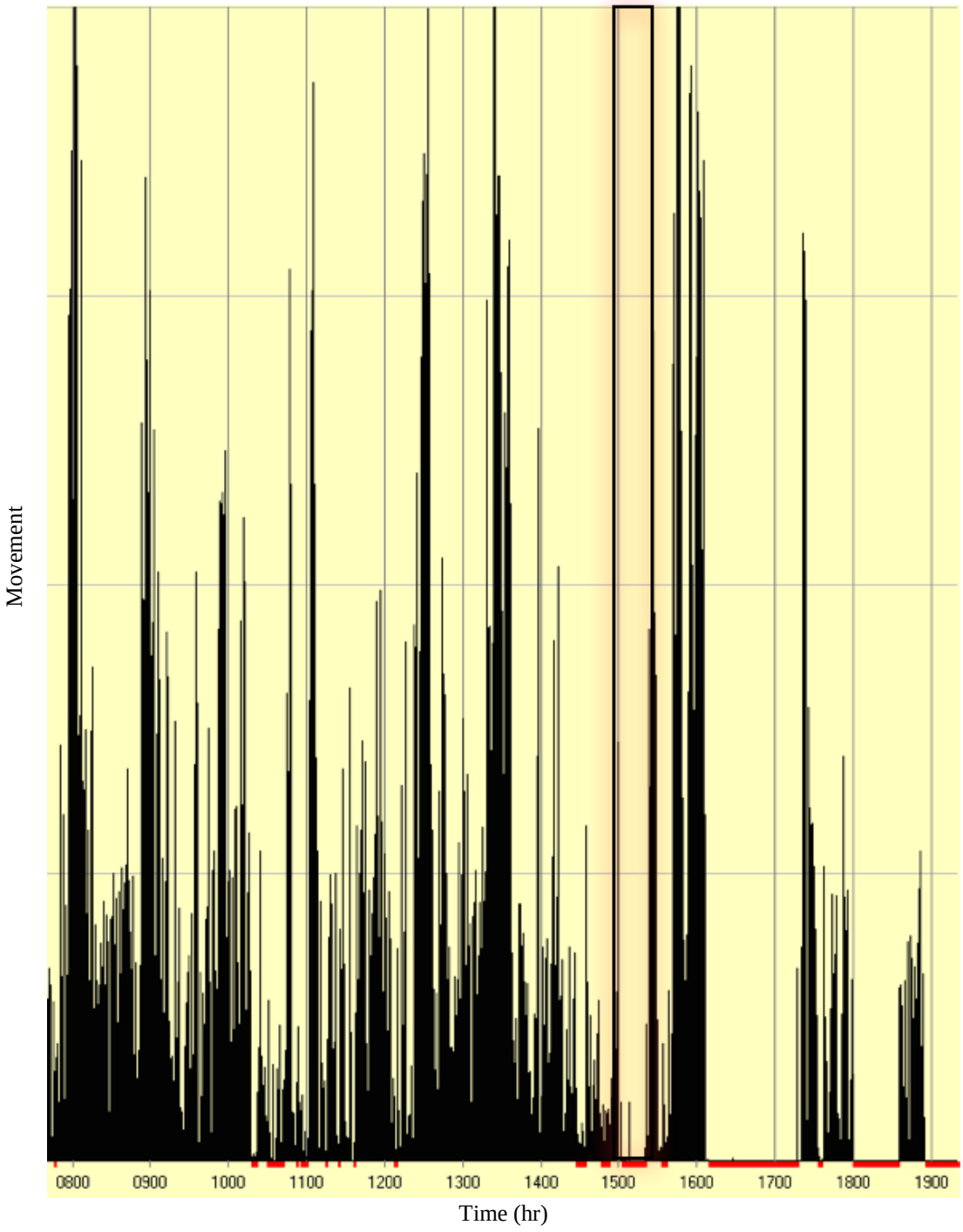

Figure A10. Actigraphy for participant 15 in napping group, activity versus time of day. Napping period activity highlighted in red box from approximately 2:40PM-3:00PM (may have been delayed).

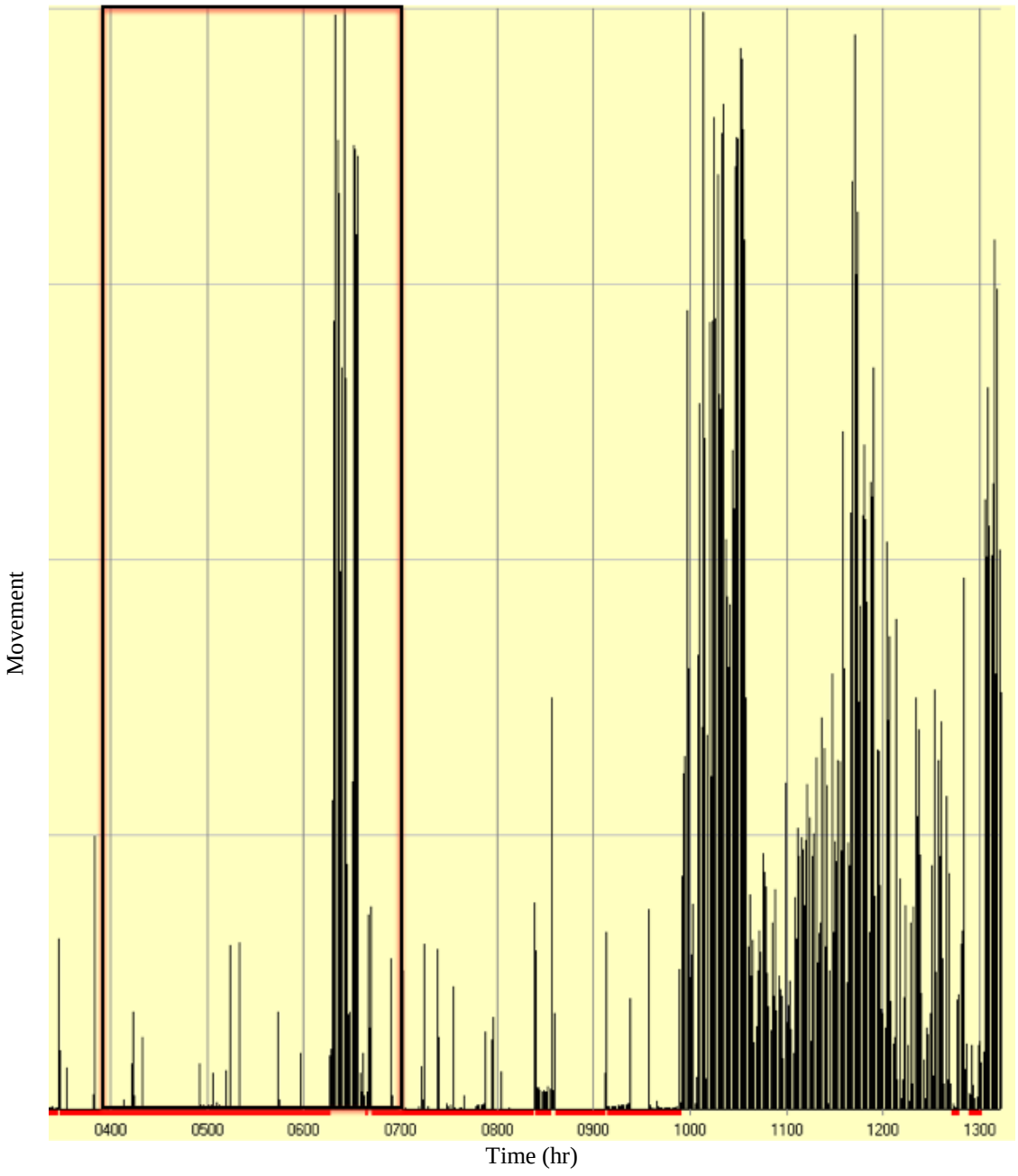

Figure A11. Actigraphy for participant 18 in napping group, activity versus time of day. Sleep period activity highlighted in red/black box from 4:00AM-7:00AM (may be off due to daylight savings).

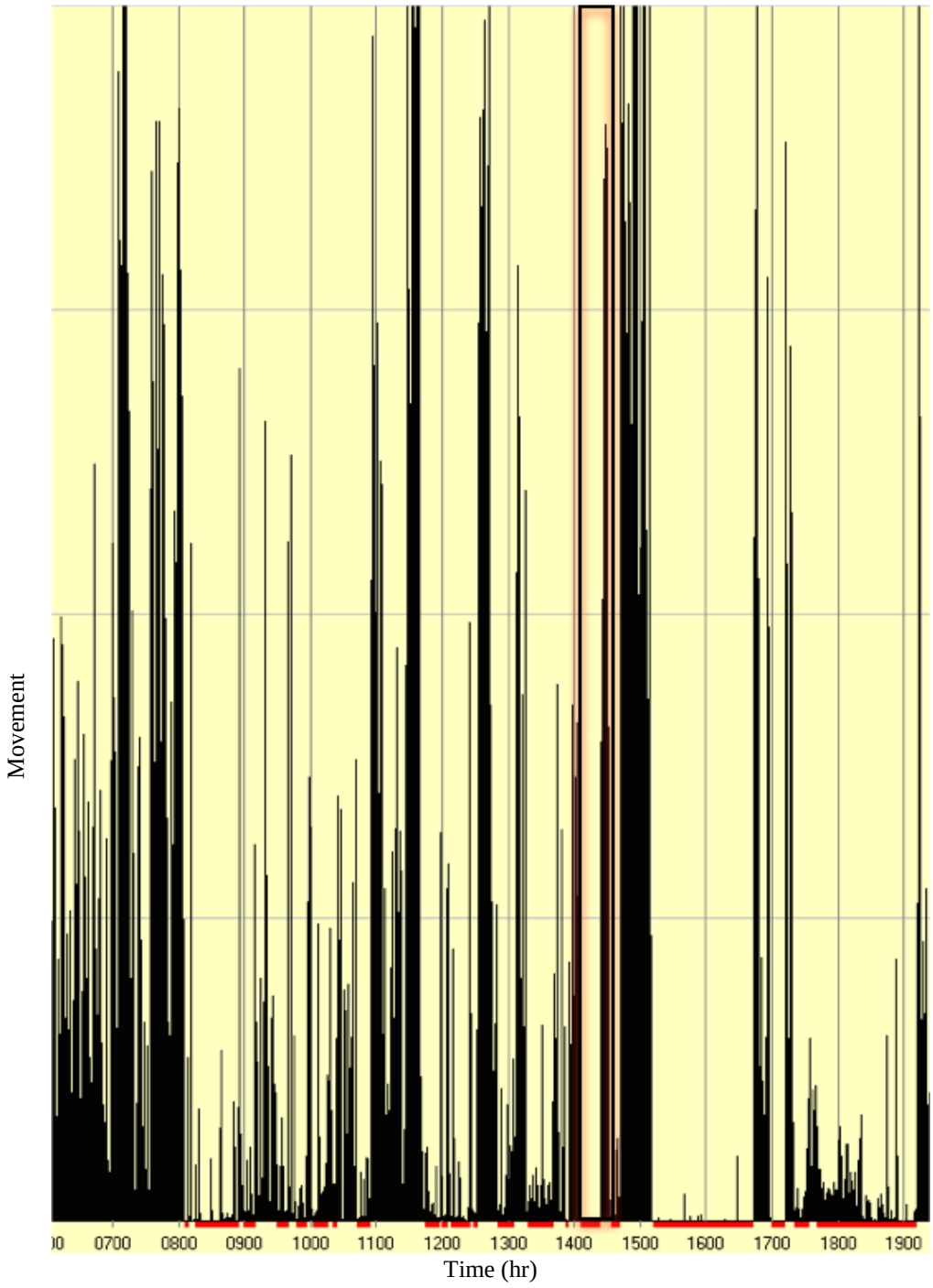

Figure A12. Actigraphy for participant 18 in napping group, activity versus time of day. Napping period activity highlighted in red box from approximately 2:40PM-3:00PM (may have been off with daylight savings and recording was late due to sandman issues).