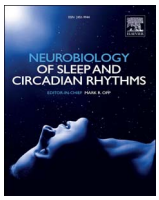
Neurobiology of Sleep and Circadian Rhythms xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Neurobiology of Sleep and Circadian Rhythms

journal homepage: www.elsevier.com/locate/nbscr



Research Paper

Sex hormones play a role in vulnerability to sleep loss on emotion processing tasks

K.A. Lustig, E.M. Stoakley, K.J. MacDonald, S.N. Geniole, C.M. McCormick, K.A. Cote*

Psychology Department, Brock University, 1812 Sir Isaac Brock Way, St. Catherines, Ontario, Canada L2S 3A1

ARTICLE INFO

Keywords:
Sleep restriction
Emotion processing
Testosterone
Progesterone
Estradiol

ABSTRACT

The central aim of this study was to investigate hormones as a predictor of individual vulnerability or resiliency on emotion processing tasks following one night of sleep restriction. The restriction group was instructed to sleep 3 a.m.–7 a.m. (13 men, 13 women in follicular phase, 10 women in luteal phase of menstrual cycle), and a control group slept 11 p.m.–7 a.m. (12 men, 12 follicular women, 12 luteal women). Sleep from home was verified with actigraphy. Saliva samples were collected on the evening prior to restriction, and in the morning and afternoon following restriction, to measure testosterone, estradiol, and progesterone. In the laboratory, event-related potentials (ERPs) were recorded during presentation of images and faces to index neural processing of emotional stimuli. Compared to controls, sleep-restricted participants had a larger amplitude Late Positive Potential (LPP) ERP to positive vs neutral images, reflecting greater motivated attention towards positive stimuli. Sleep-restricted participants were also less accurate categorizing sad faces and exhibited a larger N170 to sad faces, reflecting greater neural reactivity. Sleep-restricted luteal women were less accurate categorizing all images compared to control luteal women, and progesterone was related to several outcomes. Morning testosterone in men was lower in the sleep-restricted group compared to controls; lower testosterone was associated with lower accuracy to positive images, a greater difference between positive vs neutral LPP amplitude, and lower accuracy to sad and fearful faces. In summary, women higher in progesterone and men lower in testosterone were more vulnerable to the effects of sleep restriction on emotion processing tasks. This study highlights a role for sex and sex hormones in understanding individual differences in vulnerability to sleep loss.

1. Introduction

Individual differences in response to sleep loss have long been an interest in the field of sleep (Kleitman, 1963). It has been proposed that vulnerability to sleep loss is a trait-like variable, which is supported by replicability across sleep deprivation events (Van Dongen et al., 2004; Van Dongen, and Belenky, 2009). The major contributors to the trait component of variability have remained elusive (Van Dongen et al., 2004). The central focus of the current study was to investigate sex hormones as predictors of susceptibility to sleep loss on emotion processing tasks in men and women. Investigating the role of hormones in sleep loss vulnerability is important for understanding relationships between brain function and performance as well as for elucidating the functions of sleep.

Previous research has identified a role for testosterone in the processing of emotional stimuli in rested participants (Van Honk et al., 1999; Derntl et al., 2009; Goetz et al., 2014; Pereira and Moita, 2016). As well, sleep loss has been shown to impact emotion processing (for review, see Beattie et al., 2015), and to reduce testosterone (Carter et al., 2012; Cortés-Gallegos et al., 1983; González-Santos et al., 1989; Cote et al., 2013; Leproult and Van Cauter, 2011; Schmid et al., 2012; Wittert, 2014). Thus, testosterone in men may have a predictive role in emotion processing difficulties following sleep loss. The effect of sleep loss on sex hormones such as progesterone and estradiol in women has not been well studied, but there is a large body of research on the relationship between these hormones and emotion processing in women (Guapo et al., 2009; Derntl et al., 2008a, 2008b; Van Wingen et al., 2008; Majewska et al., 1986; Van Wingen, et al., 2011; Conway et al., 2007). Based on the findings that hormones play a role in emotion processing for well-rested participants, they were investigated as predictors for individual differences in the effects of sleep loss.

1.1. Effects of sleep loss on emotion processing

Sleep deprivation is associated with reduced recognition and production of, but increased reactivity to, facial emotional expressions

* Corresponding author.
E-mail address: kcote@brocku.ca (K.A. Cote).

http://dx.doi.org/10.1016/j.nbscr.2017.10.001
Received 17 July 2017; Received in revised form 4 October 2017; Accepted 6 October 2017

(Beattie et al., 2015). A study by Van der Helm and colleagues (2010) found diminished performance in the recognition of subtle expressions of happy and angry faces in a sleep deprivation group compared to a control group. Similarly, a population of clinically diagnosed insomnia patients rated fearful and sad faces as less intense than good sleepers (Kyle et al., 2010). In another study, after sleep deprivation, participants displayed fewer facial expressions to emotional images than they had when well-rested (Minkel, 2011). Taken together, these studies indicate that overall emotion processing and expressiveness is blunted after sleep loss.

However, studies employing physiological measures of emotional reactivity have shown increased response to emotional stimuli after sleep loss. Using pupillary dilation as a measurement of emotional reactivity, Franzen and colleagues (2009) reported that sleep-deprived participants experienced greater pupil dilation for negative images than well-rested controls, illustrating enhanced autonomic arousal to emotional stimuli in the sleep-deprived. Brain imaging studies have found increased amygdala activity to negative stimuli after sleep deprivation, and reduced functional connectivity with regulatory regions (Yoo et al., 2007; Motomura et al., 2013). As well, total sleep deprivation was associated with increases in activation in mesolimbic reward areas for positive stimuli (Gujar et al., 2011).

Event-related potential (ERP) methods, which allow for temporal sensitivity in measuring information processing, have also been applied to investigate neural processing of emotional stimuli. For emotional faces, sleep deprived individuals generated a larger N170 ERP peak for threat (fear, angry) faces when the expressions were more subtle, in addition to a reduction in amplitude for sad faces; these data reflect greater encoding of the structural features of a threatening face perhaps due to salience of the emotion, yet diminished processing of sad faces (Cote et al., 2013). For emotional images, sleep deprived participants had a greater Late Positive Potential (LPP) ERP amplitude to emotional images than well-rested controls, but especially for negative images (Cote et al., 2014), reflecting enhanced motivated attention towards emotional stimuli after sleep loss. In contrast, a recent study (Alfarra et al., 2015) reported a failure to discriminate emotional from neutral stimuli that was driven by a larger LPP to neutral stimuli following a night of total sleep deprivation compared to a rested night. Although differences in design, and stimulus and response parameters of the tasks, may account for the different outcomes in these two studies, both converge to show deficits in attention allocated to processing emotional stimuli. In summary, the research converges to show that sleep loss results in reduced behavioural performance, but increased physiological reactivity (with fMRI and ERP studies) during emotion processing tasks particularly for salient emotions.

1.2. Effects of sleep loss on sex hormones

Several studies have reported effects of sleep loss on testosterone concentrations. Reports of decreased testosterone following one night of total sleep deprivation have varied from 18.5% (Carter at al., 2012) to 30.4% decreases in plasma testosterone (Cortés-Gallegos et al., 1983; González-Santos et al., 1989), and a 27% decrease in salivary testosterone that was associated with reductions in reactive aggression on a laboratory task (Cote et al., 2013). Sleep restriction has shown similar, yet smaller, effects of sleep loss on testosterone. When sleeping only the first half of the night for eight nights, men experienced 10–15% reductions in testosterone (Leproult and Van Cauter, 2011). Another study found that two nights of 4-h sleep with an early awakening reduced testosterone, but a late bedtime did not affect testosterone (Schmid et al., 2012). One report indicated that testosterone followed a typical rhythm if a minimum of three hours of slow wave sleep were obtained, and decreased across the duration of time spent awake (Wittert, 2014).

The effect of sleep loss on sex hormones in women is less studied. Women experience large fluctuations in estradiol and progesterone across the 28-day menstrual cycle. The follicular phase of the menstrual cycle is characterized by low concentrations of progesterone with higher levels of estradiol. During the luteal phase, women experience a decrease in estradiol with a significant increase in progesterone (Conway et al., 2007; Baker & Driver, 2007). In men, estradiol has been found to decrease over the first 24 h awake, and continue decreasing from 24 to 48 h of deprivation (González-Santos et al., 1989). Carter et al. (2012) reported that one night of sleep deprivation reduced progesterone but not estradiol in women. As well, in female nurses working nightshifts, 53% of the sample experienced alterations in their typical menstrual cycles (Labyak et al., 2002). Thus, it is possible that one night of sleep restriction would influence sex hormones in women.

1.3. The role of hormones in emotion processing

Testosterone in well-rested men has been found to have relationships to the processing of threat in a growing literature. For instance, higher concentrations of testosterone resulted in increased attention to angry faces in an Emotional Stroop task (Van Honk et al., 1999). Testosterone has been associated with reaction time to fearful faces, and amygdala activity to threatening images but not neutral stimuli in an emotion recognition task (Derntl et al., 2009). Also, testosterone administration increased hypothalamus, periaqueductal gray, and left corticomedial amygdala reactivity to angry versus neutral faces (Goetz et al., 2014), regions implicated in the fight, flight, and freeze responses to potential threats (Pereira and Moita, 2016).

In well-rested women, studies have found differences in performance on emotion processing tasks across the menstrual cycle. A study found follicular women to have greater accuracy for the categorization of angry and sad faces than luteal women and men; the authors argued a unique role for estradiol levels (Guapo et al., 2009). Similarly, for an emotional face categorization task, women in the follicular phase showed greater activation in the temporal lobe and hippocampus during viewing and also had greater behavioural performance on categorization (Derntl et al., 2008a). The authors suggested that there may be an evolutionary basis for women in the follicular phase to be able to accurately detect emotional faces for mate selection. A second study from this group found better emotional face categorization during the follicular phase and a negative correlation between progesterone and accuracy (Derntl et al., 2008b). Greater progesterone was also associated with a tendency to incorrectly categorize a face as angry.

Imaging studies also have revealed menstrual phase differences for emotion processing. Increases in amygdala activity and reductions in functional connectivity with the fusiform gyrus have been connected to progesterone administration due to progesterone increasing GABA activity through effects on GABA receptors (Van Wingen et al., 2008; Majewska et al., 1986). In a later review, van Wingen and colleagues (2011) summarized that the literature suggests higher amygdala activity during emotional tasks in the luteal phase, although, this finding may vary based on the nature of the task. Other studies have supported a possible role for progesterone in increased processing of threat. Conway and colleagues (2007) found that women with higher concentrations of progesterone tended to rate faces displaying fear and disgust as a greater intensity when the eyes were averted. As the luteal phase is a preparation for pregnancy, the authors suggested an increased response to threat and potential illness that may be damaging to a pregnancy, as an averted gaze suggests a health threat in the environment.

1.4. Aims of the current study

The current study investigated hormone concentrations measured pre- and post-sleep restriction as predictors of emotion processing deficits after short-term sleep restriction. Sleep times from a single night at home were verified with actigraphy. It was expected that there would be an effect of this degree of sleep loss on waking function and