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The Effects of Sleep Restriction on Biological, Psychological, and Neurocognitive Measures of Health

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THE EFFECTS OF SLEEP RESTRICTION ON BIOLOGICAL, PSYCHOLOGICAL, AND NEUROCOGNITIVE MEASURES OF HEALTH

by

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Statement of Original Work

I declare the following:

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Margaret S. Lorenzetti

May 17, 2020

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THE EFFECTS OF SLEEP RESTRICTION ON BIOLOGICAL, PSYCHOLOGICAL, AND NEUROCOGNITIVE MEASURES OF HEALTH

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ABSTRACT

Chronic sleep restriction impacts a significant proportion of the population, even though health is optimized following a minimum of seven hours of sleep. A preponderance of the literature examining the effects of sleep loss focuses on males and total sleep deprivation. Sleep restriction paradigms provide more ecological validity, as they are more consistent with sleep loss characterized in epidemiological studies. Moreover, enhancing the understanding of sleep loss among women, who are generally the gender most likely to encounter negative health as a result of poor sleep quality, is crucial. Thus, this investigation aimed to examine sleep restriction amongst a female sample. Group assignment was determined on the basis of objective and subjective measures of sleep collected in the baseline phase. Participants were then placed in the Naturally Sleep Restricted (NSR) group (n = 11), or the Experimentally Sleep Restricted (ESR) group (n = 9). The ESR group was assessed on Day 1 and Day 7 (i.e., prior to and following sleep restriction).

We hypothesized that following sleep restriction, the ESR group would exhibit decrements in biological, psychological, and neurocognitive functioning. We further hypothesized that relative to the ESR group at Day 1, the NSR group would exhibit reduced functioning. However, we hypothesized that the NSR participants would fare better compared to the ESR group at Day 7. Results indicated that following sleep restriction, the ESR group exhibited elevated IL-1β, anxiety, tension, and fatigue and a decrease in depression, anger, and reaction time. The NSR group evidenced elevated IL-6 relative to the ESR group at Day 1. Finally, relative to the NSR group, the ESR group at Day 7 exhibited elevated anxiety, tension, fatigue, confusion, and correct non-matches on a measure of working memory. Further, the ESR group at Day 7 evidenced lower levels of depression and anger relative to the NSR group. Generally, results indicate that volitional sleep restriction (NSR) produces a different constellation of outcomes relative to non-volitional sleep restriction (ESR). Future research should examine these variables with a larger sample size and over a longer period of sleep restriction in order to assess further changes in functioning.

Chapter 1: Statement of the Problem

Chronic sleep restriction appears to be a characteristic feature of modern society (Stenuit & Kerkhofs, 2008). For instance, the average number of hours slept in 1910 was estimated at nine hours per night, whereas this number has fallen to an estimated seven and a half hours per night (Stenuit & Kerkhofs, 2008). Furthermore, it appears as though this rate of decline (i.e., average number of hours slept per night) has continued to fall over the last two decades. Specifically, the proportion of the population that now sleeps less than six hours per night has nearly doubled, with an estimated 20% of individuals sleeping less than six hours per night in 2009, compared to 12% in 1998 (National Sleep Foundation, 2009). More recently it is estimated that one-third of the adult American population sleeps less than seven hours per night (Luyster, Strollo, Zee, & Walsh, 2012). Given that the Centers for Disease Control ([CDC], 2014)) state that health and well-being are optimized when individuals routinely achieve a minimum of seven hours of sleep per night, it is alarming to see that a large proportion of the population achieves well below what is recommended, a term the CDC (2014) refers to as *short sleep duration* (i.e., sleeping less than seven hours per night within a 24-hour period).

Vgontzas and colleagues (2004) argue that this fall in average sleep time stems from evolving societal pressures in the form of work, family, and social changes. With respect to occupational pressures, short sleep duration results from extended work hours, shift work, and commute times, whereas societal pressures impinge on one's sleep in the forms of enhanced reliance on technology (i.e., electricity, electronic devices) (Faraut, Boudjeltia, Venhamme, & Kerkhofs, 2012; Luyster et al., 2012). Furthermore, a pervasive, Western attitude that if "you snooze, you lose" (Luyster et al., 2012) conveys

the message that sleep is secondary to occupational success. In such cases, the enhanced occupational demands seen in modern society may be tolerated at the expense of reduced sleep. Finally, it may also be conceivable that a lack of awareness surrounding the deleterious effects of shortened sleep duration persists in the population. For instance, Luyster and colleagues (2012) speculate that individuals may view "their sleep as adequate as long as a minimal level of behavioral functioning can be maintained." (p. 727). As such, a large number of individuals may chronically operate at a reduced level of functioning without recognizing that this may in fact be deleterious.

While there is a large degree of agreement in the literature with respect to what constitutes significant sleep loss, less agreement exists on three other considerations, which are important in establishing the impact of sleep loss. First, there are inconsistencies in the literature with respect to the specific paradigm of sleep manipulation employed and its ensuing consequences. In other words, the literature draws a distinction between sleep *deprivation* and sleep *restriction*, and while both may constitute short sleep duration as defined by the CDC (2014), they differ vastly not only in the quantity of how much sleep is shortened, but also in their deleterious effects. Whereas sleep deprivation refers to the complete absence of sleep for a given amount of time (e.g., lasting one night or more), sleep restriction refers to a reduction in sleep quantity compared to the individual's respective baseline amount of sleep (Reynolds & Banks, 2010). The most widely adopted and researched paradigm in behavioral sleep medicine focuses on sleep deprivation (Reynolds & Banks, 2010). Despite this, sleep restriction is a phenomenon that better approximates the current state of affairs in terms

of the general populations; meaning, it has a higher degree of external validity when considering what generalizes to the population at large (Stenuit & Kerkhofs, 2008).

Second, disagreement exists as to whether individuals incur a different spectrum of deleterious effects depending on whether their restricted sleep is habitual versus imposed (i.e., in times of stress or periods of time requiring a condensed amount of sleep). In other words, how is an individual's functioning differentially impacted depending on whether they are volitionally sleeping less versus non-volitionally sleeping less? An emerging trend in sleep research has attempted to address inter-individual differences as they pertain to sleep needs (Banks & Dinges, 2007), and that depending on one's biological propensity, individuals may require different amounts of sleep. Thus, it is possible that individuals who sleep less than seven hours *volitionally*, have different homeostatic processes and genetics subserving the sleep-wake cycle (Goel, Basner, Rao, & Dinges, 2013), relative to individuals that *non-volitionally* sleep less than seven hours per night. For instance, Goel and colleagues (2013) found "trait-like individual differences in the magnitude of fatigue, sleepiness, sleep homeostasis, and cognitive performance vulnerability to acute total sleep deprivation and to chronic sleep restriction" (p. 9). Meaning, individual differences in biological rhythms and genetics may bolster one's abilities to better negate the effects of short sleep duration. Despite this, it remains unclear as to whether individuals who are chronically and volitionally sleeping fewer than seven hours per night are incurring negative health effects, or is the chronic and habitual nature of their short sleep duration an indicator of their natural biological propensity? Additionally, if individuals habitually sleeping greater than seven hours per night are asked to restrict their sleep, are they more likely to encounter the deleterious

effects of sleep restriction due to its non-volitional nature? While sleep research has long addressed and manipulated intra-individual differences with respect to sleep, far less research has addressed the impact that 'trait-like' inter-individual differences play.

Third, there exists disagreement as to how, and to what extent women encounter the deleterious effects of sleep loss. In large part, these uncertainties stem from a lack of research that has examined sleep loss amongst samples of women (Stenuit & Kerkhoffs, 2008; Suarez, 2008). By virtue of their biological and physiological makeup, women exhibit "distinct hormonal and physical changes at specific time points, such as puberty, pregnancy, and menopause" (Mallampalli & Carter, 2014, p. 553), which lead to gender-specific sleep patterns and habits (Suarez, 2008). It is these specific hormonal changes that complicate the process of studying sleep amongst female samples, and have rendered them the understudied gender. For instance, in times of hormonal fluctuations, including puberty, the week prior to menstruation, pregnancy, and menopause, the rate at which women report sleep problems increases (Mallampalli & Carter, 2014). Yet, it cannot be assumed that the existing sleep literature that *has* included female participants has accounted for, or has controlled for the effects of hormonal fluctuations (e.g., Dinges et al., 1997; Faraut et al., 2012). Additionally, it cannot be assumed that findings from sleep research including a strictly male sample can be extrapolated to a female sample. More specifically, women differ from men with respect to hormonal makeup and fluctuations, sleep architecture, sleep latency, and in the rate at which they are diagnosed with clinical sleep disorders (Mallampalli & Carter, 2014). Thus, in order to adequately understand how women are impacted by poor sleep quality, a female sample in which the effects of hormonal fluctuations are accounted for is necessary.

Mounting evidence suggests that, despite the relative lack of sleep research involving women, they are the gender most likely to encounter negative health effects as a result of poor sleep quality (Suarez, 2008). From an epidemiological standpoint, women are diagnosed with insomnia 40% more and are diagnosed with restless legs syndrome twice as often, compared to men (Mallampalli & Carter, 2014). Furthermore, women under the age of 55 report more sleepiness compared to men, and they also experience longer sleep latency (Mallampalli & Carter, 2014). There is a pressing need to empirically document how the sleep paradigm having the most ecological validity, namely, chronic sleep restriction, impacts the gender not only incurring the greatest deleterious effects, but also represents the gender that has seemingly been disproportionately overlooked in the existing literature. Thus, the current study will attempt to address these issues by employing a short-term sleep restriction paradigm amongst a sample of young women, by specifically examining their biological, psychological, and neurocognitive functioning. Because sleep restriction takes many forms, particularly depending on its chronicity, we will attempt to uncover whether short-term sleep restriction differentially impacts women's functioning depending on whether the sleep restriction is naturally-occurring, or whether it is imposed in an experimental manner.

Chapter 2: Review of the Literature

Sleep restriction has long been thought to be a benign phenomenon, relative to sleep deprivation (Banks & Dinges, 2007; Dinges et al., 1997; Short & Banks, 2014). This assumption in part stems from previous literature that failed to incorporate adequate methodological considerations required in sleep restriction research (Banks & Dinges, 2007), thus leading to the belief that sleep restriction produces little adverse effects (Short & Banks, 2014). Conceivably, this assumption may also stem from the reported phenomenon in which sleep restricted individuals underreport and lack insight into the negative effects they experience as a result of their reduced sleep duration (Banks & Dinges, 2007; Short & Banks, 2014). Meaning, sleep restricted individuals tend to underreport and not accurately pinpoint areas of their functioning that may be harmed by chronic sleep restriction. In addition, sleep restriction has increasingly become a characteristic feature of modern society (Luyster et al., 2012) and may thus be viewed as a normalized experience, possibly leading individuals to discount the negative impacts that their restricted sleep habits may have.

Increasing amounts of research however, are documenting the deleterious effects that sleep restriction poses for one's health and wellbeing. For instance, Banks and Dinges (2007) reported that short-term sleep restriction, as defined by restricting one's sleep to four hours per night for a span of six nights, is associated with marked physiological changes, such as reduced glucose intolerance, elevated blood pressure and inflammatory markers, increased activation of the sympathetic nervous system and reduced leptin levels. Furthermore, they also reported a relationship between sleep restriction and weight gain (and possibly obesity) – a relationship primarily mediated by appetite-

regulating hormones, such as leptin and ghrelin (Banks & Dinges, 2007). Moreover, sleep restriction results in elevated markers of inflammation, including IL-6 and TNF-alpha, having consequences in the form of insulin-resistance, osteoporosis and cardiovascular disease (Banks & Dinges, 2007). In terms of the psychological consequences, they found ensuing mood disturbances in the form of sleepiness, confusion, and fatigue, and in terms of the neurocognitive consequences, detailed a reduction in psychomotor vigilance and slowed working memory (Banks & Dinges, 2007). Finally, the summation of physiological, psychological, and neurocognitive deficits resulting from sleep restriction enhance the risk of motor vehicle accidents and death (Banks & Dinges, 2007).

Luyster and colleagues (2012) echo similar warnings with respect to the deleterious effects associated with sleep restriction. Broadly speaking, they state that individuals encounter the greatest risks in the realms of cardiovascular and metabolic functioning and develop increased vulnerability for developing cancer and/or being involved in a motor vehicle accident. More specifically, they posit that short sleep duration is associated with increased risk of cerebrovascular accidents, particularly of an ischemic nature, as well as myocardial infarction and atherosclerosis. Metabolically, they described an emerging trend in behavioral sleep medicine to hypothesize an inverse relationship between habitual number of hours slept and one's body mass index, obesity, and risk of developing type 2 diabetes. With respect to the link between short sleep duration and cancer, Luyster et al., (2012) indicated that individuals routinely having short sleep durations are at an increased risk of developing breast, colorectal and prostate cancer. Finally, and similar to Banks and Dinges' (2007) stance, Luyster and colleagues (2012) indicated that "sleep deprivation results in impairments in cognitive and motor

performance that are comparable to those induced by alcohol consumption at or above the legal limit" (p. 731). While referring to sleep deprivation and not *restriction*, it stands to reason that chronically achieving fewer hours of sleep than is needed and experiencing feelings of sleepiness has implications for one's cognitive and motor performance as well. Importantly, it is estimated that approximately 20% of motor vehicle accidents are attributable to impaired driving as a result of sleepiness (Luyster et al., 2012).

Suarez (2008) went a step further and provided intriguing evidence that many of the links between short sleep duration and reduced health may be mediated by one's gender. In other words, it was found that there are gender-specific associations when it comes to sleep restriction and ensuing consequences for one's health. For example, increased sleep latency, and reduced self-reported sleep quality – measures of poor sleep hygiene, were associated with elevated psychosocial distress, fasting insulin, fibrinogen and inflammatory biomarkers, but *only* amongst the women in the study (Suarez, 2008). The author reasoned that these findings may be partially explicated by the gender-related differences that have been observed with a variety of neurochemicals, including tryptophan, serotonin, and melatonin (Suarez, 2008). More specifically, these neurochemicals play a role in sleep, sleep onset, as well as biological and psychological processes including mood regulation, inflammation, thrombogenesis, and eating, and may exert differential effects when it comes to women's sleep patterns. Of importance, is the notion that women differ in their hormonal composition and vulnerability to the negative effects of sleep restriction, thus adding weight to the importance of partialing out gender in research paradigms of behavioral sleep medicine.

Broadly speaking, the negative outcomes that individuals encounter as a result of sleep restriction have biological, psychological, or neurocognitive consequences. Given that sleep is a behavior that uniformly takes place across the animal kingdom, that it is encoded in our genes, and that it is necessary for our survival (Luyster et al., 2012), it stands to reason that restricted amount of sleep have the potential to produce profound deficits in one's health and wellbeing. As indicated, the current study will attempt to explore the biological, psychological, and neurocognitive consequences of sleep that is either naturally restricted or experimentally restricted amongst a sample of women.

Biological Consequences

Previous research examining the deleterious effects of sleep restriction and deprivation on one's biological functioning have traditionally examined pro-inflammatory cytokines, such as the interleukins, as well as glucocorticoids, such as cortisol (Vgontzas et al., 2004). While these have not been uniformly studied, a general trend suggesting elevations amongst the interleukins (i.e., IL-6, IL-1ß) and cortisol following poor sleep is apparent. Meaning, various forms of sleep restriction and deprivation have been associated with either elevations or alterations in daily IL-6, IL-1ß, and cortisol secretory patterns, which not surprisingly have implications for one's endocrine and metabolic health, as well as self-reported psychological health (e.g., Omisade, Buxton, & Rusak, 2010).

With respect to the gender gap in sleep research (i.e., disproportionately conducted on males), it is most apparent when considering the biological factors, as females have traditionally been excluded as a result of having comparatively complex and fluctuating hormonal makeups.

Given that the interleukins and cortisol exhibit diurnal patterns, and that females exhibit monthly hormonal fluctuations, additional steps must be taken to ensure that these are not confounded. For instance, LeRoux, Wright, Perrot, and Rusak (2014) specify that one's menstrual cycle phase produces altered cortisol responses, having implications for one's endocrine and adrenal status following sleep loss. In particular, in their study consisting of 18 females divided equally into either the follicular or luteal phase of their cycles, participants spent two nights in the lab, in which they slept 10 hours the first night and restricted their sleep to three hours the second night. Results indicated that following the night of sleep restriction, "Women in the follicular phase showed a significant decrease in their cortisol awakening responses…and a sustained elevation in afternoon/evening cortisol levels, as has been reported for men. Women in the luteal phase showed neither a depressed CAR, nor an increase in afternoon/evening cortisol levels." (p.34). Thus, women in the follicular phase did not exhibit a comparable decrease in their cortisol levels in the afternoon following sleep restriction, having significant implications for endocrine readings and interpretations. Conversely, women in the luteal phase did exhibit sustained elevations in cortisol throughout the afternoon. Taken together, these results demonstrate the intricate interplay between menstrual cycle phase, sleep, and endocrine status, highlighting the importance of implementing the necessary parameters to account for these fluctuations.

As a result of the reduced female inclusion in this line of study, uncertainties surrounding whether, and to what extent, their biological functioning is impacted following sleep restriction is unclear. For instance, Vgontzas et al., (2004) state that, compared to males, females are more resilient to the effects of sleep loss (in terms of

their post sleep-restriction IL-6), whereas others (i.e., Irwin, Carillo, & Olmstead, 2010; Suarez, 2008; Tartar et al., 2015) note that women are more impacted by sleep restriction, as they evidence a heightened psychological and physiological toll. Evidently, additional research is needed as a means for understanding how women's biological functioning is impacted following sleep restriction. The current body of literature either fails to account for females' hormonal fluctuations, comprises groups composed of both males and females, or simply excludes females from the study altogether. Thus, the current review of the literature will cite studies comprising both genders, and when possible, results specific to females will be highlighted.

Cortisol. With respect to cortisol, Banks and Dinges (2007) indicate that sleep restriction, which comprised of sleeping approximately four hours per night for 10 nights, resulted in elevations in cortisol, having negative outcomes in the form of increased sympathetic activation, diminished thyrotropin activity, and decreased glucose tolerance. Omisade and colleagues (2010) add that acute sleep loss is associated with sustained elevations of cortisol in the evening, and this has been tied to diminished leptin (an appetite-suppressing hormone), increased ghrelin (an appetite-stimulating hormone), as well as increases in self-reported hunger and a particular preference for foods high in calories and/or carbohydrates. Importantly, in the absence of disrupted sleep, cortisol follows a diurnal pattern, such that it is at its zenith in the morning, and at its nadir in the evening (Pledge, Grosset, & Onambélé-Pearson, 2011). Whereas some studies (e.g., Vgontzas et al., 2004) have found that sleep restriction results in an altered pattern of cortisol secretion, others (e.g., Omisade et al., 2010), have found evidence for both

elevations of mean cortisol levels throughout the day, as well as altered secretory patterns.

Vgontzas and colleagues (2004) examined how participants' (12 men and 13 women) cortisol was impacted following 8 days of sleep restriction. More specifically, following a 4-day baseline period, wherein participants were asked to sleep 8-hours per night, participants were then asked to restrict their sleep to 6-hours per night. Results indicated that sleep restriction did not impact mean amounts of cortisol secretion, but results did suggest that, compared to their baseline, men exhibited reduced peak levels of cortisol in the morning, compared to women, and the authors speculated that this may be evidence that women are more resilient to the effects of sleep restriction. Similarly, cortisol patterns were observed in both men (n = 5) and women (n = 6) following 14 days of either 8.5 or 5.5 hours of time in bed (Nedeltcheva, Kessler, Imperial, & Penev, 2009). Results did not suggest differences between the 8.5 and 5.5 hour group with respect to peak, trough, daytime, and nighttime cortisol concentrations. Information regarding gender differences was not provided.

In contrast, Kumari, Badrick, Ferrie, Perski, Marmot, and Chandola (2009) found that short sleep duration, as defined by sleeping less than five hours per night, is associated with an altered diurnal pattern amongst both males *and* females (N = 2751), such that cortisol patterns become flattened. Participants provided six saliva samples over the course of the day, the first upon waking, the second 30 minutes afterwards, the third two and a half hours afterwards, the fourth eight hours afterwards, the fifth twelve hours afterwards, and the sixth at bedtime (Kumari et al., 2009). Results indicated that number of hours slept the previous night is correlated with higher cortisol on awakening, whereas

participants having slept five hours or less exhibited the lowest cortisol in the morning. However, this group exhibited the steepest morning rise in cortisol; thus, sleeping more hours is associated with a less steep rise in morning cortisol (Kumari et al., 2009). Interestingly, this effect remained even after controlling for potential confounders such as age, sex, and awakening time (Kumari et al., 2009).

In an attempt to address the lack of well-controlled studies examining females' biomarkers in response to sleep loss, Tartar and colleagues (2015) examined whether volitional and chronic sleep restriction impacted participants' psychological and physical health. In particular their study examined a female-specific sample's (N = 60) cortisol levels on the basis of total sleep time and sleep delay. More specifically, their study was divided into two groups on the basis of sleep time, such that participants sleeping fewer than seven hours were deemed chronically sleep restricted, whereas the other group was deemed non-chronically sleep restricted. Results indicated a positive relationship between cortisol levels and a later time to fall asleep, although amongst the chronically sleep-restricted group, this relationship only persisted when accounting for a later time to fall asleep (Tartar et al., 2015). Finally, the non-chronically sleep restricted group did not significantly differ from the chronically sleep restricted group in terms of cortisol levels when both groups did not delay their time to fall asleep. Thus, in isolation, cortisol was significantly correlated with delayed sleep time. The authors reasoned that chronically achieving fewer than seven hours of sleep conceivably constitutes a physiological stressor, thus underscoring elevations in cortisol via the hypothalamic-pituitary-adrenal axis (Tartar et al., 2015). However, it should be noted that precautions were not taken to

account for participants' menstrual cycle phase, thus raising the possibility that an altered cortisol awakening response confounded the results (LeRoux et al., 2014).

Similarly, in a study comprising exclusively females (n = 15) aged 18-25, Omisade et al., (2010) found that, compared to non-sleep restricted individuals, participants' peak morning cortisol levels tapered off at a slower rate over the course of the day, meaning that their levels were elevated in the evening hours. They indicated that elevations in evening levels of cortisol are associated with decreased leptin and increased ghrelin, and stated that it is worth considering whether these hormonal changes stem from the flattened diurnal pattern seen in cortisol secretion following sleep restriction. Thus, it remains unclear as to whether the specific mechanism leading to these physiological changes are a result of discrete elevations in cortisol levels over the course of the day, or rather, an altered pattern. What also remains unclear is how men and women's cortisol levels and patterns are differentially impacted following sleep restriction, although evidence (i.e., Kumari et al., 2009) suggests that they may in fact experience it in a similar manner. As was repeatedly mentioned, there is a stark lack of research that has addressed women, therefore also having the consequence of having a poverty of studies comparing men and women, further obscuring our understanding. In addition, the specific manipulations (e.g., number of hours restricted, number of days restricted, method of monitoring the restriction) that were employed to restrict sleep differed, thus it is unclear to what extent these may have impacted the results, although it appears as though the baseline conditions were relatively consistent between studies. In all, there is mounting evidence that would suggest altered cortisol patterns in response to altered sleep patterns, yet our understanding is far from comprehensive.

IL-6. In terms of IL-6, it is an inflammatory marker involved in a variety of pro- and anti-inflammatory functions, having endocrine and metabolic effects (Agorastos et al., 2014). More specifically, IL-6 is implicated in acute immune responses, thyroid function, as well as the secretion of C-reactive protein. Vgontzas et al., (2004) articulate that IL-6 and sleep restriction are intrinsically linked, such that in the face of sleep loss, IL-6 levels increase, having consequences in the form of insulin resistance, osteoporosis, and cardiovascular disease. Further, elevations have also been associated with obesity, aging, morbidity, and mortality (Vgontzas et al., 2004). IL-6 follows a diurnal pattern, and this too, can become disrupted in the face of disrupted sleep. Agorastos and colleagues (2014) indicate that IL-6 concentrations are generally lower over the course of the day and increase overnight, but are prone to 'rhythmic oscillations' - alterations in one's circadian circulating IL-6 concentrations, following sleep deprivation.

Like cortisol, IL-6 has reportedly received insufficient attention in sleep research, *particularly* as it pertains to *chronic* sleep restriction versus acute sleep deprivation (Banks & Dinges, 2007), as well as whether gender moderates the relationship between sleep and IL-6 (Hong, Mills, Loredo, Adler, & Dimsdale, 2005). For instance, the vast majority of existing studies have disproportionately included men (i.e., Lekander et al., 2013) , and those that have included both genders have inconsistently yielded differences (Mullington, Haack, Toth, Serrador, & Meier-Ewert, 2009). Of the studies that have included women, gender differences in inflammatory response following sleep loss tend to not be reported, as the studies were not powered to test for differences (Mullington et al., 2009), although there is one exception that demarcates gender differences (e.g., Vgontzas et al., 2004).

In addition to cortisol, Vgontzas et al., (2004) examined the impact that sleep restriction has on participants' IL-6 levels. Results did not reveal an effect of gender, as sleep restriction was associated with increased levels of IL-6 across both sexes. Moreover, Shearer and colleagues (2001) examined whether two different sleep manipulations (i.e., sleep restriction vs. sleep deprivation) interfered with markers of immunity, including IL-6. Their study comprised exclusively of males (n = 42), who were randomly assigned to either restrict their sleep to two hours per day, or to refrain from sleeping, thus deprive themselves for a period of four days. Results indicated that participants who underwent four days of sleep deprivation exhibited significant increases in plasma levels of IL-6, but that the group undergoing sleep restriction did not. They reasoned that the two-hour period of sleep may have been sufficient to prevent the immune changes observed within the total sleep deprivation group.

Further, Vgontzas et al., (2002) conducted a study in which levels of IL-6 in participants with insomnia were compared to those of age and body mass index-matched controls. The insomnia group included six men and five women, whereas the control group included eight men and three women. Insomnia was determined on the basis of whether participants reported sleeping less than 6.5 hours per night, at least four nights a week, for a span of at least six months and/or requiring 45 minutes or more to fall asleep. Participants' slept in a sleep laboratory for four consecutive nights. Results indicated that mean levels of IL-6 secretions did not differ between the insomnia and control group, although the timing of IL-6's peak secretion occurred earlier in the evening amongst the participants with insomnia, relative to those in the control group, whose peak IL-6 secretion occurred throughout the nighttime. The authors reasoned that IL-6's shifted

time of peak secretion may account for insomniacs' greater difficulty falling asleep, thus accounting for the greater daytime sleepiness experienced. While the study comprised both males and females, information related to a gender-interaction was unavailable.

In contrast, Suarez (2008) found an effect of gender in the relationship between poor sleep quality and inflammatory biomarkers. In other words, self-reported poor sleep quality, as measured by the Pittsburgh Sleep Quality Inventory (PSQI), was related to enhanced levels of IL-6 in women (Suarez, 2008). His study included 95 women and 115 men. Results indicated that PSQI score correlated positively with IL-6 in women and not men, and that specific symptoms of poor sleep gauged from the PSQI accounted for the majority of this relationship. In particular, greater and more frequent bouts of difficulty falling asleep were positively associated with elevations of IL6 exclusively amongst female participants. Suarez (2008) concludes that his results underscore why women are more likely to incur cardiovascular difficulties such as hypertension compared to men as a result of sleep disturbances. While poor sleep quality does not necessarily serve as a substitute for sleep deprivation or restriction, it does provide evidence that subjective reports of sleep loss also correlate positively with elevated inflammatory markers, such as IL-6.

In accordance with Suarez's (2008) findings, Irwin et al. (2010) found that one night of partial sleep deprivation in which participants (11 women and 15 men) were awake between the hours of 23:00 and 3:00, preceded greater IL-6 morning production compared to levels of IL-6 following uninterrupted sleep. Interestingly, while males and females did not differ in IL-6 morning elevations following interrupted sleep, they did differ with respect to their IL-6 levels the following day (Irwin et al., 2010). In other

words, relative to males, the female participants exhibited increases in IL-6 in the evening hours the day following partial sleep deprivation. Importantly, however, testing was not restricted to a particular phase of women's menstrual cycle (Irwin et al., 2010), which may have inadvertently impacted their results.

In a study comprising exclusively of males (N = 9), Lekander and colleagues (2013) incorporated a within-subjects sleep restriction model, in which participants' sleep was restricted to four hours per night for a span of five days. This followed an initial baseline phase in which participants slept eight hours per night for a span of three nights, and preceded a recovery period in which participants again slept eight hours per night for a span of three nights. Results indicated that, on the basis of self-report, participants reported a decrement in subjective health as well as an increase in fatigue (Lekander et al., 2013). With respect to IL-6, it did not change significantly following sleep restriction, raising the possibility that the participants' sleep had not been restricted for a long enough span. In addition, the authors questioned whether gender may have played a role, in that females' IL-6 has been shown to change following sleep restriction across other studies (i.e., Irwin et al., 2010), and theirs included a sample devoid of females.

An additional study solely composed of male participants (N = 19) found that sleep restriction resulted in significantly elevated levels of IL-6 relative to the participants' baseline levels (van Leeuwen et al., 2009). More specifically, participants first underwent a two-day baseline period in which they slept eight hours per night. This was followed by a five-day restriction period in which sleep was reduced to four hours in bed. Finally, they underwent a recovery period of three days in which they slept eight hours per night. As stated, sleep restriction resulted in increased activation of IL-6 synthesis.

Interestingly, the specific sleep restriction manipulation employed throughout van Leeuwen et al.,'s (2009) largely mirrored that of Lekander et al.,'s (2013), although producing different results, thus calling into question Lekander et al.,'s (2013) stipulation that their participants' sleep had not been restricted for a long enough period.

Finally, Hong and colleagues (2005) examined the relationship between various indicators of sleep architecture and IL-6 amongst a sample of males (n = 36) and females (n = 34). Participants' sleep was monitored for two consecutive nights using polysomnography, and IL-6 was collected upon awakening on both mornings. Results revealed positive correlations between IL-6 levels and REM latency, and wake after sleep onset, whereas negative correlations between IL6 and sleep efficiency and slow wave sleep were found (Hong et al., 2005). Interestingly, gender was significantly associated with sleep efficiency, percentage of stage 1 sleep, wake after sleep onset, in that women exhibited reduced time in stage 1 sleep, longer sleep times, and reduced waking after sleep onset. In other words, women exhibited less fragmented sleep, increased amounts of deep sleep, and greater sleep efficiency relative to men. As this pertains to IL6, Hong et al. (2005) specified that the relationships between IL6 and sleep efficiency and wake after sleep onset were stronger amongst the male participants in their study. Thus, suggesting that gender differences in sleep architecture in relation to IL-6 are apparent. Although this does not serve as a substitute for sleep restriction, these results underscore the importance of accounting for gender when examining the relationship between sleep and markers of inflammation, such as IL-6.

IL-1ß. Compared to IL-6, IL-1ß has received far less attention with respect to its relationship with sleep, although preliminary evidence (i.e., Krueger, 2008) has linked

sleep restriction to elevations in IL-1ß, having subsequent consequences related to cognition, memory, pain sensitivity, and mood. For instance, Krueger (2008) indicates that the relationship between sleep deprivation and IL-1ß results in symptoms associated with sensitivity to kindling, pain stimuli, cognition, memory, impairments in performance, depression, sleepiness, and fatigue. Further, he details ensuing health consequences in the form of metabolic syndrome, chronic inflammation, and cardiovascular disease (Krueger, 2008). IL-1ß follows a comparable diurnal pattern to IL-6, such that it is lower over the course of the day, and peaks around bedtime (Okun & Coussons-Read, 2010). Okun and Coussons-Read (2010) detail IL-1ß as a cytokine having a crucial role in both sleep and immunity, and describe it as having an interplay between the immune, endocrine, and sleep-wake cycle. Further, IL-1ß is implicated in the body's response to infection and injury, including how it responds to pathogens (Lopez-Castejon & Brough, 2011). Additional evidence suggests that IL-1ß and sleep are intrinsically tied, such that IL-1ß administration amongst both humans and animals has been associated with spontaneous sleep and fatigue (Jewett & Krueger, 2012). Similarly, disruptions in rats' sleep has been associated with elevations in IL-1ß (Zielinski, Kim, Karpova, McCarley, & Strecker, 2014).

Because it is so intimately tied to the body's sleep-wake cycle, it is not surprising that disruptions in one's sleep leads to disruptions in IL-1ß. For instance, Covelli et al., (1992) found significant differences in participants' IL-1ß production, depending on whether they had slept the preceding night. It should be noted that the study's participants were all male ($N = 4$), and two of the participants were unable to sleep. Relative to the participants who did sleep, those who did not sleep, failed to exhibit any IL-1ß secretion throughout

the study, leading the authors to conclude that normal sleep is associated with nocturnal rises in IL-1ß, whereas altered sleep patterns are inversely related to IL-1ß secretion (Covelli et al., 1992).

In addition to cortisol, Tartar et al. (2015) examined whether chronically and non-chronically sleep restricted individuals, who either delayed or did not delay falling asleep, differed with respect to IL-1ß. Results indicated that IL-1ß levels were inversely related with sleep duration, such that shortened sleep duration was associated with marked increases in circulating IL-1ß (Tartar et al., 2015). Further, IL-1ß was also elevated amongst the chronically sleep restricted group going to bed at a later time. Given IL-1ß's somnogenic factor in humans, the authors highlighted the apparent contradictory nature of the prolonged wakefulness and shortened sleep duration evidenced by this group (Tartar et al., 2015). These results stand in contrast with Covelli et al.,'s (1992) wherein one night of total sleep deprivation was associated with the absence of the expected nocturnal rise in IL-1ß. Given that Covelli et al.,'s (1992) study comprised exclusively of males, and that Tartar et al.,'s (2015) study comprised exclusively of females, it raises the possibility that male and females' IL-1ß is differentially impacted as a result of sleep loss.

Finally, van Leeuwen and colleagues (2009) also examined IL-1ß. Similar to IL-6, they reported an increase following sleep restriction, and sustained elevations throughout the recovery phase. Like Covelli et al.,'s (1992) study, van Leeuwen and colleagues' (2009) study solely included male participants, yet their results are not comparable. In other words, Covelli and colleagues (1992) reported that following one night of total sleep deprivation, participants did not exhibit the expected nocturnal rise in IL-1ß.

Conversely, five days of sleep restriction resulted in sustained elevations in IL-1ß among the participants in van Leeuwen and colleagues' (2009) study. The divergent results raise several possibilities including whether the specific manipulation induced the divergent results, or whether the small sample size ($N = 4$) in Covelli et al.,'s (1992) study was sufficient to produce replicable and generalizable results.

As stated, there is a stark lack of research examining IL-1ß in the context of sleep loss involving either sexes. While there is reason to believe that it is altered as a result of disrupted sleep, little research has addressed to what extent this occurs, and whether females are impacted by this in a differential manner compared to males. While IL-1ß in particular has been understudied in the context of sleep loss, as it stands, our understanding of how other biological markers, including IL-6 and cortisol are impacted is also far from clear. What is especially unclear is whether, and to what extent, women are differentially impacted following sleep loss compared to males. As a testament to this uncertainty, it has yet to be established whether men *or* women are most resilient to the effects of sleep loss, with certain studies (i.e., Vgontzas et al., 2004) suggesting that females are more resilient, whereas others (i.e., Suarez, 2008) state that females incur the greatest detriments in their psychological and physiological health. By virtue of their distinct hormonal composition, it is inherently a more complex process to examine biological changes in response to sleep loss amongst women. Therefore, in the absence of properly controlled studies examining women's biological markers in response to sleep loss, statements regarding which gender is most at risk (for encountering the deleterious effects associated with sleep loss) and how women's pro-inflammatory cytokines, as well as glucocorticoids are impacted, cannot be ascertained with confidence.

Psychological Consequences

With regards to psychological indices, as was described previously, there is a high prevalence of women impacted by sleep pathologies, yet this is far from a complete picture. In other words, not only do women comprise a significant proportion of those diagnosed with sleep problems, but they also encounter profound difficulties *as a result* of their poor sleep quality (Mallampalli & Carter, 2014). For instance, chronic insomnia has been linked with heightened levels of depression, rumination, chronic anxiety, inhibited emotions and anger (Basta et al., 2007). Not only does poor sleep induce additional psychological problems, but existing psychopathologies (e.g., depression, bipolar disorder, etc.) are also frequently associated with impaired sleep (Basta et al., 2007). Thus, there is evidence to suggest that the relationship between sleep and psychopathology is bidirectional. Traditionally, this relationship has been conceptualized from the perspective of poor sleep quality leading to reduced psychological well-being. However, there is a body of clinical research that has examined how sleep deprivation may actually serve to *reduce* symptoms of depression (Wirz-Justice & Van den Hoofdakker, 1999).

More specifically, depriving depressed patients' sleep may alleviate symptoms of depression, an intervention referred to as *induced-wakefulness therapy* (Hemmeter, Hemmeter-Spernal, & Krieg, 2010). While the majority of studies involving induced-wakefulness therapy have incorporated a sleep deprivation paradigm, Hemmeter and colleagues (2010) report that partial sleep deprivation, or sleep restriction, may be as effective in reducing depressive symptomatology. Of importance, the clinical effects observed are short-lived (Wirz-Justice & Van den Hoofdakker, 1999), and are often

unstable (Hemmeter et al., 2010); despite this, the approach has been efficacious for a broad range of individuals, regardless of their gender, age, number of hospitalizations, and severity of symptomatology (Hemmeter et al., 2010). However, restricting a non-depressed individual of their sleep leads to *diminished* positive affect, and may induce a manic or hypomanic state in up to 25% of individuals with bipolar disorder (Hemmeter et al., 2010; Wirz-Justice & Van den Hoofdakker, 1999), further reinforcing the notion of how intrinsically linked sleep duration and psychological well-being are. Additionally, in a study comprising exclusively of females (N = 621), de Wild-Hartmann et al. (2013), found that "measures of sleep were good predictors of subsequent daytime affect, whereas measures of affect did not predict subsequent sleep. Notably, negative affect did not have an impact on subsequent sleep" (p. 410). Meaning, subjective reports of poor sleep quality lead to a reduction in self-reported positive affect, whereas the reverse did not hold true.

There exists strong agreement within the literature with regards to how sleep and psychological well-being mutually impact one another (Bower, Bylsma, Morrris, & Rottenberg, 2010; de Wild-Hartmann et al., 2013; Kahn, Sheppes, & Sadeh, 2013; Minkel et al., 2010; Steptoe et al., 2008; Tartar et al., 2015). For instance, sleep deprivation may result in enhanced anxiety and depressive symptomatology amongst non-clinical samples (Hemmeter et al., 2010; Kahn et al., 2010). Further, Dinges et al., (1997) found that participants (eight females and eight males) reported an increased global score of mood disturbance following seven days of sleep restriction that required participants to restrict their sleep to five hours per night. In addition, they also found that participants' reported levels of tension-anxiety, confusion, and fatigue increased (Dinges

et al., 1997). Information regarding main effects of gender or interactions in the context of mood and sleep restriction were not highlighted. While biological samples were not collected, Dinges et al. (1997) denied taking steps to account for the females' menstrual-cycle phase, which may have inadvertently impacted their results, given that Mallampalli and Carter (2014) report that the rate at which women report sleep problems increases the week prior to menstruation.

Similar to Dinges and colleagues' (1997) findings, Tartar et al., (2015) reported that sleep loss and delayed sleep both independently contribute to decrements on clinical health measures. As stated, their study was composed entirely of female participants (N = 60) grouped on the basis of number of hours slept and whether time to sleep was delayed – information derived from a self-report questionnaire on sleep quality. Results indicated that sleep restriction, as defined by sleeping fewer than seven hours per night, was associated with reduced psychological functioning (Tartar et al., 2015). More specifically, significant correlations between sleep quality, insomnia severity, and sleepiness were found with increased total mood disturbance, perceived stress, and depressive symptomatology. Participants in the chronically sleep restricted group reported poorer sleep quality, increased reports of insomnia, as well as increased depressive symptomatology, whereas the non-chronically sleep restricted participants reported higher scores on attitude to life, better physical health, better environment health (Tartar et al., 2015). In other words, self-reported sleep restriction and a later time to bed were both associated with reduced measures of psychological health. While it was not specified whether measures were taken to account for the participants' menstrual cycle phase, the results support the notion that chronically sleep restricted individuals

encounter deleterious effects in the realm of psychological well-being. Further, it provides evidence that routinely achieving fewer than seven hours per night produces deleterious effects amongst female participants in particular, a claim that cannot be made on the basis of Dinges et al.,'s (1997) results.

With respect to sleep and its relationship to stress, Minkel et al., (2012) examined whether sleep deprived participants (one night of total sleep deprivation) differed compared to non-sleep deprived participants (one night consisting of nine hours of sleep) in both a low- and high-stress condition. Their study included 30 participants, with an equal number of men and women. In short, the stress manipulations involved mental arithmetic, with the low-stress condition having comparatively easier problems than the high-stress condition - where participants also received negative feedback to their responses. Results indicated that the sleep deprived participants exhibited elevated levels of subjective stress, anger, and anxiety throughout the low-stress condition, but that participants in both conditions exhibited comparable levels of these indicators throughout the high-stress condition. The authors reasoned that the sleep deprivation manipulation likely lowered the participants' threshold for enduring the stressful task, and therefore exhibited greater distress in the low-stress condition. Again, no information regarding main effects of gender or interactions was provided.

While Minkel et al., (2012) provided evidence that sleep deprivation results in a diminished threshold for enduring stressful tasks, additional research suggests that sleep loss may also hinder lower one's threshold for emotional regulation (Baum, Desai, Field, Miller, Rausch, & Beebe, 2014). In their study consisting of an equal number of males and females (N = 50), Baum and colleagues (2014) found that following five nights of

sleep restriction consisting of 6.5 hours of sleep, participants exhibited elevated scores on mood disturbance indices. In particular, a decrement in mood was noted, as evidenced by increased tension, anger, anxiety, fatigue, confusion, helplessness, forgetfulness, and exhaustion, and a drop in energy, alertness, and efficiency was also reported (Baum et al., 2014). Participants also endorsed feeling increasingly "on edge", nervous, and restless. It should be noted that the study's participants did not endorse heightened depressive symptomatology, and the authors reasoned that this may be attributable to the age range of the participants. More specifically, the participants ranged from the ages of 14-17, and Baum et al., (2014) argued that depressive symptoms may instead manifest as increased irritability amongst adolescents. Given that the current study will be examining college-aged students, some of whom are adolescents, having an awareness that mood decrements may manifest as irritability is valuable.

While the majority of research has traditionally linked sleep problems to indicators of negative affect, increasing amounts of research have begun incorporating indicators of positive affect (i.e., Bower et al., 2010; Haack & Mullington, 2005; Steptoe et al., 2008). For instance, in a study consisting of 14 females and 26 males, Haack and Mullington (2005) found that participants randomly assigned to restrict their sleep to 4-hours per night exhibited diminished levels of optimism-sociability compared to the group that slept 8-hours per night. This took place over the course of 12 consecutive nights. Interestingly, they noted that the sleep-restricted participants' levels of optimism-sociability declined steadily over the course of the week. Information related to main effects or interactions of gender were not discussed.

Similarly, Bower et al., (2010) conducted a study in which sleep quality and affect were examined. Their study included 96 participants (75% female), that were divided into three groups on the basis of diagnosis; more specifically, 35 participants were in the major depression group, 25 participants were in the minor depression group, and 36 participants were in the control group – a group with no history of psychopathology. Bower and colleagues (2010) indicated that groups were matched on the basis of age, ethnicity, and gender. Sleep quality was assessed using the PSQI. Results indicated that participants who reported poor sleep quality evidenced elevated negative affect and reduced positive affect. Interestingly, poor sleep quality no longer significantly predicted negative affect once the impact of depression status was accounted for. This stands in contrast with the relationship between sleep quality and positive affect, which persisted regardless of depression status.

Finally, Steptoe and colleagues (2008) examined the relationship between positive affect and wellbeing, and how these relate to reported sleep problems. The study included 486 men and 250 women, all of whom were asked to complete measures related to positive affect, eudaimonic wellbeing, and sleep problems (as measured by the Jenkins Sleep Problems Scale). Results indicated self-reported positive affect and eudemonic well-being were correlated with fewer self-reported sleep problems. With respect to gender differences, women exhibited significantly higher scores on the sleep problems scale, and men exhibited elevated positive affect and eudaimonic wellbeing.

In all, it is evident that the relationship between poor sleep quality and quantity and mood disturbance is well established. Nonetheless, certain gaps and limitations are quite prominent. Most notably, it has been reported that subjective measures of sleep do not

necessarily approximate an individual's objective sleep and mood (de Wild-Hartmaan et al., 2013), therefore calling into question the external validity of the studies, typically employing a self-report methodology involving sleep *quality* (i.e., Bower et al., 2010) or *problems* (i.e., Steptoe et al., 2008). Further, it appears as though sleep *deprivation* manipulations are more frequently encountered throughout the literature, and while important, it does not represent the type of short sleep duration most frequently encountered in the general population. Moreover, women have been shown to experience psychological problems in a different manner compared to men (Mallampalli & Carter, 2014), which tend to follow poor sleep, rather than precede it (de Wild-Hartmann et al., 2013). It is therefore surprising that studies (i.e., Dinges et al., 2007; Haack & Mullington, 2008; Minkel et al., 2012) that have examined the interplay of psychological well-being and sleep have not partialed out main effects or interactions involving gender. Generally, little research has included a female-specific population as a means for further elucidating this gender's combined experience of short sleep and affect, which may likely be different from that of males'. Despite there being a strong body of literature examining the impact that short sleep has on ensuing mood, our understanding is far from comprehensive, especially in light of these limitations.

Neurocognitive Consequences

Like the biological and psychological realms of behavioral sleep research, the neurocognitive consequences following sleep *restriction* have received far less attention, relative to the consequences following sleep *deprivation* (Stenuit & Kerkhofs, 2008). Of the studies that have examined the neurocognitive consequences of sleep restriction, tests such as the "Wilkinson Auditory Vigilance" or the "Psychomotor Vigilance Test" (PVT)

have frequently been employed (Belenky et al., 2003; Dinges et al., 1997; Stenuit & Kerkhofs, 2008), and results have consistently shown that restricted sleep produces increased reaction times. The relative impact of sleep restriction on other neurocognitive variables, such as attention, memory, language-based tasks, visuo-spatial ability, motor performance, mental arithmetic, and executive functions such as mental flexibility, divided attention, verbal fluency, and inhibition are not as well understood (Stenuit & Kerkhofs, 2008). To further complicate our understanding, a large proportion of sleep restriction studies that have examined neurocognitive variables have also been biased towards including a male, rather than a female or mixed-gender sample (e.g., Belenky et al., 2003; Faraut et al., 2012). Given that females have been shown to encounter the deleterious effects of sleep restriction in a different capacity than men, such as enhanced deficits on tasks of vigilance, including the PVT (Stenuit & Kerkhofs, 2005), and that extant results on the neurocognitive consequences of sleep restriction are mixed, it is evident that there is a need for replications of prior paradigms involving female-specific samples.

In a comprehensive review of the literature, Waters and Bucks (2011) summarized the neuropsychological effects of sleep loss, which they defined as routinely achieving less than seven hours of sleep. Specific consequences on one's neuropsychological functioning following sleep loss include decrement in working memory, divided attention, inhibition, verbal fluency, and problem solving. In addition, increased response time on the Digit Symbol Modality Test and Trail Making Tests, as well as a reduction in performance on tests of attention and vigilance, such as the PVT have been noted (Martin, Engleman, Deary, & Douglas, 1996). There is also evidence of

diminished mental arithmetic performance in the form of slower performance and an increase in number of errors made and interestingly, this was a linear relationship, in that the longer an individual had been sleep deprived for, the worse their performance (Van Dongen, Maislin, Mullington, &Dinges, 2003). Further, Pilcher et al., (2007) reported decreased performance on language-based and speech tasks, motor tasks, and social cognition following sleep loss, such that sleep deprived participants exhibited a reduction in expressive language, as evidenced by a notable decrease in the number of spontaneously produced words. With respect to motor performance, approximately a 30% decrease in hand-eye coordination performance, particularly in the realms of speed and accuracy have been reported (Williamson & Feyer, 2000). Consequences in terms of one's social cognition have also been documented, in the form of deficits in emotional decision-making, interpersonal functioning, and moral judgment (Killgore, Balkin, & Wesenstem, 2006).

Stenuit and Kerkhofs (2008) conducted a study wherein the neurocognitive effects of sleep restriction were assessed amongst a female sample (N = 20). The study took place over the course of five nights. The first night, the baseline, participants slept from 11 pm to 7 am. The following three nights, the participants' sleep was restricted, and they slept from 1 am to 5 am. The last night was their recovery night and they slept from 11 pm to 7 am. They assessed the participants' cognitive functioning in the following three domains: attention, memory, and abstraction. Attention was assessed using selective and divided attention tasks and tasks requiring the inhibition of automatic processes (e.g., the Stroop test, Trail Making Test - Part B). Memory was assessed using tasks of visual, auditory, and logical memory (e.g., Buschke 16 items, Paced Auditory Serial Task, etc.).

Abstraction was assessed using the Wisconsin Card Sorting Task (WCST), a measure of cognitive flexibility that is particular attuned to frontal lobe dysfunction.

In all, results supported previous findings that demonstrate an increase in reaction time following sleep restriction (Stenuit & Kerkhofs, 2008). Additionally, they found diminished performance on tasks requiring the inhibition of automatic activity (e.g., Stroop task) and those requiring the formation of a memory trace (e.g., Buschke's 16 items memory test). Interestingly, there was no indication that participants' response accuracies diminished, just that the time required to respond increased. Somewhat paradoxically, the enhanced response latencies were accompanied by impulsiveness in responding, in that the participants exhibited difficulties inhibiting their dominant response in tests of attention. Interestingly, participants' performance on the WCST, a measure of frontal abstraction abilities did not reflect evidence of diminished performance, thus failing to support the frontal lobe hypothesis detailed in Waters and Bucks' (2011) review, which posits that sleep restriction disproportionately impinges on the frontal lobes' ability to successfully perform its executive functions as a result of changes in cerebral metabolism. Critics of this hypothesis, however, point out that sleep research has failed to find consistent deficits in tasks requiring frontal functions.

Response speed is the traditional metric used to determine one's information processing speed, a domain which has also been shown to increase following sleep loss (Cohen-Zion, Shabi, Levy, Glasner, & Wiener, 2016). Cohen-Zion et al., (2016) examined adolescent participants' (N = 41) (23 males, 18 females) processing speed in response to both partial sleep deprivation and sleep extension. The partial sleep deprivation condition required that participants spend six hours per night in bed for a

span of four nights, whereas the sleep extension condition required that participants spend ten hours in bed for a span of four nights. Results indicated that relative to the sleep extension condition, participants in the partial sleep deprivation condition exhibited poorer performance on tasks of information processing speed, executive function, motor skills, and attention (Cohen-Zion et al., 2016). The authors reasoned that sleep loss results in significant decrements in performance, whereas "sleep satiation seemed to allow for optimal performance on components of the task that required heightened effort or motivation." (Cohen-Zion et al., 2016, p. 396). Thus, having implications in terms of how individuals approach, interpret, encode, and subsequently respond to data they are confronted with on a daily basis.

Doran, Van Dongen, and Dinges (2001) also examined the cognitive consequences following sleep deprivation in the realms of reaction time and performance variability. Their sample included 28 male participants, 13 of whom were placed in the experimental group, who underwent four days of total sleep deprivation. The other group underwent sleep restriction, and they were permitted to sleep two hours every 12 hours. Results indicated that participants in the total sleep deprivation group exhibited greater reaction times and greater performance variability on the PVT relative to the sleep restriction group. Additionally, participants in the sleep deprivation group exhibited a greater number of omission as well as commission errors, characterized by performance variability and instability. Doran et al., (2001) remarked that the performance instability could possibly be accounted for by the reduced attention and alertness experienced following a period of sustained wakefulness, placing the participant in a state in between wakefulness and sleep. In all, these results are largely consistent with those reported by

Martin and colleagues (1996) which detail an increase in reaction time following sleep deprivation.

Given that chronic sleep restriction is far more common of an occurrence amongst the general population compared to sleep deprivation, it is imperative to understand whether there are differences in how this manifests cognitively. In other words, having a participant come into the lab and deprive them of a single night of sleep certainly produces deleterious effects (Van Dongen et al., 2003), but how would this compare to an individual who experiences poor sleep on a longer-term basis? In an attempt to address these questions, Van Dongen and colleagues (2003) conducted a study wherein participants either underwent total sleep deprivation, or chronic sleep restriction. The total sleep deprivation group was split into three levels, such that participants' cognitive functioning was tested following one, two, and then three nights of total sleep deprivation (Van Dongen et al., 2003). The chronic sleep restriction group was also divided into three levels, and participants either slept four, six, or eight hours per night for a period of 14 days (Van Dongen et al., 2003). While eight hours of sleep per night does not constitute sleep restriction by most standards (e.g., Alhola & Polo-Kantola, 2007), this group was likely included as a control group. Specific cognitive areas that were assessed included attention, working memory, and reaction time.

Not surprisingly, results indicated that the most profound deficits were seen in the group that underwent three days of total sleep deprivation. Another expected result was that the group that slept eight hours per night over the span of 14 days did not exhibit any deficits (Van Dongen et al., 2003). The chronic sleep restriction group that slept six hours per night exhibited the same deficits as participants who underwent total sleep

deprivation for a period of one night (Van Dongen et al., 2003). Meaning, if an individual were to pull an ‘all-nighter’ for instance, they would exhibit the same sort of cognitive deficits as an individual who has been moderately restricting their sleep for a period of two weeks. These deficits included a decline in PVT and working memory performance. Finally, the chronic sleep restriction group that slept four hours per night exhibited deficits in attention and working memory similar to deficits exhibited in the two-night sleep deprivation group, whereas participants that restricted their sleep to six-hours per night exhibited comparable impairments to the one-night sleep deprivation group (Van Dongen et al., 2003).

Importantly, out of the study’s 48 participants, no females were assigned to the total sleep deprivation group (which consisted of 13 males), two females (and seven males) were assigned to the eight-hour sleep restriction group, three females (and ten males), were assigned to the six-hour sleep restriction group and finally, one female (and 12 males) was assigned to the four-hour sleep restriction group. Thus, out of the study’s 48 participants, only six were female. In light of mounting research that suggests sleep restriction and deprivation differentially impact men and women, it is conceivable that a sleep deprivation group devoid of any females, and sleep restriction groups that are disproportionately male are questionable in terms of their external validity. Meaning, it is likely that their results are more appropriately extrapolated to represent males as opposed to females.

While it is recognized that sleep restriction leads to an increase in reaction time, our understanding of how other neurocognitive domains such as attention, memory, executive functioning, and verbal fluency are impacted remains far from clear (Stenuit &

Kerkhofs, 2008). Similar to the biological and psychological realms, there exists a stark lack of research examining the neurocognitive consequences that females encounter following sleep restriction, as the vast majority of studies have utilized an exclusively male (e.g., Belenky et al., 2003; Doran et al., 2001; Faraut et al., 2012) rather than a female, or mixed-gender sample. Studies that have included women (i.e., Stenuit & Kerkhofs, 2008) note that they encounter the deleterious effects of sleep restriction differently than men in the form of enhanced deficits on tasks of vigilance. From a practical standpoint, deficits in neurocognitive functioning have consequences in the form of motor vehicle accidents, sustaining attention in the home/work environment, as well as problem-solving everyday tasks (Short & Banks, 2014). Without a proper understanding of whether and how women are differentially impacted, our understanding of the functional neurocognitive consequences associated with sleep restriction are incomplete.

Conclusion

Sleep restriction has become a characteristic feature of modern society (Stenuit & Kerkhofs, 2008), and the average number of hours slept continues to decline to the extent that approximately one-third of the American population is now chronically sleep restricted (Luyster et al., 2012). While this may be attributable to a number of factors including evolving societal pressures, cultural attitudes, and a lack of awareness, the extent to which individuals encounter sleep-related ailments in the form of biological, psychological, and neurocognitive functioning will inevitably increase. As it stands, behavioral sleep medicine's literature is plagued by a number of flaws, including a lack of attention devoted to sleep *restriction* as compared to sleep *deprivation* (Stenuit &

Kerkhofs, 2008) as well as whether an individual's functioning is differentially impacted depending on whether their contracted amount of sleep is due to volitional or non-volitional factors (Goel et al., 2013). A particularly prominent flaw within the literature pertains to women's underrepresentation or exclusion in studies (Stenuit & Kerkhofs, 2008; Suarez, 2008), or the lack of controls implemented to account for their endogenous hormonal fluctuations (i.e., Dinges et al., 1997; Faraut et al., 2012). While there is reason to believe that females encounter greater deleterious effects following poor sleep quality compared to men (i.e., Suarez, 2008), our understanding is far from clear, especially when examining the biological, psychological, and neurocognitive elements.

For instance, when examining glucocorticoids such as cortisol or pro-inflammatory cytokines including IL-6 and IL-1ß, it has yet to established whether men *or* women are most resilient to the effects of sleep loss, as certain studies (i.e., Vgontzas et al., 2004) suggest that women are most resilient to the effects of sleep loss, whereas others (i.e., Suarez, 2008) report that women are most likely to encounter the deleterious effects, relative to males. Our understanding is further clouded, as there is a lack of properly controlled studies (i.e., Dinges et al., 2007; Faraut et al., 2012) that account for women's hormonal fluctuations, which have the potential to obscure fluctuations in biological markers following sleep loss. While this is especially problematic in terms of biological variables, what has yet to be established is whether these are measures that are as essential when examining other variables, such as in the psychological and neurocognitive realms. There is however reason to believe that women's endogenous hormonal fluctuations have the potential to impact one's subjective report of sleep, as Mallampalli and Carter (2014) indicated that the rate at which women report sleep

problems increases the week preceding menstruation, and given that poor sleep precedes a decrease in positive affect (de Wild-Hartmann et al., 2013), it stands to reason that psychological variables, including well-being, are vulnerable to hormonal fluctuations as well. Further, if females are reporting diminished sleep quality at greater frequencies at certain phases of their menstrual cycle, then it also stands to reason that they are also vulnerable to neurocognitive consequences as well. In particular, what is well established is that increases in reaction time reliably follow sleep restriction, but similar to studies examining biological and psychological variables, the vast majority of studies have utilized an exclusively male (e.g., Belenky et al., 2003; Doran et al., 2001; Faraut et al., 2012) rather than a female, or mixed-gender sample. In all, it is conceivable that some form of pathological sleep, whether this takes the form of poor sleep quality, diminished quantity, deprivation, or restriction, produces adverse effects in one's functioning. However, our ability to extrapolate these results is limited, particularly when the sleep *restriction* is specifically encountered at an increasingly high rate in the American population. What is also limited is our ability to make specific claims regarding how women in particular are impacted. Thus, there is a crucial need to examine whether and to what extent females' biological, psychological, and neurocognitive functioning is affected following sleep restriction that is either naturally occurring or imposed in an experimental manner.

Hypotheses

It is apparent that sleep problems precede a host of deteriorations in the biological, psychological, and neurocognitive realms. Despite this, our understanding of how sleep restriction in particular, impacts women, relative to males, is far from comprehensive, as

evidenced by the limited number of studies including women, or allotting women necessary representation relative to men. Given that sleep restriction best approximates the current state of sleep in the general population, there is a pressing need to identify its consequences. As a means for addressing these gaps and inconsistencies, the current study will attempt to uncover how females' biological, psychological, and neurocognitive functioning is impacted depending on whether their sleep is restricted in an acute manner, or whether it is restricted in a chronic manner. In other words, we will examine participants who, without any experimental manipulation, sleep an average of less than seven hours per night and also report reduced sleep quality. These participants are referred to as *naturally sleep restricted (NSR).* Conversely, participants who sleep between seven and nine hours per night, and do not report reduced sleep quality will undergo an experimental manipulation that restricts their sleep. These participants are referred to as *experimentally sleep restricted (ESR).*

Research question 1.1. Are there significant differences between NSR and ESR groups on biological markers of health?

First, we hypothesize that at baseline, the NSR group will have elevations relative to the ESR group (i.e., prior to any sleep restriction manipulation). Second, following sleep restriction, we hypothesize that the ESR group will have elevations on their biological markers of health relative to the NSR group.

Research question 1.2. Are there significant differences between baseline and post sleep restriction on biological measures of health in the ESR group?

We hypothesize that the ESR group will exhibit elevations on biological measures following a week of sleep restriction.

Research question 2.1. Are there significant differences between NSR and ESR groups on psychological markers of health?

First, we hypothesize that at baseline, the NSR group will exhibit reduced psychological functioning relative to the ESR group (i.e., prior to any sleep restriction manipulation). Second, following sleep restriction, we hypothesize that the ESR group will exhibit reduced psychological functioning relative to the NSR group.

Research question 2.2. Are there significant differences between baseline and post sleep restriction on psychological measures of health in the ESR group?

We hypothesize that the ESR group will exhibit reduced psychological functioning following a week of sleep restriction.

Research question 3.1. Are there significant differences between NSR and ESR groups on neurocognitive markers of health?

First, we hypothesize that at baseline, the NSR group will exhibit reduced neurocognitive functioning relative to the ESR group (i.e., prior to any sleep restriction manipulation). Second, following sleep restriction, we hypothesize that the ESR group will exhibit reduced neurocognitive functioning relative to the NSR group.

Research question 3.2. Are there significant differences between baseline and post sleep restriction on neurocognitive measures of health in the ESR group?

We hypothesize that the ESR group will exhibit reduced neurocognitive functioning following a week of sleep restriction.

Chapter 3: Method

Participants

Twenty healthy participants divided in two groups were included in the study. There were 11 participants in the Naturally Sleep Restricted (NSR) group, and 9 participants in the Experimental Sleep Restriction Group (ESR). All participants were female, and ranged from 18 to 22 years old (M = 19.65 ± SD 1.182). In order to be included in the study, participants had to meet certain inclusion criteria, which were ascertained during a preliminary telephone interview. In order to be included, participants denied having trouble sleeping, receiving a formal diagnosis related to sleep or psychiatric functioning, or using any drugs and/or medications that would interfere with their sleep. In order to be included, all participants needed to be females between the ages of 18-35. If participants met the inclusion criteria, an initial meeting in the laboratory was scheduled, in which the Mini International Neuropsychiatric Interview (MINI) (Sheehan et al., 1998) was administered to ascertain that participants did not meet criteria for a psychiatric condition.

Determination of group assignment was based on normality of sleep, as determined by the following: average number of hours slept throughout an initial baseline week (recorded via actigraphy), score on the Insomnia Severity Index (ISI) (Morin, 1993), and the Pittsburgh Sleep Quality Inventory (PSQI) (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). Generally, if participants slept an average of less than 7 hours per night, scored above a 5 on the PSQI, and above an 8 on the ISI, these sufficed as indicators of reduced sleep quality; viewed in conjunction with one another, these participants were placed in the NSR group. If they slept between 7-9 hours and had scores on the ISI and

PSQI that were within normal limits, they were placed in the ESR group (see Appendix A).

Due to the confounding effects of hormones throughout the menstrual cycle's follicular phase, all participants biological samples were collected throughout the luteal phase of their cycle. The two groups did not differ significantly with respect to age or body mass index (see Appendix B), and all were students enrolled in an undergraduate program. The study was approved by the Internal Review Board at Nova Southeastern University. All women gave a written informed consent. The participants received financial compensation in the form of a gift card for their involvement in the study.

Measures/Materials

Screening measure. Participants who met initial inclusion criteria were scheduled for further screening of possible psychiatric condition via a clinical interview. This was completed using the Mini International Neuropsychiatric Interview (MINI) (Sheehan et al., 1998).

MINI. The MINI is a diagnostic interview that focuses on the diagnosis of mental disorders in addition to suicidality based on the Diagnostic and Statistical Manual IV (DSM-IV) and the International Classification of Diseases 10 (ICD-10), and its administration takes approximately 15 minutes (Hyphantis, Kotsis, Voulgari, Tsifetaki, Creed, & Drosos, 2011). The MINI entails branching tree logic, such that if a participant or patient endorses symptoms associated with a particular disorder, then a more in-depth screening of that disorder will take place (Hyphantis et al., 2011). Inter-rater reliability as well as test-retest reliability of the MINI compared to the Structured Clinical Interview for DSM (SCID) and the Composite International Diagnostic Interview (CIDI)

demonstrate that the MINI yields valid and reliable DSM-IV diagnoses (Hyphantis et al., 2011).

Sleep measures. Sleep was assessed using questionnaires and actigraphy. More specifically, the Insomnia Severity Index (ISI) (Morin, 1993) and the Pittsburgh Sleep Quality Inventory (PSQI) (Buysse et al., 1989) were administered as screening measures to identify participants' reported symptoms of insomnia and sleep quality. Throughout the experiment, objective measures of sleep were collected using actigraphy (Actiwatch Spectrum Plus, Philips Respironics) and a daily sleep diary.

ISI. The ISI is a 7-item self-report questionnaire that assesses insomnia severity (Morin, 1993). The ISI has a cut-off score of 8, which is suggestive of sub-threshold insomnia (Morin et al., 2011). Scores ranging from 0-7 indicate the absence of insomnia, scores ranging from 8-14 indicate sub-threshold insomnia, scores ranging from 15-21 indicate moderate insomnia, and scores ranging from 22-28 indicate severe insomnia (Morin et al., 2011). It has strong internal consistency for clinical samples having insomnia and those without, demonstrating Cronbach's alpha estimates of 0.90 and 0.91, respectively (Morin, Belleville, Belanger, & Ivers, 2011). Morin et al., (2011) report that the ISI exhibits strong convergent validity, as it correlates strongly with the PSQI (r = 0.80), and also exhibits significant correlations with measures of anxiety and depression, as well as different dimensions of fatigue and quality of life, all of which are variables associated with insomnia.

PSQI. The PSQI is a 19-item assessment of sleep quality that includes 7 components, including subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medications, and daytime dysfunction,

which are derived based on responses to the assessment's 19 items (Buysse et al., 1989). It also provides a global component score of sleep quality. It has a cutoff score of 5, which distinguishes good sleepers from poor sleepers (Smith & Wegener, 2003). The PSQI exhibits high internal consistency, with Cronbach's alpha of 0.83 for the global component score, and correlation coefficients for component to global scores ranging from 0.35 (sleep disturbance) to 0.76 (habitual sleep efficiency and subjective sleep quality) (Smith & Wegener, 2003). Further, there is also a strong intercorrelation coefficient of 0.83 among the items (Smith & Wegener, 2003). With respect to validity, many PSQI components correlated significantly with sleep diary scores, providing evidence of criterion validity. In particular, amongst a sample of participants diagnosed with primary insomnia, PSQI estimates of sleep duration ($r = 0.81$, $p < .001$) and sleep latency ($r = 0.71$, $p < .001$) correlated significantly with sleep diary estimates.

Actigraphy. Actigraphy provides an objective estimate of participants' sleep quantity and quality, is worn like a watch, and is sensitive to motion (Sciberras et al., 2010). The 'gold standard' of sleep assessment is polysomnography, but due to limitations surrounding its implementation (i.e., cost, transportation, etc.), actigraphy has been explored as an alternative (Aili, Åström-Paulsson, Stoetzer, Svartengren, & Hillert, 2017). Sadeh, Hauri, Kripke, and Lavie (1995) report that actigraphy is a valid measure of sleep, having significant correlations with polysomnographic measures of total sleep period ($r = 0.90$), total sleep time ($r = 0.89$), and wake after sleep onset ($r = 0.70$).

Biological measures. The specific biological measures that were employed assessed participants' cortisol, IL-6, and IL-1β. Saliva samples were run in duplicate and measured using human enzyme immunoassay kits per the manufacturer's instructions

(Salimetrics LLC, USA). All samples, which were within the detection ranges specified in the immunoassay kits, were read in a BioTek ELx800 plate reader (BioTek Instruments, Inc, USA) at 450 nm with a correction at 630 nm. The variation of cortisol, IL-6, and IL-1β were within the expected limits. The final concentrations for the biological variables were produced by interpolation from the standard curve in μg/dL for cortisol and pg/mL for IL-6 and IL-1β.

Psychological measures. The specific psychological measures that were administered include the Profile of Mood States (POMS) (McNair, Lorr, & Droppleman, 1971), the State-Trait Anxiety Inventory (STAI) (Spielberger, Gorsuch, & Lushene, 1970), the Perceived Stress Scale (PSS) (Cohen, Kamarck, & Mermelstein, 1983) and the Epworth Sleepiness Scale (ESS) (Johns, 1991).

POMS. The POMS is 65-item self-report assessment that includes six factors, including confusion, tension, depression, anger, fatigue, and vigor (McNair et al., 1971). It also includes a composite score of total mood disturbance. McNair et al., (1971) report that internal consistency ranges from 0.63 to 0.96 whereas test-retest reliabilities range from 0.65 for vigor and 0.74 for depression, while also noting that it also has strong criterion-related validity. Subsequent factor analyses, however, suggest that the POMS may actually tend towards three state dimensions; namely, neuroticism, extraversion, and arousal (Boyle, 1987). Conversely, evidence derived from a principal components factor analysis suggests that five, rather than six of the original POMS factors emerge (Bourgeois, LeUnes, & Myers, 2010). Meaning, the confusion scale did not soundly emerge as a factor, and interestingly, there was an additional suggested factor that emerged, namely, mild depression (Bourgeois et al., 2010). There is also short version,

which includes 37 items (POMS-SV) (Schacham, 1983), as well as the EPOMS, a 30-item abbreviated scale (EDITS, 1999). The current study will utilize the original long-form, consisting of 65-items (McNair et al., 1971).

STAI. The STAI is a 40-item self-report questionnaire that assesses both state and trait anxiety, each comprising 20 questions each. This instrument has been widely used in both research and clinical settings. Spielberger et al., (1983) report that internal consistency coefficients range from .86 to .95, and that for young adult women, internal consistency is 0.93 for state anxiety, and 0.92 for trait anxiety. Test-retest reliability coefficients range from .65 to 0.75. In addition, Spielberger (1989) provides extensive evidence regarding the measure's construct and concurrent validity. In terms of content validity, Julian (2011) reports overall correlations between the STAI and related measures of anxiety to be 0.73 and 0.85 respectively for the Taylor Manifest Anxiety Scale (Taylor, 1953) and the Cattell and Scheier's Anxiety Scale Questionnaire (Krug, Scheier, & Cattell, 1976).

PSS. The PSS is a 10-item self-report questionnaire that assesses the perception of stress (Cohen et al., 1983). Lee (2012) reports that it exhibits a Cronbach's alpha of 0.78 and a test-retest reliability of 0.85 following two days, and 0.55 following six weeks. Construct validity has been established between the PSS and other measures of stress and health behaviors (Cohen & Janicki-Deverts, 2012).

ESS. The ESS is an 8-item questionnaire that assesses daytime sleepiness in adults, such as the propensity to fall asleep while performing activities throughout the daytime (Johns, 1991). The ESS has been shown to have an internal consistency of 0.71 amongst a sample of 18-25 year olds (Lukowski & Milojevich, 2015), and a test-retest

reliability of 0.82 (Johns, 1992). Johns (1991) provides evidence of this measure's construct validity; in particular, it is capable of detecting changes in sleepiness amongst a sample of individuals with narcolepsy.

Neurocognitive measures. The neurocognitive measures were all administered via Joggle Research's *Cognition* platform (Joggle Research, Inc., Seattle, WA). The specific tasks include the psychomotor vigilance task (PVT) (Dinges & Powell, 1985), the motor praxis task (MP) (Gur et al., 2001), the visual object learning test (VOLT) (Glahn, Gur, Ragland, Censits, & Gur, 1997), the line orientation test (LOT) (Benton, Varney, & Hamsher, 1978), the digit symbol substitution task (DSST) (McLeod, Griffiths, Bigelow, & Yingling, 1982; Wechsler, 1958), the balloon analog risk test (BART) (Lejeuz et al., 2002), the N-back (Kirchner, 1958), and abstract matching (AM) (Glahn, Cannon, Gur, & Ragland, 2000).

PVT. The PVT is a measure of reaction time to visual stimuli occurring at random (Basner & Dinges, 2011). Basner et al., (2015) note that the PVT measures vigilant attention and is sensitive to the effects of acute and chronic sleep deprivation. Reportedly, it has negligible practice effects and has been regarded as an externally valid measure of sustained attention deficits (Basner & Dinges, 2011). The primary brain regions involved when performing the PVT include the prefrontal cortex, the motor cortex, the inferior parietal, and portions of the visual cortex (Basner et al., 2015). The *Cognition* platform utilizes a 3-minute version of the PVT, which has been documented to have adequate reliability and validity. Specifically, Basner, Mollicone, and Dinges (2011) report that intraclass correlation coefficients indicate maximal reliability for the number of PVT lapses (ICC = 0.888, $p < .0001$) as well as median response time (ICC = 0.826, $p <$

.0001). In terms of validity, the computerized 3-minute PVT paralleled impairments observed in the 10-minute PVT following sleep restriction, and has been reported to have good validity (Elmenhorst, Hormann, Oeltze, Pennig, & Vejvoda, 2013).

MP. The MP assesses sensorimotor control and requires that participants click on an ever-shrinking box that appears on their screen (Neves et al., 2014). The participant is exposed to 20 boxes, which become increasingly smaller and move locations, and are thus increasingly difficult to track (Basner et al., 2015). This particular subtest is believed to incorporate the brain's sensorimotor cortex (Basner et al., 2015). Swagerman and colleagues (2016) report a Cronbach's alpha of 0.93 for accuracy and 0.95 for speed. The MP has been validated for detecting sex-differences (Roalf et al., 2014), age effects (Gur et al., 2012), and has been shown to have associations with psychiatric disorders (Neves et al., 2014).

VOLT. The VOLT is a measure of participants' memory for complex figures (Glahn et al., 1997). Participants are presented with a series of 10 complex figures that they must later correctly identify from a group of 20 figures, some of which include the previously presented figures. The VOLT is regarded as a measure of spatial learning and memory, and requires involvement from the medial temporal cortex and hippocampus (Basner et al., 2015). Glahn et al.'s (1997) initial study indicates that it demonstrates strong internal consistency of 0.92, and a split-half reliability of 0.906. as well as convergent validity with the Continuous Visual Memory Task (r = 0.56) and discriminant validity with the Vocabulary subtest of the Wechsler Adult Intelligence Scale-Revised (Glahn et al., 1997).

LOT. The LOT is derived from the widely-used and well validated Judgment of Line Orientation (JLO) (Benton et al., 1978). Throughout the test, participants are required to maneuver one line to match another's orientation; in particular, the test items vary in difficulty based on the line's angle, length, and distance from the stationary line (Basner et al., 2015). The LOT assesses participants' spatial orientation, which requires involvement of the right temporo-parietal cortex and visual cortex (Basner et al., 2015). As indicated, the LOT is derived from the JLO, which is a well-validated measure. In terms of reliability, Swagerman et al., (2016) report that the LOT exhibits adequate reliability, with a Cronbach's alpha of 0.79 for accuracy and 0.97 for speed.

DSST. The DSST is a computerized version of the widely used Wechsler Adult Intelligence Scale-III's (WAIS-III) subtest (McLeod et al., 1982). Wechsler (1958) described the subtest as an assessment of associative learning, and relative to the current WAIS-V edition, can be best compared to the *Coding* subtest. The task requires that participants refer to a displayed legend that refers digits 1-9 to a specific symbol; importantly, each number has its own specific symbol. Throughout administration, each number appears in isolation, and the participant is required to match the digit to the correct symbol as quickly as they can. The DSST is described as a task of complex scanning and visual tracking and requires the involvement of the temporal cortex, prefrontal cortex, and motor cortex (Basner et al., 2015). The test-retest correlation coefficient of the DSST has been reported to be 0.84 (Bittner, Carter, Kennedy, Harbeson, & Krause, 1986). In terms of concurrent validity, the subtest correlates with other conventional, computerized neuropsychological tests (e.g., Finger Tapping,

Switching Attention, and the Continuous Performance Test) by a margin of 0.28-0.40 (Gualtieri & Johnson, 2006).

BART. The BART is a measure of risk-taking behavior (Lejeuz et al., 2002). It requires that participants either inflate an animated balloon, or conversely, collect a reward. The reward increases proportionally to how inflated the balloon becomes. Although, the balloon 'pops' following a hidden number of pumps, in which case, the participant is not rewarded. Participants are therefore required to modulate the extent of their risk-taking behavior in the form of number of pumps. Basner et al., (2015) report that risk-taking behaviors implicate the orbital frontal and ventromedial prefrontal cortex, amygdala, hippocampus, anterior cingulate cortex, and the ventral striatum. White, Lejeuz, and de Wit (2008) indicate that the BART has strong reliability, such that test-retest following sessions was estimated to range from 0.66-0.78. In terms of validity, the BART has been shown to correlate with several risk-taking behaviors including drug and alcohol use, gambling, theft, and aggression, in both adolescent and adult populations (Hunt, Hopko, Bare, Lejeuz, & Robinson, 2005).

N-back. The N-back is a measure of working memory capacity and continuous performance (Kirchner, 1958). In short, the participant is presented with a series of stimuli, and they are then asked to denote when the current stimulus matches the one presented *n* steps earlier (Kane, Conway, Miura, & Colflesh, 2007). In order to vary the task's difficulty, the load factor *n* can be adjusted. Basner et al., (2015) report that the N-back requires involvement from the dorsolateral prefrontal cortex, the cingulate, and the hippocampus. In terms of reliability, Kane et al., (2007) report that Cronbach's alpha ranges from 0.54-0.84, thus denoting strong reliability. With respect to validity, the N-

back exhibits convergent validity, although the findings are generally mixed. For instance, Shelton, Elliot, Hill, Calamia, and Gouvier (2009) found strong convergent validity between performance on an operation span task and the N-back (r = 0.46), although its validity as a "pure" working memory has been contested, likely stemming from the fact that working memory and/or executive functioning are not unitary abilities (Jaeggi, Buschkuehl, Perrig, & Meier, 2010). More specifically, Jaeggi et al., (2010) failed to find evidence of convergent validity between the N-back and other measures (e.g., Reading Span Task) of working memory.

AM. The AM task assesses abstraction and concept formation (Glahn et al., 2000), and is regarded as a validated test of executive function (Swagerman et al., 2016). Participants are asked to discern general rules regarding the presented objects' properties from specific examples. Specific object properties differ based on perceptual dimensions, such as shape and color, and participants are asked to sort a target object to one of two pairs. Sorting is based on implicit, abstracted rules, derived from the different object properties (Swagerman et al., 2016). Basner et al., (2015) indicate that AM involves the prefrontal cortex. In terms of validity, Glahn et al., (2000) report that a positive correlation between performance on an AM task with memory and Digit Span may be viewed as initial convergent validity, and Basner et al., (2015) report that it is a validated measure.

Procedures

Participants were initially screened for the preliminary inclusion criteria by means of a brief telephone interview. Those who met preliminary inclusion criteria and agreed to be evaluated were scheduled for further screening via a clinical interview. The clinical

interview began with a review and completion of the informed consent form. The clinical interview incorporated the MINI, and administration took approximately 15 minutes. Participants also completed additional measures, including a demographic form, the PSQI, and the ISI. Following this, participants were given an actigraph, and were provided with instructions and requirements. Participants were asked to sleep as usual, to press a button on the actigraph prior to falling asleep and upon waking up (referred to as an *event marker*), and to keep the actigraph on their wrist for a total of seven days, and that it should only be removed when bathing and/or swimming. This period of seven days was referred to as the baseline week. Throughout the seven days, participants were instructed that they would receive an email every morning prompting them to complete a sleep diary, which included questions pertaining to overall well-being, on facets such as sleep quality and appetite. Finally, a second meeting was scheduled in which participants would return to the lab seven days later to return the actigraph and await further instruction. All participant information was coded and stored in a locked cabinet. Electronic sleep diary data was stored online in a password-protected account.

Procedures for participants representing the Naturally Sleep Restricted (NSR) group. Based on the preliminary sleep measures collected throughout the baseline week, participants generally exhibited two of the following: an average sleep time of less than 7 hours (per actigraphy), and/or ISI score of greater than 8, and/or a PSQI score of greater than 5. These participants were assigned to the NSR group. Participants returned to the lab for one testing session, in which the biological, psychological, and neurocognitive measures were collected. Importantly, this session always took place between the hours of 4-6pm as a means for controlling for the biological variables' time-

of-day effects. In addition, as a means for controlling for the effects of females' monthly hormonal fluctuations, the testing session took place during the participants' luteal phase of their menstrual cycle, which was ascertained via self-report. Upon completion of this session, the participants were compensated $35 in the form of a gift card.

Procedures for participants representing the Experimentally Sleep Restricted (ESR) group. Based on the preliminary sleep measures collected throughout the baseline week, participants who generally exhibited an average sleep time of greater than seven hours, and ISI and PSQI scores within normal limits, were assigned to the ESR group. Participants returned to the lab to initiate their week of sleep restriction. On day 1, participants' biological, psychological, and neurocognitive measures were collected. At the end of the session, participants were given an actigraph, were instructed to sleep 90 minutes less than their recorded average throughout the initial baseline week, for a span of 7 days. Similar to the baseline week, participants were asked to refrain from swimming and bathing while wearing the actigraph, as well as to press the event marker prior to falling asleep and again when waking up. Participants were also instructed to respond to the daily sleep diary email that included questions of wellbeing, exercise, and appetite.

They were further instructed to return to the lab on Days 3, 5, and 7 of the sleep restriction week. Specifically, on Days 3 and 5, the same biological measures collected at baseline and Day 1 were collected, whereas on Day 7, the same biological, psychological, and neurocognitive measures previously collected were again obtained from the participants. Throughout this week, participants were instructed to refrain from operating any motor vehicles, consuming caffeine, or napping throughout the course of the day.

They were also advised that, while in the lab on Days 3 and 5, their actigraphs were verified as to ensure that the sleep restriction protocol was being adhered to. Importantly, all data collection sessions over the sleep restriction week took place between the hours of 4-6pm as a means for controlling for the biological variables' diurnal fluctuations. In addition, as a means for controlling for the effects of females' monthly hormonal fluctuations, the sleep restriction week took place during the participants' luteal phase of their menstrual cycle, which was ascertained via self-report. Following 7 days of sleep restriction, participants were compensated $75 in gift cards.

Statistical Analyses

Intragroup comparisons. Before conducting the statistical analyses, preliminary checks on statistical assumptions were verified. In particular, the assumption of normal distribution was met for some, but not all variables, warranting the inclusion of both parametric and nonparametric, within-subjects comparisons (Field, 2013). Assumptions were verified using both graphical and non-graphical approaches.

Research design. In each analysis addressing the within-group comparison research questions, the independent variable is the time of testing. In the ESR group, participants completed biological, psychological, and neurocognitive measures on Days 1 and 7 of the sleep restriction week. Thus, the independent variables were these two times of testing. Biological samples collected on Days 3 and 5 were excluded due to inconsistencies in specimen collection; meaning, samples were unable to be consistently obtained on these days due to factors such as scheduling conflicts. The dependent measures include the biological (i.e., cortisol, IL-6, IL-1β), psychological (i.e., STAI, ESS, PSS, POMS), and neurocognitive (i.e., all 8 subtests of Joggle Research's *Cognition*

platform) measures. Because the comparisons involve two time points of the same group of individuals, the repeated-samples *t*-test will be used. For variables failing to meet the assumption of normality, the nonparametric equivalent, the Wilcoxon signed-rank test (Wilcoxon, 1945) was used.

In addition, delta values from Day 1 to Day 7 were computed for all the biological, psychological, and neurocognitive variables. Following this, delta values for each variable were correlated; more specifically, delta values for the biological variables were correlated with the psychological variables, which were correlated with the neurocognitive variables, in order to ascertain whether deltas in one class of variable (i.e., biological, psychological, or neurocognitive) are associated with deltas in another class of variable. Pearson correlations were conducted for normally distributed variables, and Spearman correlations (Spearman, 1910) were conducted for non-normally distributed variables.

Intergroup comparisons. Before conducting the statistical analyses, preliminary checks on statistical assumptions were verified. In particular, the assumption of normal distribution was met for some, but not all variables, warranting the inclusion of both parametric and nonparametric, between-subjects comparisons (Field, 2013). Assumptions were verified using both graphical and non-graphical approaches.

Research design. In each analysis addressing the between-group comparison research questions, the independent variable was group membership (i.e., NSR, ESR). Although there are two groups, two between-group comparisons were tested; specifically, the NSR group and the ESR group at Day 1, and the NSR group and the ESR group at Day 7. Testing for NSR and ESR Day 1 comparisons allowed us to determine whether

the groups differed in terms of their biological, psychological, and neurocognitive composition in the absence of imposed sleep restriction. Conversely, testing for NSR and ESR Day 7 comparisons provided additional data, and allowed us to examine whether the NSR group, which is habitually achieving reduced sleep quantity and/or quality differs with respect to biological, psychological, and neurocognitive functioning with the ESR group, which is not habitually achieving reduced sleep quantity and/or quality. The dependent measures included the biological (i.e., cortisol, IL-6, IL-1β), psychological (i.e., STAI, ESS, PSS, POMS), and neurocognitive (i.e., all 8 subtests of Joggle Research's *Cognition* platform) measures. Because the comparisons involved two groups of different individuals, independent samples t-tests were computed, whereas Mann-Whitney tests (Mann & Whitney, 1947) were computed for analyses including variables not meeting the assumption of normality.

Chapter 4: Results

Assumptions

The Shapiro-Wilk test was utilized to verify the assumption of normality, as it is the recommended analysis when working with smaller sample sizes (Fields, 2013). Significant values are identified in Table 1, and these indicate that the distribution of scores deviates from a normal distribution.

Table 1
Shapiro-Wilk Test of Normality (Significant Cases)

Category	Variable	W	*p*
Biological	IL1B_ESR_D1	.798	.027
	CORT_NSR	.811	.013
Psychological	STAI-T_ESR_D7	.794	.017
	POMS_Tension_ESR_D1	.747	.005
	POMS_Tension_NSR	.815	.015
	POMS_Depr_ESR_D7	.781	.012
	POMS_Confusion_ESR_D1	.775	.011
	POMS_Anger_NSR	.737	.001
	POMS_TMD_NSR	.823	.019
Neurocognitive	3PVTerr_ESR_D7	.808	.049
	3PVTme_ESR_D1	.745	.005
	3PVTme_ESR_D7	.791	.033
	3PVTme_NSR	.393	.000
	BARTme_ESR_D7	.761	.017
	NBACKCrMatch_ESR_D7	.742	.010
	DSSTcr_NSR	.855	.050
	NBACKCrNonMatch_NSR	.712	.001

Additional indicators of normality, such as skewness and kurtosis were also examined. Select variables in which skewness or kurtosis were outside the recommended range are depicted in Table 2. Generally, skewness and kurtosis values ranging from -2 to +2 are indicative of a normally distributed sample (George & Mallery, 2010). However, these are highly variable in small samples and hence are often difficult to interpret (Ullman, 2006). Importantly, variables that exhibited a significant Shapiro-Wilk statistic

inconsistently evidenced skewness and kurtosis values outside of the recommended range. Thus, in light of inconsistent evidence to suggest a violation of the normality assumption, in conjunction with the robustness of parametric tests (Rasch & Guiard, 2004), it was determined that parametric analyses were most appropriate. More specifically, it has been shown that the "two-sample t-test is so robust that it can be recommended in nearly all applications," even when the assumption of normality is violated (Rasch, Teuscher, & Guiard, 2007, p. 2706).

Table 2
Large Skewness and Kurtosis Values

Category	Variable	Skewness	Kurtosis
Psychological	STAI-S_ESR_D7	-2.04*	0.11
	POMS_Tension_ESR_D1	2.11*	4.99*
	POMS_Depr_ESR_D1	-1.43	2.41*
	POMS_Anger_ESR_D1	0.35	2.65*
	POMS_Confusion_ESR_D1	-1.80	3.52*
	POMS_TMD_ESR_D1	-0.34	2.37*
Neurocognitive	MPTme_ESR_D7	1.48	2.40*
	BARTme_ESR_D7	1.94	3.94*
	NBACKCrMatch_ESR_D7	-0.51	-2.26*
	NBACKRtme_ESR_D1	1.04	2.56*
	3PVTme_NSR	3.28*	10.91*
	LOTme_NSR	1.14	2.00*
	BARTbp_NSR	0.19	2.51*
	NBACKCrMatch_NSR	-1.22	2.71*
	NBACKCrNonMatch_NSR	-2.23*	5.97*

Note. Large values (i.e., >2) are denoted by an asterisk.

With respect to the intragroup analyses, homogeneity of variance, and more specifically, sphericity was assumed as tenable because there was only one set of difference scores for each research question (Myers & Well, 2003). With respect to the intergroup analyses, Levene's Test of Homogeneity of Variance was utilized to ascertain homogeneity of variance. Violations of this assumption are reported in Table 3.

Table 3
Group Comparisons: Levene's Test of Homogeneity of Variance (Non-Tenable Cases)

Comparison	Variable	F	*p*
1 vs. 2	IL-6	15.235	.001
1 vs. 3	STAI-S	5.333	.033
1 vs. 3	MPTme	5.811	.028
1 vs. 2	Amme	6.986	0.017
1 vs. 3	Amme	5.526	0.032

Note. 1 = Group 1 (NSR); 2 = Group 2 (ESR, Day 1); 3 = Group 3 (ESR, Day 7).

Additionally, steps to identify whether specific data points exerted an undue influence on a specific variable's distribution were also computed using regression diagnostics. This was examined through DFBETAS, which identifies influential observations by producing a standardized change in test parameters when a given observation is deleted from the analysis (Rawlings, Pantula, & Dickey, 2001). Six variables included influential cases beyond the recommended range of greater than positive two and less than negative two (Belsley, Kuh, & Welsch, 1980); these included IL-1β, POMS_Depr, POMS_Tension, POMS_Confusion, PSS, STAI-T, and Amcr. Because the inclusion of the influential cases impacted findings in terms of descriptives and test statistics, the influential cases were removed from the variables on interest. In other words, it was determined that removal of the influential case was the appropriate step in light of the impact it had on subsequent interpretations of findings.

Intragroup Analyses

With regard to the research questions to address within-group differences on biological, psychological, and neurocognitive measures between Days 1 and 7 of the sleep restriction week, paired-samples t-tests were used to examine how scores changed over the course of the week. Because several analyses were conducted, the Bonferroni correction was utilized to maintain a conservative familywise error rate (Fields, 2013).

Familywise error was established on the basis of variable class; meaning, the alpha level was divided by the number of comparisons in the respective biological, psychological, and neurocognitive classes of variables.

Biological variables. With regard to the biological variables, we hypothesized that participants would exhibit elevations on their biological markers of health on Day 7 of the sleep restriction week, relative to Day 1. Results for the effect of sleep restriction were analyzed using a paired-samples t-test to examine how participants' levels of cortisol, IL-6, and IL-1β changed over the course of the week. The means (*M*) and standard deviations (*SD)* for these scores can be found in Table 4. Specific hypothesis testing results including test statistics (*t*), significance values (*p*), and effect sizes (Cohen's *d*) may be found in Table 5.

Table 4
Means and SDs on Pre and Post Sleep Restriction

Category	Variable	Time of Testing	*M*	*SD*
Biological	Cortisol	1	0.32	0.25
		2	0.28	0.23
	IL-6	1	44.14	45.70
		2	90.98	101.32
	IL-1B	1	30.00	23.09
		2	80.10	15.32

Note. Time of Testing 1 = ESR Day 1; Time of Testing 2 = ESR Day 7.

Table 5
Pre and Post Sleep Restriction Comparisons

Comparison	*n*	*t*	*df*	*p*	*d*
Cortisol	7	.524	6	0.62	0.23
IL-1B	4	-6.39	3	0.008*	3.20
IL-6	8	-1.99	7	0.09	0.70

Note. Comparisons are based on Day 1 and Day 7 results in the ESR group.
*p<0.0167

Hypotheses for the biological variables posited elevations of mean levels of cortisol, IL-6, and IL-1β as a direct function of sleep restriction. Results indicated a significant increase in IL-1β following a week of sleep restriction, as well as a large magnitude of difference between IL-1β prior to and following sleep restriction. Results did not demonstrate additional significant differences or large effect sizes on measures of biological health as a function of sleep restriction.

Psychological variables. With regard to the psychological variables, we hypothesized that participants would exhibit a decrement in their psychological health on Day 7 of the sleep restriction week, relative to Day 1. Results for the effect of sleep restriction were analyzed using paired-samples t-tests to examine how participants' levels of anxiety (both state and trait), perceived stress, sleepiness, tension, depression, anger, fatigue, confusion, vigor, and total mood disturbance changed over the course of the week. The means (*M*) and standard deviations (*SD)* for these scores can be found in Table 6. Specific hypothesis testing results including test statistics (*t*), significance values (*p*), and effect sizes (*d*) may be found in Table 7.

Table 6
Means and SDs on Pre and Post Sleep Restriction

Category	Variable	Time of Testing	*M*	*SD*
Psychological	STAI-S	1	35.44	7.00
		2	46.67	10.75
	STAI-T	1	35.75	7.57
		2	45.88	9.42
	PSS	1	16.11	5.37
		2	18.11	2.76
	ESS	1	5.78	2.77
		2	7.78	4.06
	POMS_Tension	1	1.88	1.96
		2	11.63	7.50
	POMS_Depr	1	18.88	4.67
		2	4.25	6.74
	POMS_Anger	1	10.44	5.77
		2	3.67	4.12
	POMS_Fatigue	1	5.33	2.92
		2	11.56	5.86
	POMS_Confusion	1	5.75	1.66
		2	8.25	4.06
	POMS_Vigour	1	7.22	3.93
		2	5.89	3.89
	POMS_TMD	1	33.67	16.96
		2	35.00	28.47

Note. Time of Testing 1 = ESR Day 1; Time of Testing 2 = ESR Day 7.

Results indicated that participants' mean level of depression significantly decreased following a week of sleep restriction, while also exhibiting a large magnitude of difference prior to and following sleep restriction. Additional large effect sizes were observed with state anxiety, trait anxiety, tension, anger, and fatigue. More specifically, there was a large magnitude of difference between pre and post sleep restriction scores across these variables, such that higher scores were observed following the week of sleep restriction, with the exception of anger, which was lower following sleep restriction. Results did not demonstrate additional significant differences or large effect sizes on measures of psychological health as a function of sleep restriction.

Table 7
Pre and Post Sleep Restriction Comparisons

Comparison	*n*	*t*	*df*	*p*	*d*
STAI-S	9	-2.73	8	0.03	1.80
STAI-T	8	-2.31	7	0.05	0.82
PSS	9	-0.88	8	0.40	0.29
ESS	9	-2.19	8	0.06	0.73
POMS_Tension	8	-4.06	7	0.01	1.44
POMS_Depression	8	5.29	7	0.001*	1.87
POMS_Anger	9	2.59	8	0.03	0.86
POMS_Fatigue	9	-3.22	8	0.01	1.07
POMS_Confusion	8	-1.85	7	0.11	0.66
POMS_Vigour	9	0.89	8	0.40	0.30
POMS_TMD	9	-0.11	8	0.92	0.04

Note. Comparisons are based on Day 1 and Day 7 results in the ESR group.
*p<0.0045

Neurocognitive variables. With regard to the neurocognitive variables, we hypothesized that participants would exhibit a decrement in their neurocognitive functioning on Day 7 of the sleep restriction week, relative to Day 1. Results for the effect of sleep restriction were analyzed using paired-samples t-tests to examine how participants' performance on a variety of neurocognitive measures changed in response to sleep restriction. The neurocognitive measures assessed skills such as vigilant attention, sensorimotor control, visuo-spatial memory, spatial orientation, processing speed, risk-taking behavior, working memory capacity, and abstraction. The means (*M*) and standard deviations (*SD)* for these scores can be found in Table 8. Specific hypothesis testing results including test statistics (*t*), significance values (*p*), and effect sizes (*d*) may be found in Table 9. Results did not demonstrate any significantly different mean values on neurocognitive variables as a function of sleep restriction. Despite this, a large effect size was found for reaction time on the NBACK subtest, wherein the mean reaction time following sleep restriction decreased.

Table 8
Means and SDs on Pre and Post Sleep Restriction

Category	Variable	Time of Testing	*M*	*SD*
Neurocognitive	3PVTerr	1	3.33	2.78
		2	2.57	3.16
	3PVTme	1	345.97	151.76
		2	364.50	147.80
	MPTme	1	488.79	75.55
		2	505.87	127.29
	VOLTcr	1	16.11	2.03
		2	16.14	3.29
	VOLTme	1	1739.61	334.82
		2	1611.41	342.13
	LOTcr	1	12.89	2.42
		2	12.43	2.15
	LOTme	1	5941.99	1432.82
		2	4871.73	1381.05
	DSSTcr	1	87.78	10.85
		2	87.86	15.32
	DSSTme	1	903.12	127.68
		2	905.54	195.28
	BARTbp	1	12.56	2.65
		2	13.57	6.48
	BARTme	1	558.99	323.34
		2	419.01	358.20
	NBACKCrMatch	1	7.44	4.30
		2	9.57	1.81
	NBACKCrNonMatch	1	43.67	3.24
		2	41.00	5.86
	NBACKRtme	1	590.53	76.14
		2	528.70	59.32
	Amcr	1	17.67	1.97
		2	16.67	1.21
	Amme	1	1935.93	880.62
		2	1454.44	710.41

Note. Time of Testing 1 = ESR Day 1; Time of Testing 2 = ESR Day 7.

Table 9
Pre and Post Sleep Restriction Comparisons

Comparison	*n*	*t*	*df*	*p*	*d*
3PVTerr	7	1.23	6	0.27	0.19
3PVTme	7	0.01	6	0.99	0.10
MPTme	7	-0.32	6	0.76	0.24
VOLTcr	7	-0.11	6	0.92	0.01
VOLTme	7	2.20	6	0.70	0.27
LOTcr	7	0.63	6	0.55	0.69
LOTme	7	1.67	6	0.15	0.60
DSSTcr	7	-0.30	6	0.77	0.00
DSSTme	7	0.11	6	0.92	0.01
BARTbp	7	-0.53	6	0.61	0.15
BARTme	7	1.62	6	0.16	0.29
NBACKCrMatch	7	-2.55	6	0.04	0.46
NBACKCrNonMatch	7	1.43	6	0.20	0.52
NBACKRtme	7	2.04	6	0.87	0.85
Amcr	6	1.07	5	0.33	0.44
Amme	7	2.24	6	0.07	0.43

Note. Comparisons are based on Day 1 and Day 7 results in the ESR group.
*$p < 0.003$

Intergroup Analyses

With regard to the research questions to address between-group differences on biological, psychological, and neurocognitive measures, comparisons were drawn between ESR Day 1 and the NSR group, as well as ESR Day 7 and the NSR group. Two classes of independent-samples t-tests were conducted in order to compare the NSR group with the ESR group on Day 1 of the sleep restriction week and to compare the NSR group with the ESR group on Day 7 of the sleep restriction week. Comparing the NSR group to the ESR group prior to the sleep restriction manipulation allowed us to determine whether the groups differed in terms of their biological, psychological, and neurocognitive composition in the absence of imposed sleep restriction on the ESR group. Conversely, comparing the NSR group to the ESR group following sleep restriction (i.e., Day 7) allowed us to also compare the effects of long-standing and

volitional sleep restriction (i.e., the NSR group) to short-term and non-volitional sleep restriction (i.e., ESR Day 7) on a variety of health indicators. Because several analyses were conducted, the Bonferroni correction was utilized to maintain a conservative familywise error rate (Fields, 2013). Familywise error was established on the basis of variable class; meaning, the alpha level was divided by the number of comparisons in the respective biological, psychological, and neurocognitive classes of variables.

Biological variables. With respect to the biological variables, we hypothesized that the NSR group would exhibit elevations on their biological markers relative to the ESR group on Day 1 of the sleep restriction week. Meaning, we anticipated that participants who did not initially report subjective or objective sleep difficulties (ESR) to exhibit comparatively lower mean levels of cortisol, IL-6, and IL-1β, relative to participants who were deemed to be naturally sleep restricted. Second, following a week of sleep restriction, we hypothesized that participants in the ESR group would exhibit elevations with their biomarkers relative to the NSR group, due to the non-volitional nature of the manipulation. The means (*M*) and standard deviations (*SD)* for these measures can be found in Table 10. Specific hypothesis testing results including test statistics (*t*), significance values (*p*), and effect sizes (*d*) may be found in Table 11.

Table 10
Means and SDs on Based on Group and Time of Testing

Category	Variable	Group	*n*	*M*	*SD*
Biological	Cortisol	1	11	0.22	0.15
		2	7	0.32	0.25
		3	7	0.28	0.23
	IL-6	1	11	107.33	96.74
		2	8	44.14	45.70
		3	8	90.98	101.32
	IL-1B	1	11	62.70	54.88
		2	6	51.97	51.73
		3	4	80.10	15.32

Note. 1 = Group 1 (NSR); 2 = Group 2 (ESR, Day 1); 3 = Group 3 (ESR Day 7).

Table 11
Group Comparisons on Biological Variables

Variable	Comparison	*t*	*df*	*p*	*d*
Cortisol	1 vs. 2	-1.11	16	0.28	0.52
	1 vs. 3	-0.68	16	0.51	0.27
IL-6	1 vs. 2	1.90	15.05	0.08	0.79
	1 vs. 3	0.36	17	0.73	0.17
IL-1B	1 vs. 2	0.39	15	0.70	0.20
	1 vs. 3	-0.95	12.79	0.36	0.36

Note. 1 = Group 1 (NSR); 2 = Group 2 (ESR, Day 1); 3 = Group 3 (ESR, Day 7).
*$p < 0.0083$

Results did not yield any significant between-group differences when comparing the NSR group to the ESR group on either Day 1 or Day 7 of the sleep restriction week. Similarly, there were no large effect sizes, although the between-groups comparison involving the NSR group and ESR group on Day 1 for IL-6 yielded an effect size of 0.79, just shy of the recommended designation of 0.8 for large effect sizes (Cohen, 1988).

Psychological variables. With respect to the psychological variables, we hypothesized that the NSR group would exhibit reduced psychological functioning relative to the ESR group on Day 1 of the sleep restriction week. Meaning, we anticipated that participants who did not initially exhibit subjective or objective sleep difficulties (ESR) to exhibit comparatively lower mean levels of anxiety (both state and trait),

perceived stress, sleepiness, tension, depression, anger, fatigue, confusion, vigor, and total mood disturbance relative to naturally sleep restricted participants. Second, following a week of sleep restriction, we hypothesized that participants in the ESR group would exhibit a greater decrement in psychological functioning relative to the NSR group, due to the non-volitional nature of the manipulation. The means (*M*) and standard deviations (*SD)* for these measures can be found in Table 12. Specific hypothesis testing results including test statistics (*t*), significance values (*p*), and effect sizes (*d*) may be found in Table 13.

Table 12
Means and SDs on Based on Group and Time of Testing

Category	Variable	Group	*n*	*M*	*SD*
Psychological	STAI-S	1	11	31.82	7.25
		2	9	35.44	7
		3	9	46.67	10.75
	STAI-T	1	11	34.55	6.83
		2	8	35.75	7.57
		3	8	45.88	9.42
	PSS	1	11	15.09	6.24
		2	9	16.11	5.37
		3	9	18.11	2.76
	ESS	1	11	5.73	2.83
		2	9	5.78	2.77
		3	9	7.78	4.06
	POMS_Tension	1	11	1.27	1.1
		2	8	1.88	1.96
		3	8	11.63	7.5
	POMS_Depr	1	11	13.45	9.95
		2	8	18.88	4.67
		3	6	5.67	7.34
	POMS_Anger	1	11	8.64	5.66
		2	9	10.44	5.77
		3	9	3.67	4.12
	POMS_Fatigue	1	11	4.36	3.33
		2	9	5.33	2.92
		3	9	11.56	5.86
	POMS_Confusion	1	11	4.73	3.47
		2	8	5.75	1.66
		3	8	8.25	4.06
	POMS_Vigour	1	11	4.91	3.67
		2	9	7.22	3.93
		3	9	5.89	3.89
	POMS_TMD	1	11	27.55	19.1
		2	9	33.67	16.96
		3	9	35.00	28.47

Note. 1 = Group 1 (NSR); 2 = Group 2 (ESR, Day 1); 3 = Group 3 (ESR, Day 7).

Table 13
Group Comparisons on Psychological Variables

Variable	Comparison	*t*	*df*	*p*	*d*
STAI-S	1 vs. 2	-1.13	18	0.27	0.51
	1 vs. 3	-3.68	18	0.002*	1.65
STAI-T	1 vs. 2	-0.36	17	0.72	0.17
	1 vs. 3	-3.05	17	0.01	1.42
PSS	1 vs. 2	-0.39	18	0.70	0.17
	1 vs. 3	-1.34	18	0.20	0.60
ESS	1 vs. 2	-0.40	18	0.97	0.02
	1 vs. 3	-1.33	18	0.20	0.59
POMS_Tension	1 vs. 2	-0.86	17	0.40	0.40
	1 vs. 3	-3.87	7.22	0.01	2.12
POMS_Depression	1 vs. 2	-1.58	15.01	0.13	0.66
	1 vs. 3	1.67	15	0.12	0.85
POMS_Anger	1 vs. 2	-0.71	18	0.49	0.32
	1 vs. 3	2.20	18	0.04	0.99
POMS_Fatigue	1 vs. 2	-0.69	18	0.50	0.31
	1 vs. 3	-3.46	18	0.003*	1.56
POMS_Confusion	1 vs. 2	-0.91	12.90	0.38	0.36
	1 vs. 3	-2.04	17	0.06	0.95
POMS_Vigour	1 vs. 2	-1.36	18	0.19	0.61
	1 vs. 3	-0.58	18	0.57	0.26
POMS_TMD	1 vs. 2	-0.75	18	0.46	0.34
	1 vs. 3	-0.70	18	0.49	0.31

Note. 1 = Group 1 (NSR); 2 = Group 2 (ESR, Day 1); 3 = Group 3 (ESR, Day 7).
*$p < 0.0023$

Results yielded a significant difference between the NSR group and the ESR group at Day 7 with state anxiety and fatigue. The ESR group exhibited significantly higher levels of state anxiety and fatigue relative to participants in the NSR group. Several large effect sizes were also noted, all between the NSR group and the ESR group at Day 7 of the sleep restriction week. More specifically, there was a large magnitude of difference between these two groups for state anxiety, trait anxiety, tension, depression, anger, fatigue, and confusion. Mean levels for all of these with the exception of anger and depression were higher in the ESR group compared to the NSR group. In other words,

there was a large effect that revealed higher levels of state anxiety, trait anxiety, tension, fatigue and confusion in the ESR group compared to the NSR group, and a large effect that revealed lower levels of depression and anger in the ESR group compared to the NSR group.

Neurocognitive variables. With respect to the neurocognitive variables, we hypothesized that the NSR group would exhibit decrements in their neurocognitive functioning relative to the ESR group on Day 1 of the sleep restriction week. Meaning, we anticipated that participants who did not initially exhibit subjective or objective sleep difficulties (ESR) to exhibit greater reductions in performance on tasks requiring vigilant attention, sensorimotor control, visuo-spatial memory, spatial orientation, processing speed, risk-taking behavior, working memory, and abstraction relative to naturally sleep restricted participants. Second, following a week of sleep restriction, we hypothesized that participants in the ESR group would exhibit a greater decrement in neurocognitive functioning relative to the NSR group, due to the non-volitional nature of the manipulation. The means (*M*) and standard deviations (*SD)* for these measures can be found in Tables 14a-14b.

Table 14a
Means and SDs on Based on Group and Time of Testing

Category	Variable	Group	*n*	*M*	*SD*
	3PVTerr	1	11	4.27	3.5
		2	9	3.33	2.78
		3	7	2.57	3.16
	3PVTme	1	11	419.35	509.87
		2	9	345.97	151.76
		3	7	364.5	147.8
	MPTme	1	11	477.19	37.85
		2	9	488.79	75.55
		3	7	505.87	127.29
	VOLTcr	1	11	15.27	2.87
		2	9	16.11	2.03
		3	7	16.14	3.29
	VOLTme	1	11	1731.37	409.04
		2	9	1739.61	334.82
		3	7	1611.41	342.13
Neurocognitive	LOTcr	1	11	13.09	2.84
		2	9	12.89	2.42
		3	7	12.43	2.15
	LOTme	1	11	6806.83	1621.46
		2	9	5941.99	1432.82
		3	7	4871.73	1381.05
	DSSTcr	1	11	83.27	9.23
		2	9	87.78	10.85
		3	7	87.86	15.32
	DSSTme	1	11	959.47	112.97
		2	9	903.12	127.68
		3	7	905.54	195.28
	BARTbp	1	11	11.82	5.36
		2	9	12.56	2.65
		3	7	13.57	6.48

Note. 1 = Group 1 (NSR); 2 = Group 2 (ESR, Day 1); 3 = Group 3 (ESR, Day 7)

Table 14b
Means and SDs on Based on Group and Time of Testing

Category	Variable	Group	*n*	*M*	*SD*
Neurocognitive	BARTme	1	11	544.86	234.64
		2	9	558.99	323.34
		3	3	419.01	358.2
	NBACKCrMatch	1	11	9	2.93
		2	9	7.44	4.3
		3	7	9.57	1.81
	NBACKCrNonMatch	1	11	39.09	7.04
		2	9	43.67	3.24
		3	7	41	5.86
	NBACKRtme	1	11	578.02	37.3
		2	9	590.53	76.14
		3	7	528.7	59.32
	Amcr	1	11	16.82	3.19
		2	8	17.63	2.13
		3	6	16.67	1.21
	Amme	1	11	1643.13	381.36
		2	9	1935.93	880.62
		3	7	1454.44	710.41

Note. 1 = Group 1 (NSR); 2 = Group 2 (ESR, Day 1); 3 = Group 3 (ESR, Day 7).

Specific hypothesis testing results including test statistics (*t*), significance values (*p*), and effect sizes (*d*) may be found in Table 15. While results did not reveal any significant between-group differences with the NSR and ESR groups on neurocognitive variables, there was evidence of large effect sizes. First, the NSR group had a higher mean reaction time on the line orientation task compared to the ESR group following sleep restriction. Second, the ESR group at Day 1 had a higher mean level of correct non-matches on the NBACK task compared to the NSR group. Finally, the NSR group exhibited a higher mean reaction time on the NBACK compared to the ESR group following sleep restriction. Summary tables illustrating significant and large effect sizes

for the intragroup comparisons are displayed in Table 16, and those for intergroup comparisons are displayed in Table 17.

Table 15
Group Comparisons on Neurocognitive Variables

Variable	Comparison	*t*	*df*	*p*	*d*
3PVTerr	1 vs. 2	0.65	18	0.52	0.29
	1 vs. 3	1.04	16	0.31	0.50
3PVTme	1 vs. 2	0.42	18	0.68	0.19
	1 vs. 3	0.28	16	0.79	0.13
MPTme	1 vs. 2	-0.45	18	0.66	0.20
	1 vs. 3	-0.71	16	0.49	0.34
VOLTcr	1 vs. 2	-0.74	18	0.47	0.33
	1 vs. 3	-0.59	16	0.56	0.29
VOLTme	1 vs. 2	-0.05	18	0.96	0.02
	1 vs. 3	0.64	16	0.53	0.31
LOTcr	1 vs. 2	0.17	18	0.87	0.08
	1 vs. 3	0.53	16	0.61	0.25
LOTme	1 vs. 2	1.25	18	0.23	0.56
	1 vs. 3	2.61	16	0.02	1.26
DSSTcr	1 vs. 2	-1.00	18	0.33	0.45
	1 vs. 3	-0.80	16	0.44	0.39
DSSTme	1 vs. 2	1.05	18	0.31	0.47
	1 vs. 3	0.75	16	0.47	0.35
BARTbp	1 vs. 2	-0.38	18	0.71	0.17
	1 vs. 3	-0.63	16	0.54	0.30
BARTme	1 vs. 2	-0.11	18	0.91	0.05
	1 vs. 3	0.91	16	0.38	0.44
NBACKCrMatch	1 vs. 2	0.96	18	0.35	0.43
	1 vs. 3	-0.46	16	0.65	0.22
NBACKCrNonMatch	1 vs. 2	-1.80	18	0.09	0.81
	1 vs. 3	-0.60	16	0.56	0.23
NBACKRtme	1 vs. 2	-0.48	18	0.64	0.22
	1 vs. 3	2.18	16	0.05	1.05
Amcr	1 vs. 2	-0.62	17	0.54	0.29
	1 vs. 3	0.11	15	0.91	0.06
Amme	1 vs. 2	-0.93	10.45	0.37	0.45
	1 vs. 3	0.65	8.24	0.54	0.36

Note. 1 = Group 1 (NSR); 2 = Group 2 (ESR, Day 1); 3 = Group 3 (ESR, Day 7).
*$p < 0.0015$

Table 16
Significant and Large Effect Sizes for the Intragroup Comparisons

Comparison	*n*	*t*	*df*	*p*	*d*
IL1B	4	-6.39	3	0.008*	3.20
STAI-S	9	-2.73	8	0.03	1.80
STAI-T	8	-2.31	7	0.05	0.82
POMS_Tension	8	-4.06	7	0.01	1.44
POMS_Depression	8	5.29	7	0.001*	1.87
POMS_Anger	9	2.59	8	0.03	0.86
POMS_Fatigue	9	-3.22	8	0.01	1.07
NBACKRtme	7	2.04	6	0.87	0.85

Note. Comparisons are based on Day 1 and Day 7 results in the ESR group.
*p<0.0167 for the biological variables, *p<0.0045 for the psychological variables, and *p < 0.003 for the neurocognitive variables.

Table 17
Significant and Large Effect Sizes for the Intergroup Comparisons

Variable	Comparison	*t*	*df*	*p*	*d*
IL-6	1 vs. 2	1.90	15.05	0.08	0.79
STAI-S	1 vs. 3	-3.68	18	0.002*	1.65
STAI-T	1 vs. 3	-3.05	17	0.01	1.42
POMS_Tension	1 vs. 3	-3.87	7.22	0.01	2.12
POMS_Depression	1 vs. 3	1.67	15	0.12	0.85
POMS_Anger	1 vs. 3	2.20	18	0.04	0.99
POMS_Fatigue	1 vs. 3	-3.46	18	0.003*	1.56
POMS_Confusion	1 vs. 3	-2.04	17	0.06	0.95
LOTme	1 vs. 3	2.61	16	0.02	1.26
NBACKCrNonMatch	1 vs. 2	-1.80	18	0.09	0.81
NBACKRtme	1 vs. 3	2.18	16	0.05	1.05

Note. 1 = Group 1 (NSR); 2 = Group 2 (ESR, Day 1); 3 = Group 3 (ESR, Day 7).
*p < 0.0083 for the biological variables, *p < 0.0023 for the psychological variables, and *p < 0.0015 for the neurocognitive variables.

Chapter 5: Discussion

In an effort to investigate the impact of sleep restriction, the current study examined sleep restriction amongst two groups of young women who were either naturally sleep restricted or experimentally sleep restricted. In doing so, we examined the impact that sleep restriction has on biological, psychological, and neurocognitive functioning and whether the impact on functioning differs based on the nature of the sleep restriction; meaning, is one differentially impacted depending on whether sleep is restricted in a volitional manner, as in the naturally sleep restricted group, or whether it is restricted in a non-volitional manner, as in the experimentally sleep restriction group? As previously noted, the basis for this study derives from numerous gaps in the literature, all pertaining to an understudied area having a high degree of relevance and ecological validity in modern society.

Specifically, chronic sleep restriction impacts a significant proportion of the American population (Luyster et al., 2012), even though the CDC (2014) stipulates that health and well-being are optimized following a minimum of seven hours of sleep. While agreement exists as to *why* there has been a general reduction in number of hours slept, our ability to answer *how* this impacts individuals is far from complete, owing to three primary disagreements in the literature. First, sleep deprivation research is a far more prolific area of study compared to sleep restriction, and while they both result in fewer hours of time spent sleeping, it cannot be assumed that their ensuing consequences are comparable. Second, whether and how individuals' functioning differs as a result of sleep restriction, depending on whether it is imposed in a volitional or non-volitional manner, has yet to be determined. Third, the extent to which sleep restriction affects females is

unclear, as they have either been excluded from the literature, or if they have been included, it cannot be assumed that the necessary steps to account for their endogenous hormonal fluctuation were taken, thereby limiting our ability to extrapolate these findings.

There is a pressing need to further our understanding, given that women are the gender most likely to encounter negative health as a result of poor sleep quality, and that sleep restriction is the sleep paradigm having the greatest ecological validity. As such, this investigation involved research questions aimed at learning more about sleep restriction amongst a female sample. In addition, research questions specifically addressed whether sleep restriction produced alterations in one's biological, psychological, and neurocognitive functioning. Finally, the current study also addressed whether naturally-occurring sleep restriction produced a different constellation of biological, psychological, and neurocognitive consequences, relative to sleep restriction that was imposed in an experimental manner.

Pre Versus Post Sleep Restriction Findings

Biological variables. The extent to which IL-1β changes in response to sleep restriction is not a well understood or studied area within the literature. Our results demonstrated that following a week of sleep restriction, participants' mean level of IL-1β significantly increased, with a large magnitude of effect between IL-1β levels prior to and following sleep restriction. To our knowledge, this is first study to examine females' IL-1β, while accounting for endogenous hormonal fluctuations, and while also implementing a sleep restriction manipulation. Existing literature has primarily included a male-only sample (i.e., Covelli et al., 1992; van Leeuwen et al., 2009), or studies that have included

females (i.e., Tartar et al., 2015) have not employed a sleep restriction manipulation or accounted for females' hormonal fluctuations. Although Tartar et al.'s (2015) research did not experimentally restrict participants' sleep, subjective report on amount of time slept was collected, and participants deemed chronically sleep restricted evidenced heightened levels of IL-1β relative to participants deemed non-chronically sleep restricted. Importantly, this sample consisted exclusively of females, thereby supporting the current study's findings.

Additional studies examining IL-1β's relationship to sleep exclusively included a male sample (i.e., Covelli et al., 1992; van Leeuwen et al., 2009), and employed divergent manipulations. For instance, Covelli et al. (1992) found that one night of total sleep deprivation did not result in IL-1β elevations, whereas elevations in IL-1β were observed in participants that slept normally. However, it should be noted that the sleep deprivation experienced by the two participants was not a sleep manipulation per se, but rather the result of being *unable* to sleep. Thus, their results suggesting no effect of sleep deprivation on subsequent levels of IL-1β were derived from two participants, neither of whom slept as a result of non-volitional factors. With respect to van Leeuwen and colleagues' (2009) study, sustained marked elevations in IL-1β were found five days following the end of a prolonged sleep restriction manipulation, raising the possibility that alterations in IL-1β may be the result of a prolonged duration of shortened sleep, as was seen in the current study.

Evidently, additional research needs to be conducted in order to ascertain the extent to which IL-1β levels are impacted following sleep restriction. It should also be noted that our within-groups comparison only included four participants, and given that

these may be the first findings to illustrate a rise in IL-1β following sleep restriction in women, it is imperative that these results be replicated in order to enhance our understanding of the relationship between IL-1β and sleep. Importantly, as it pertains to the study of biomarkers, one is able to study differences in mean levels, or one may choose to examine alterations in secretory patterns. The current study exclusively examined whether mean levels of the three biomarkers changed in response to sleep restriction, although we are unable to ascertain whether the sleep restriction manipulation has any impact on the secretory patterns, including whether the diurnal pattern was flattened, as has been seen in some studies (i.e., Irwin et al., 2010; Vgontzas et al., 2002). Therefore, this may be a worthy avenue of further exploration in order to decipher whether as well as *how* sleep restriction may be impacting females' biomarkers.

Finally, in terms of cortisol and IL-6, the current study did not yield a significant difference in either biomarker following a week of sleep restriction. Like IL-1β, our understanding of how these are impacted following sleep restriction is far from complete. For instance, while some studies (i.e., Banks & Dinges, 2007; Omisade et al., 2010) exhibit elevations in cortisol following sleep restriction, others (i.e., Tartar et al., 2015) do not. Similarly, with IL-6, some studies illustrate a rise following sleep restriction (i.e., Suarez, 2008; Vgontzas et al., 2004), whereas others (i.e., Vgontzas et al., 2002) do not. As such, additional exploration of these biomarkers would allow our understanding of the relationship between sleep and biological functioning to be better elucidated.

Psychological variables. Sleep and psychological functioning are intrinsically tied, with research indicating a link between short sleep duration and reduced psychological well-being (Mallampalli & Carter, 2014), changes in sleep as a result of

psychopathology (Basta et al., 2007), and sleep interventions aimed at ameliorating psychological functioning (Wirz-Justice & Van den Hoofdakker, 1999). In line with existing research, the current study found that following a week of sleep restriction, the ESR group exhibited significantly lower levels of depression. Large effect sizes indicating an increase in state anxiety, trait anxiety, tension, and fatigue were found, in addition to large effect sizes demonstrating a reduction in depression and anger. Contrary to the literature, no significant differences or large effect sizes were found for perceived stress, sleepiness, confusion, vigor, and total mood disturbance.

The significant decrease in depression following a week of sleep restriction aligns with the induced-wakefulness therapy intervention, which posits a reduction in depressive symptomatology following sleep deprivation and partial sleep deprivation (Hemmeter et al., 2010). However, induced-wakefulness therapy has been shown to lead to reductions in depression amongst *clinical* samples (Hemmeter et al., 2010), and that diminishing a non-clinical sample's sleep usually leads to diminished positive affect (Wirz-Justice & Van den Hoofdakker, 1999). Our findings are intriguing given that the ESR group *is* a non-clinical group, as determined by their responses to a structured clinical interview at the current study's outset. This result is even more compelling when viewed in conjunction with the additional large effect sizes; more specifically, increases in state and trait anxiety, tension and fatigue, as well as a reduction in anger.

The overlap in depression and anxiety throughout the literature is well established, yet the current findings suggest a negative trend between these two constructs. What may possibly account for these findings? Hirschfeld (2001) indicates that approximately 50% of patients presenting with an anxiety or depressive disorder

present with a comorbid secondary anxiety or depressive disorder. Further, patients with anxiety and depression present with sleep complaints at a higher frequency than patients without anxiety and depression (Basta et al., 2007; Hirschfeld, 2001). However, sleep deprivation results in alleviation of depressive symptoms and not anxiety symptoms (Wirz-Justice & Van den Hoofdakker, 1999), thereby drawing a distinction between the two constructs as they pertain to sleep loss. Taken together, what mechanism may be at play that would warrant a decrease in depression yet an increase in anxiety? Additionally, why would a *non-clinical* sample be evidencing reductions in depressive symptomatology?

Induced-wakefulness therapy has been implicated in the reduction of depression when implemented in a total or partial sleep deprivation paradigm (Hemmeter et al., 2010) – the latter also constituting a sleep restriction paradigm. An overlap in neurotransmitter system, circadian rhythms, and mood state regulation specifically involving serotonin is believed to underscore the mechanism of action (Wirz-Justice & Van den Hoofdakker, 1999). In particular, total sleep deprivation increases the turnover of serotonin (Hemmeter et al., 2010), and also, "a functional polymorphism within the promoter of the 5HT transporter gene is associated with a better response to fluvoxamine and paroxetine… is also associated with a better mood amelioration after sleep deprivation" (Wirz-Justice & Van den Hoofdakker, 1999, p. 448). Meaning, individual differences in clinical response to selective-serotonin reuptake inhibitor therapy predicts whether mood is improved following sleep deprivation, further highlighting the link between sleep, depression, and serotonin. Finally, it has also been hypothesized that

altered serotonergic activity results from immune dysfunction, including immune responses (Dinges, Douglas, Hamarman, Zaugg, & Kapoor, 1995).

Taken together, there is reason to believe that serotonin plays an instrumental role in explicating the alleviation of depressive symptoms following a week, yet this effect is traditionally observed among clinical samples, whereas the reverse holds true with non-clinical samples. This raises the possibility that the *short-term* nature of induced-wakefulness therapy constitutes one of the mechanisms leading to a reduction in depressive symptomatology, which according to the current findings, may be observed in both clinical and non-clinical samples. In other words, although induced-wakefulness therapy has typically been regarded in terms of its *clinical* significance for depressed individuals, the current results demonstrate *statistical* significance for non-depressed individuals. In addition, it may also be postulated that the increased availability of circulating serotonin not only accounts for a reduction in depressive symptomatology, but also a reduction in negative affect – a mood characteristic observed in both clinical and non-clinical samples. Thus, even though induced-wakefulness therapy has been regarded as a treatment in the alleviation of depression among clinical samples, it may be that this effect is also observed among non-clinical samples, but given the reduced relevance for non-clinical samples, it may be that this effect has been overlooked in the literature.

In addition to a reduction in depression, the current study exhibited a large magnitude of effect for the decrease of anger prior to and following sleep restriction. We suspect that the observed reduction in anger is related to the observed reduction in depression. Meaning, depression has frequently been conceptualized as a form of self-directed anger (Sahu, Gupta, & Chatterjee, 2014), and favorable responses to induced-

wakefulness therapies include positive effects on thought content, including the reduction of negative cognitions (Hemmeter et al., 2010). In addition, positive associations between depression and anger have been found, but only for anger that was suppressed, rather than expressed (Sahu et al., 2014). Moreover, a large effect size was found for an increase in fatigue, and viewed in conjunction with the decrease in anger, it may be possible that the heightened fatigue muted participants' anger (Hatfield et al., 2002). However, recent evidence (i.e., Krizan & Hisler, 2018) suggests that sleep loss leads to a reduction in one's ability to inhibit their anger; meaning, sleep loss may actually increase anger. Yet, this finding implicates neurocognitive functioning as a mediating factor, rather than sleep restriction as a causal factor, which still leaves us with unanswered questions. For instance, in the absence of changes in one's ability to inhibit their anger, is anger impacted following sleep restriction?

Finally, large effect sizes denoting an increase in state and trait anxiety were found, and these effects largely mirror the documented increase in anxiety following sleep loss (i.e., Dinges et al., 1997; Hemmeter et al., 2010; Kahn et al., 2010; Minkel et al., 2012; Tartar et al., 2015). Like anger, it has been hypothesized that anxiety increases following sleep loss as a result of one's diminished ability to regulate emotions (Baum et al., 2014; Minkel et al., 2012), whereas other research (i.e., Tartar et al., 2015) directly ascribe the increase in anxiety to sleep loss. Although depressive symptomatology, like anxiety, is said to increase following sleep restriction among non-clinical samples, induced wakefulness paradigms have been shown to specifically alleviate depression and not anxiety (Wirz-Justice & Van den Hoofdakker, 1999), again drawing a distinction between the two as they pertain to sleep loss. While both sleep restriction and induced

wakefulness paradigms require a restriction of the individual's time spent sleeping, sleep restriction is typically implemented in a non-volitional manner whereas induced wakefulness paradigms are implemented in a volitional fashion with the goal of alleviating depressive symptoms. Further, due to the high degree of overlap in content validity between tension and anxiety, we believe that these represent the same, rather than different effects. More specifically, the tension subscale on the POMS has been operationalized as to include "feelings such as nervousness, apprehension, worry, and anxiety." (Terry et al., 2003, p. 131). As such, we believe that the observed increase in tension may be accounted for by the concomitant increase in anxiety.

In their study examining anxiety and depression in response to sleep restriction, Baum and colleagues (2014) found that participants were increasingly "on edge", nervous, and restless following sleep restriction but they did not exhibit elevated depression. They attributed this finding to the participants' ages, which ranged from 14-17, and suggested that depressive symptoms manifest as irritability rather than depression within this age group. Given that the current study included a similarly-aged sample of young women, is it possible that the reduction in depression and increase in anxiety and tension reflect this age-related trend? Or rather, are Baum and colleagues' (2014) findings also an indication that anxiety and depression may be differentially affected by short-term sleep restriction, with younger individuals exhibiting a greater propensity to develop anxiety as opposed to depressive-related symptoms?

In all, our results demonstrated significant effects and large effect sizes following sleep restriction with some psychological indices, but not with others. While this is to be expected, there is a high degree of overlap in some of the psychological constructs we

assessed, and it is curious that large effects were observed for some and not others. For instance, perceived stress did not exhibit a large effect size, whereas state and trait anxiety as well as tension did. It is interesting and unlikely that the participants exhibited elevated tension and anxiety in absence of elevated stress. An additional possible discrepancy entails the large effect found for fatigue but not for sleepiness. It is suspect that participants endorsed tension and anxiety and fatigue in the absence of large effect sizes for perceived stress and sleepiness. Rather, is it conceivable that these psychological constructs lack adequate criterion validity across the measures? If so, this certainly constitutes one of the limitations in the assessment of the psychological variables, and we encourage that additional psychometric research be conducted in validating these instruments predictive and concurrent validity. Further, and equally important, is the extent to which these instruments are able to confer ecological validity within the context of sleep research, and this too should constitute an area warranting additional validation.

Neurocognitive variables. With respect to the neurocognitive variables, we did not find any significant differences, but we did find one large effect size. More specifically, the large effect denotes a decrease in reaction time on the NBACK, although this finding is not in line with existing research (Belenky et al., 2003; Dinges et al., 1997; Stenuit & Kerkhofs, 2008). Thus, none of our hypotheses and research questions examining neurocognitive functioning within the ESR group following sleep restriction were supported. This is generally contrary to what the literature suggests, as sleep loss has been associated with decrements in working memory, divided attention, inhibition, verbal fluency, problem solving, increased reaction time, mental arithmetic, language, and social cognition (Martin et al., 1996; Pilcher et al., 2007; Stenuit & Kerkhofs, 2008).

The decrease in reaction time on the NBACK runs contrary to the literature, which suggests that sleep restriction results in increased reaction time (Belenky et al., 2003; Dinges et al., 1997; Martin et al., 1996; Stenuit & Kerkhofs, 2008). What is especially surprising about this finding is that out of any neurocognitive variables, increases in reaction time following sleep loss are said to be the most reliable finding (Stenuit & Kerkhofs). An additional observation is that even though reaction time decreased following sleep restriction, no meaningful difference in number of errors made was found, negating the possibility that the decreased reaction time could be attributed to decrements in inhibition. While one may suspect a practice effect, it is unusual that it would discriminatively impact the NBACK's reaction time without any impact across the other variables. It may be that participants had difficulty comprehending the task or lacked motivation to engage with it compared to their first exposure to the task. If so, this would constitute one of the biggest limitations inherent in the neurocognitive measures. While we suspect that participants generally comprehended the tasks, relative to completion of the psychological measures for instance, they asked for clarification at a higher rate, inviting the possibility that they found some of the subtests harder to maneuver. Despite this, we do not believe that this invalidates the test, rather, they should be regarded with caution.

Experimental Versus Natural Sleep Restriction Findings

In order to examine whether NSR participants differ in terms of their biological, psychological, and neurocognitive functioning, they were compared with the ESR group. As stated, the ESR group did not exhibit any subjective or objective indicators of pathological sleep, whereas the NSR group did, and consisted of participants exhibiting

reduced sleep quality as determined by subjective report and objective measures. Therefore, in comparing the NSR group to the ESR group we sought to establish whether the NSR group exhibited a unique constellation of biological, psychological, and neurocognitive indices suggestive of poor sleep. More specifically, in comparing the NSR group to the ESR group at Day 1, we examined whether the two groups differed across classes of variables prior to any sleep restriction taking place. Meaning, in light of the NSR group's prolonged pattern of short sleep duration, we sought to examine whether participants in the NSR group exhibited a decrement in biological, psychological, and neurocognitive functioning relative to the ESR group. Further, we also compared the NSR group to the ESR group at Day 7, allowing us to ascertain whether the groups' functioning differed depending on whether the sleep restriction was implemented in a volitional manner. In other words, does the non-volitional nature of the sleep restriction manipulation lead to poorer biological, psychological, and neurocognitive outcomes for the ESR group at Day 7?

Biological variables. Although our analyses did not reveal any significant findings, a large effect size was found for IL-6 between the NSR group and ESR group at Day 1. More specifically, there was a large magnitude of difference in mean levels of IL-6, such that the NSR group exhibited higher mean levels of IL-6, relative to the ESR group at Day 1. These findings generally fit within the context of existing literature, which suggests that sleep restriction leads to an increase in IL-6 (i.e., Irwin et al., 2010; Smith et al., 2019; Suarez, 2008; van Leeuwen et al., 2009; Vgontzas et al., 2002; Vgontzas et al., 2004), although some studies (i.e., Lekander et al, 2013; Shearer et al., 2001) do not suggest an increase. Interestingly, Lekander and colleagues' (2013) and

Shearer and colleagues' (2001) studies exclusively included males, raising the possibility that men and women's IL-6 may be differentially impacted in the face of sleep loss. Similarly, both studies questioned whether IL-6 did not increase due to either an effect of gender, or possibly that the sleep restriction did not take place for an extended enough amount of time (Lekander et al., 2013; Shearer et al., 2001).

Given that our findings demonstrate elevated IL-6 amongst a sample of participants deemed naturally sleep restricted, it is conceivable that *routinely* achieving fewer than seven hours of sleep has greater power in eliciting elevations in IL-6 compared to shorter-term manipulations. Additional evidence of this derives from Vgontzas et al.'s (2002) study wherein participants routinely achieving fewer than 6.5 hours of sleep at least four times per week for a period of at least six months evidenced altered IL-6 diurnal rhythms. More specifically, they found that the sleep restricted participants' IL-6 peaked earlier in the evening relative to the controls. Given that the current study collected biological samples in the early evening, it raises the possibility of whether we captured this earlier IL-6 peak time within the naturally sleep restricted group. However, it also cannot be assumed that prolonged sleep restriction is solely responsible for elevations in IL-6, as numerous studies have also captured elevations in IL-6 following shorter-term paradigms (i.e, Irwin et al., 2010; Suarez, 2008; van Leeuwen et al., 2009; Vgontzas et al., 2004).

Psychological variables. Several large effect sizes between the NSR group and the ESR group at Day 7 were uncovered, in addition to one statistically significant finding. More specifically, the ESR group at Day 7 exhibited significantly greater fatigue compared to the NSR group. Large effect sizes were found suggesting elevated state

anxiety, trait anxiety, tension, fatigue, and confusion in the ESR group at Day 7 relative to the NSR group. Finally, the NSR group exhibited greater levels of depression and anger relative to the ESR group at Day 7. Contrary to the literature, no significant findings or large effect sizes were found for perceived stress, sleepiness, vigor, and total mood disturbance.

Beginning with the findings that denote increased anxiety, tension, fatigue, and confusion in the ESR group at Day 7 relative to the NSR group, we believe that the non-volitional nature of the sleep restriction manipulation elicited these characteristics at a greater propensity in the ESR group. To reiterate, the ESR group is the group, prior to sleep restriction, that exhibited non-pathological sleep characteristics and an average sleep time between seven to nine hours. Per Tartar and colleagues' (2015) findings, they examined volitional sleep restriction and found that this form of sleep restriction is associated with increased depressive symptomatology, findings that are consistent with the literature. However, relative to the current study's findings, we did not identify between group differences with the NSR and ESR group at Day 1, but rather, large magnitudes of differences emerged at Day 7 of the ESR's sleep restriction week. More specifically, prior to any sleep restriction, the NSR and ESR groups did not differ with respect to their psychological functioning, but rather, a decrease in depression and anger was seen among ESR participants at Day 7, with a concomitant increase in anxiety, tension, fatigue, and confusion - a group difference attributable to the sleep manipulation and not pre-existing differences. Thus, the lack of difference in the NSR and ESR group at Day 1 with respect to psychological functioning stands in contrast with existing literature (i.e., Tartar et al., 2015), possibly owing to the length of the participants' sleep

restriction, which spanned the course of one month in Tartar and colleagues' (2015) study. Given that the current study includes the addition of a group undergoing non-volitional sleep restriction, we also add to the literature in illustrating a delineation of psychological effects depending on whether sleep is restricted in a volitional versus non-volitional manner. More specifically, the current data suggest that the ESR group is more vulnerable to the effects of short-term and non-volitional sleep restriction than the NSR group is to long-term and volitional sleep restriction in terms of anxiety, tension, fatigue, and confusion.

With respect to the heightened depression and anger observed in the NSR group relative to the ESR group at Day 7, we postulate that these effects are the result of the ESR group exhibiting a decline in depression and anger. It should be noted that this finding exhibited a large magnitude of difference *only* when comparing the NSR group to the ESR group at Day 7 – not at Day 1. Meaning, there was no meaningful difference in the NSR and ESR group at Day 1, suggesting that the NSR and ESR group do not fundamentally differ with respect to their levels of depression and anger, but rather, they only differ after the ESR group underwent sleep restriction. It is conceivable that these findings are accounted for by the fact that the ESR group at Day 7 is exhibiting reduced depression and anger as a result of their short-term participation in a sleep restriction paradigm, a trend documented within induced wakefulness therapy (Hemmeter et al., 2010; Wirz-Justice & Van den Hoofdakker, 1999). Otherwise, our results do not suggest a between-groups difference in depression and anger prior to sleep restriction in the ESR group and the NSR group.

As indicated, the link between sleep loss and reduced psychological functioning is well established within the literature, although our results provide a comparison of how psychological health is differentially affected depending on the nature of the sleep restriction. Whereas some studies have supported the degradation of psychological health following short-term and non-volitional manipulations (i.e., Baum et al., 2014; Dinges et al., 1997; Haack & Mullington, 2005; Minkel et al., 2012), others have demonstrated effects following long-term and volitional patterns (i.e., Bower et al., 2010; Steptoe et al., 2008; Tartar et al., 2015). Given that our study has evaluated effects across both paradigms, we add to the literature through establishing which paradigm is associated with particular psychological changes. Evidently, the NSR group is better able to mitigate the negative consequences of sleep restriction relative to the ESR group as this pertains to psychological health. Although the NSR group and the ESR group (during sleep restriction) slept a comparable amount, the NSR group's enhanced functioning relative to the ESR group likely reflect their habituation with the reduced number of hours slept, having further implications with how the sleep restriction is perceived. Meaning, it has been shown that those who are chronically sleep restricted may lack a general awareness of how deleterious this may be, thereby minimizing its perceived impact on one's psychological functioning (Alhola & Polo-Kantola, 2007).

Of note, is that our results for the ESR group are based on two times of testing whereas our results for the NSR group are based on one time of testing. Although this was the case for the biological measures, assessing psychological functioning is complicated by the fact that participants' responses entail a degree of bias and/or subjectivity. What may also impact responses to psychological assessments are demand

characteristics, and while we do not suspect that this took place, it may be possible that the participants, after becoming more acquainted with the experimenters, felt less inclined to endorse certain items for fear of eliciting a negative response from the experimenter. Conversely, it may be that the participants wanted to provide responses that they perceived to be in line with the study's hypotheses. Given that the participants in the ESR group met with the experimenters on numerous occasions, relative to participants in the NSR group, it may be that the increased exposure to the experimenters had the potential to elicit a higher likelihood of answering psychological instruments in a biased fashion. However, it also possible that this increased contact and rapport led the participants in the ESR group to respond in a more honest fashion.

Neurocognitive variables. Although no significant findings emerged, there were three large effect sizes. First, the NSR group exhibited a higher mean reaction time on the LOT compared to the ESR group at Day 7, which runs contrary to our hypothesis. Second, the ESR group at Day 1 exhibited more correct non-matches on the NBACK compared to the NSR group, which supports our hypothesis. Third, the NSR group exhibited a higher mean reaction time on the NBACK relative to the ESR group at Day 7, and this also runs counter to our hypothesis. In addition, hypotheses suggesting stronger neurocognitive performance in the ESR group at Day 1 compared to the NSR group and stronger performance in the NSR group compared to the ESR group at Day 7 were not supported.

Like our intragroup finding demonstrating a reduced reaction time on the NBACK following sleep restriction, we see that the NSR group's reaction time is elevated compared to the ESR group at Day 7. While this may be interpreted to mean that

prolonged and volitional sleep restriction elicits greater reaction times on a working memory test relative to non-volitional sleep restriction, there is no evidence to suggest that non-volitionally restricting one's sleep leads to improved reaction time, rather, this contradicts the most well-regarded impact of sleep restriction on neurocognitive functioning; namely, increased reaction time (Belenky et al., 2003; Dinges et al., 1997; Martin et al., 1996; Stenuit & Kerkhofs, 2008). Similarly, the higher mean reaction time observed in the LOT for NSR participants relative to ESR participants at Day 7 is unlikely an accurate representation of improved performance on a visuo-spatial task for non-volitionally sleep restricted participants. Rather, we believe that the mechanism driving this effect relates to a reduction in motivation on the ESR participants at Day 7. More specifically, Cohen-Zion and colleagues (2016) illustrated that sleep satiety underscores optimal performance on tasks requiring heightened motivation, thereby having consequences in terms of how the task is approached. Thus, in the absence of sleep satiety, the ESR participants likely lacked the necessary initiative to approach the task in an effortful way, and although this translates into a reduced reaction time, this was not accompanied by an increase in number of correctly answered items. Thus, we believe these two effects should be interpreted with caution and that the results are the likely representation of reduced motivation. Importantly, we believe that reduced motivation factored into participants' performance across all subtests (following sleep restriction), yet only contributed to large magnitude of effects within discrete subtests, possibly owing to these subtests' complexity. In other words, perhaps a greater amount of motivation is required on the NBACK and LOT and the sleep restriction manipulation etched away at the required motivation and initiative required to successfully maneuver them.

With respect to the greater number of correct non-matches on the NBACK seen within the ESR group at Day 1 relative to the NSR group, we see support for our original hypothesis purporting stronger neurocognitive performance in the ESR group at Day 1 compared to the NSR group. Given that the NBACK is a working memory and continuous performance measure, it raises the possibility that prolonged and volitional sleep loss results in reduced performance. Although this finding is in line with existing research (i.e., Van Dongen et al., 2003), we are hesitant to put too much weight in this finding. In particular, out of all of our intra and intergroup neurocognitive analyses, this was the only one in line with our original research questions. Given that other neurocognitive deficits (such as increased reaction time) more reliably follow sleep restriction than correct number of non-matches, and that we failed to find any other significant effects or large effect sizes in line with our hypotheses, we suspect that the Joggle Research platform lacked sensitivity in detecting changes as a result of sleep restriction. Again, this constitutes one primary limitation within the design of the current study, and we would encourage future research to either supplement these neurocognitive measures with additional ones, or conversely to utilize a different platform altogether.

General Discussion

In synthesizing the intra and intergroup findings, we are able to examine from a holistic perspective how each class of variable responded to sleep restriction that was either volitional or non-volitional. Beginning with the biological variables, we first found a significant increase in IL-1β following a week of sleep restriction, as well as a large effect size. An additional large effect size was found between the NSR group and ESR group at Day 1 in terms of IL-6. Although both of these findings are in line with our

original hypotheses, these findings also raise interesting questions. Per our findings, it appears as though IL-1β is responsive to a non-volitional and short-term sleep restriction manipulation, whereas IL-6 was not. Rather, IL-6 was shown to have a large magnitude of difference amongst the NSR group and the ESR group at Day 1. Taken together, it stands to reason that IL-1β and IL-6 are differentially impacted depending on the nature of the sleep manipulation. More specifically, Smith et al., (2019) highlight that "unlike IL-1β, IL-6 is not a direct somnogenic factor, but sleep loss results in increased IL-6 levels (p.2)." Meaning, whereas IL-1β administration results in sleep and fatigue, sleep loss itself has been identified as a precursor to elevated IL-6. Thus, it is likely that the increase in IL-1β seen within the ESR group accounts for the enhanced fatigue also seen within this group. The absence of IL-1β elevations within the NSR group with the concomitant absence of fatigue also illustrates that the two inflammatory markers respond differently on the basis of *type* of sleep loss.

In studies (i.e., Lekander et al., 2013; Shearer et al., 2001) examining IL-6 in response to sleep restriction that did *not* result in elevations, the authors posited that this may have related to gender or the chronicity of the sleep restriction. In other words, both studies only included males, and one required that participants restrict their sleep to four hours per night for a period of five nights (Lekander et al., 2013), whereas the other study required that participants restrict their sleep to a period of two hours per day for four days (Shearer et al., 2001). In the current study, participants were asked to restrict their sleep for a seven-day period, which did not subsequently lead to an increase in IL-6. Although, participants deemed naturally sleep restricted exhibited elevations in IL-6 relative to participants who did not exhibit sleep restriction. Therefore, our finding may highlight

that *prolonged* and *volitional* sleep restriction exudes a greater increase in IL-6, rather than short-term and non-volitional sleep restriction.

With respect to IL-1β, the increase following sleep restriction mirrors a suspected inverse relationship between shortened sleep duration and increases in circulating IL-1β (Covelli et al., 1992; van Leeuwen et al., 2009). Although, these results only hold for our ESR group, in that the NSR group did not exhibit elevated IL-1β relative to the ESR group at Day 1. In other words, our study's short-term and non-volitional sleep restriction manipulation resulted in IL-1β elevations, but these were not observed amongst naturally sleep restricted participants. These results stand in contrast with Tartar and colleagues (2015) who demonstrated that self-reported volitional sleep restriction over the previous month results in increased IL-1β. Thus, the extent to which volitional versus non-volitional sleep restriction affects levels of IL-1β remains unclear; however, what may account for the rise in IL-1β across both studies relates to a possible delay in melatonin onset (Rogers & Dinges, 2008). Meaning, delaying one's sleep onset time as a result of the sleep restriction manipulation likely entailed prolonged exposure to bright lights (in an attempt to stay awake), thereby delaying melatonin onset, and melatonin itself is responsible for the secretion of IL-1β in human peripheral mononuclear cells (Tartar et al., 2015). In particular, melatonin attenuates IL-1β (Favero, Franceschetti, Bonomini, Rosella, & Rezzani, 2017), but following sleep restriction, the current study illustrated a rise in IL-1β, therefore raising the possibility that a delayed sleep-onset time reduces melatonin's impact in tapering IL-1β.

Like the biological variables, the psychological variables exhibited interesting patterns within and between subjects. As indicated, following a week of sleep restriction,

the ESR group exhibited large effect sizes denoting an increase in state anxiety, trait anxiety, tension, and fatigue. There was also a significant difference in depression, indicating a decrease following sleep restriction with a comparable large effect size. Further, a large effect size indicating a decrease in anger following sleep restriction was also found. With respect to the between-groups comparisons, the ESR group at Day 7 exhibited elevated state and trait anxiety, tension, fatigue, and confusion. Additionally, relative to the ESR group at Day 7, the NSR group exhibited elevated depression and anger.

Viewing the biological and psychological findings in conjunction, the increase in IL-1β was accompanied by an increase in anxiety, tension, and fatigue and a decrease in depression and anger following a week of sleep restriction. IL-6 was elevated in the NSR group relative to the ESR group at Day 1, making this the only large effect involving the NSR group and the ESR group at Day 1. The remaining large effects in terms of the psychological variables were found for the NSR group and the ESR group at Day 7, and included elevated state anxiety, trait anxiety, tension, and fatigue and reduced depression and anger in the ESR group at Day 7. Meaning, the NSR and ESR group (prior to sleep restriction) did not differ with respect to psychological functioning. Although the NSR group exhibited reduced sleep quantity and quality, they did not exhibit reduced psychological functioning compared to the ESR group at Day 1. Importantly, the only large between-groups effects are driven by the decrements in psychological health observed within the ESR group following sleep restriction. While these results stand in contrast with some research suggesting a decrement in functioning following long-term sleep restriction (i.e. Bower et al., 2010; Suarez, 2008; Tartar et al., 2015), it supports

other research indicating that there are between-group differences in the amount of sleep needed in order to achieve optimal functioning (i.e. Banks & Dinges, 2007). Evidently, the NSR and ESR groups fundamentally differ with respect to their ability to weather the negative psychological consequences associated with sleep restriction.

As indicated, the non-volitional component, as well as the fact that the restricted sleep runs contrary to their homeostatic sleep needs is the likely effect eliciting reduced functioning in terms of anxiety, tension, fatigue, and confusion. Interestingly, confusion did not increase over the ESR group's sleep restriction week, but rather it only emerged as a large effect between the NSR and the ESR group at Day 7, further highlighting how the routinized nature of the NSR group's restricted sleep allowed this group to better withstand these effects. Per Banks and Dinges (2007), not everyone is affected by sleep limited to less than seven hours per day in the same fashion; for instance, some individuals "experience very severe impairments even with modest sleep restriction versus those who show few if any neurobehavioral deficits…" (p. 524). Given that the current study initially categorized participants on the basis of reported and observed indicators of sleep quality and that they were differentially impacted when encountering comparable amounts of sleep, our findings support those of Banks and Dinges (2007) which highlight "trait-like" differences in neurobehavioral response to sleep loss. This suggests that the NSR group may have included participants who, relative to the ESR group, required fewer hours of sleep in order to maintain adequate functioning. While the non-volitional component of the ESR group's sleep restriction likely accounted for the decrement in psychological functioning, it is also conceivable that trait-like differences allowed the NSR group to maintain adequate psychological functioning (Banks &

Dinges, 2007; Van Dongen, Baynard, Maislin, & Dinges, 2004). Meaning, interindividual differences in the ability to withstand the deleterious effects of sleep loss may have served as a protective factor in mitigating a reduction in functioning among the NSR participants.

Our results support the notion that sleep loss elicits divergent effects on psychological functioning that are dependent upon interindividual differences. While Banks and Dinges (2007) further posit that "the biological bases of differential responses to sleep loss are not known," (p.524), we suspect that a comparable mechanism is at play. Meaning, the trait-like differences in response to sleep restriction may extend beyond psychological variables and implicate biological variables such as pro-inflammatory cytokines. More specifically, short-term sleep restriction appears to increase activity of the sympathetic nervous system, thereby increasing inflammatory responses (Irwin & Cole, 2011). The non-volitional nature of the ESR group's sleep manipulation constituted a psychological and physiological stressor, thereby having the potential to elicit increased activity of the sympathetic nervous system and inflammation. However, only an increase in IL-1β, not IL-6, was noted. Our results suggest that IL-1β, rather than IL-6, may be more responsive to sleep restriction under non-volitional circumstances. Our results also indicate that increased IL-1β (and not Il-6) is accompanied by a concomitant increase in anxiety, tension, and fatigue and a decrease in depression and anger, raising the possibility that biological and psychological health interact synergistically.

Interestingly, no significant differences between the NSR and ESR group at Day 7 emerged for IL-6, but only between the NSR group and ESR group at Day 1. This signals a between-groups difference in IL-6 in the absence of the ESR group's sleep restriction

manipulation. In other words, IL-6 is elevated amongst the group deemed naturally sleep restricted and not in the group exhibiting normal sleep. Interestingly, IL-6 was not elevated following the sleep restriction week for the ESR group, and this may be accounted for by Shearer and colleagues' (2001) finding that IL-6 elevations only began emerging following four days of sleep restriction. Although participants underwent seven days of sleep restriction, it is possible that the length of our sleep manipulation was not long enough in order to identify significant differences within and between-groups. Despite the elevated IL-6 in the NSR group, this group did not exhibit greater dysfunction across the psychological variables. Although IL-6 was elevated in the absence of psychological dysfunction, this was not the case for IL-1β, which was elevated along with concomitant decrements in psychological health.

While not directly related to our original research questions, there is an increasing amount of research examining the link between inflammation and psychological health. For instance, exposure to psychological stress is associated with elevations in pro-inflammatory cytokines (Johnson et al., 2005) and IL-6 in particular has been implicated in depression (Henry et al., 2008). Irwin (2015) further specifies that elevations in IL-6 predict depression, noting that inflammatory markers are reliably more elevated among depressed versus non-depressed individuals. This runs contrary to our findings, which demonstrate elevated IL-6 in the absence of depressive symptomatology. Of course, selection bias may have impacted these findings, given that participants with existing psychopathology were excluded from the current study. It is intriguing however, that IL-6 did not increase over the sleep restriction week, yet depressive symptomatology *decreased*. These findings raise the possibility of whether non-clinical samples'

inflammatory markers act differently in the face of sleep restriction. For instance, does the volitional component of the NSR group's reduced sleep make it less likely for them to experience depression compared to a group of depressed individuals whereby impacted sleep is a characteristic feature of depressive disorders? Similar to IL-6, IL-1β has also been implicated in depression, with elevations in IL-1β accompanying depressive-like behaviors (Liu, Wang, & Jiang, 2017). Again, the current study's results did not support an increase in depression, but rather, a rise in IL-1β was accompanied by a decrease in depression, and the fact that our study was comprised of a non-clinical sample likely impacted these findings.

Out of the various indicators of psychological health, depression has received the most attention as it pertains to its relationship to inflammation. Other indicators have received attention but have primarily been in the context of specific diagnoses. For instance, markers of inflammation have been tied to bipolar disorder (Koo & Duman, 2008), posttraumatic stress disorder (Maes et al., 1999), as well as anxiety disorders (Hou & Baldwin, 2012). While meaningful in strengthening the link between inflammation and psychological health, it is unlikely that the mechanisms explicating this relationship can be extrapolated to the current study, given the confounding factor of a psychological disorder that is central to many of these studies. According to de Wild-Hartmann and colleagues' (2013) findings, poor sleep predicts decrements in psychological functioning, whereas the reverse does not hold true. Importantly, the same cannot be said for individuals with pre-existing psychiatric diagnoses, who frequently exhibit comorbid sleep disorders secondary to their diagnosis. Even though there is some research linking various markers of inflammation to specific changes in psychological functioning among

non-clinical samples (i.e., Pitsavos, Panagiotakos, Papageotgiou, Tsetsekou, Soldatos, & Stefanadis, 2006), the roadblock that we encounter in extrapolating these results to the current study's entails the large number of variables at play, all having the potential to confound our results. These include the specific type and length of sleep restriction, gender, endogenous hormonal fluctuations, specific variables measured (i.e., biological, psychological), and inclusionary/exclusionary criteria across studies. Thus, in light of these factors, our understanding of biological and psychological functioning *especially* among non-clinical samples is not well understood.

Taken together, there is mounting evidence to suggest a relationship between sleep loss, inflammation, and psychological health, yet our understanding of the isolated effects for specific populations following certain manipulations is not well understood. Despite this, the current study suggests that IL-1β and IL-6 respond differently to sleep restriction that is either volitional or non-volitional amongst a sample of young females. Further, we identified that IL-1β and not IL-6 rises along with anxiety, tension, and fatigue, and that the rise in IL-1β is also accompanied by a decrease in depression and anger. Finally, it may be that IL-6 was not accompanied by concomitant self-reported decrements in psychological functioning as a result of factors pertaining to volition and habituation. If so, these results are a further indication that sleep restriction itself constitutes a stressor, especially under circumstance where it is non-volitionally imposed. Importantly, we cannot ascertain that the changes in psychological functioning drive the changes in biological functioning, or vice versa. Rather, it appears as though both are vulnerable to the effects of sleep loss, and further research that attempts to elucidate the specific effects and possible interactions is needed.

With respect to the neurocognitive findings, we did not find any significant results, but did find large effect sizes – although only one was in line with our hypotheses. In terms of the intragroup comparisons, we found that following sleep restriction, the ESR group's reaction time declined on the NBACK, which stands in contrast with the literature (Waters & Bucks, 2011). With respect to the intergroup findings, large effect sizes indicating increased reaction time for the NSR group compared to the ESR group at Day 7 on the LOT and NBACK were found. Again, these results did not support our hypotheses. Finally, the one large effect size supporting our original hypotheses entailed a greater number of correct matches on the NBACK for the ESR group at Day 1 relative to the NSR group. While this finding indicates reduced performance on the NBACK among the naturally sleep restricted group, it is suspect that this is the only finding out of the intragroup and intergroup comparisons that aligned with our hypotheses, given that the literature linking sleep restriction to reduced neurocognitive functioning is relatively robust. We believe that matters related to reduced motivation on the participants' part to perform optimally and understand the task may help to explain why the majority of the large effect sizes run counter to our hypotheses and the literature.

Viewed in conjunction with the biological and psychological variables, we did not see any indication across the neurocognitive measures of impaired inhibition following sleep restriction. Thus, the decline in depression and anger that was observed following sleep restriction in the ESR group may have been present as the participants' inhibition was not impacted. In other words, increased anger may be the result of reduced inhibition, and given that we did not observe reduced inhibition, perhaps explains why

anger did not increase. Rather, we are more inclined to attribute the decline in anger to a muting of their emotional response as a result of fatigue (Hatfield et al., 2002), aligning well with Cohen-Zion and colleagues' (2016) finding that attributes reduced motivation to sleep restriction. Given our lack of confidence in the neurocognitive findings we are hesitant to over-interpret what we have (and have not) found in conjunction with the biological and psychological measures.

Limitations and Future Research

As indicated, the current study examined whether sleep restriction altered one's mean levels of cortisol, IL-6, and IL-1β. While an important exploration, we did not examine the biomarkers' secretory patterns, which would have required the repeated and consistent sampling of saliva samples on a daily basis. As a result, our ability to infer whether naturally or experimentally sleep restricted participants experienced alterations in their biomarkers' diurnal rhythms cannot be ascertained. It is possible that our observed lack of difference in cortisol within the ESR group can be accounted by the length of the sleep manipulation; more specifically, increases in cortisol following sleep restriction have been documented following 10 nights (e.g., Banks & Dinges, 2007) as well as eight nights (e.g., Vgontzas et al., 2004). Further, Tartar et al. (2015) demonstrated that sleep restriction is associated with elevations in mean cortisol levels, however *only* when accounting for a later time to bed – a variable not accounted for in the current study. Thus, additional research examining various length of sleep restriction in addition to participants' time to bed would further our understanding.

An additional limitation regarding the biological variables relates to the small sample size; in particular, our significant finding of an increase in IL-1β following a

week of sleep restriction is based on a sample size of four. While this result was accompanied by a very large effect size, the extant literature regarding the interplay of IL-1β and sleep remains misunderstood and understudied. Finally, it may be that IL-6 in the ESR group did not significantly increase in response to sleep restriction due to the constricted time period, as has been noted in the literature (i.e., Shearer et al., 2001). Taken together, additional research should attempt to examine whether cytokines' patterns of secretion change in response to sleep manipulations, as well as identifying how long sleep restriction must occur for prior to identifying elevations in IL-6. In doing so, this would inform the timing and number of samples needed to detect alterations. Finally, and in light of the small sample size seen particularly in our examination of IL-1β, we encourage that additional research be conducted as to attempt a replication of our findings.

With respect to the psychological variables, as indicated a possible limitation pertaining to the instruments' criterion validity is suspected. Given our findings that denote increased fatigue in the absence of sleepiness, and increased anxiety and tension in the absence of stress, we question whether these measures adequately captured the participants' psychological status. As such, psychometric research attempting to verify matters related to criterion, convergent, and discriminant validity is warranted. An additional limitation relates to demand characteristics participants may have experienced, particularly amongst those in the ESR group. Given that the ESR participants met with the experimenters across several sessions, relative to the NSR participants who only met with the experimenters on one occasion, we raise the possibility that the increased exposure inadvertently led the participants to answer questions in a biased fashion as to

confirm suspected hypotheses. Finally, in synthesizing our interpretation of the biological and psychological variables, our exclusion of participants having pre-existing and/or current psychopathologies negated our ability to identify whether elevations among specific cytokines related to elevations among specific indicators of psychological health. While the current study found an increase in IL-1β along with an increase in anxiety, tension, and fatigue along with a decrease in depression and anger, these results stand in contrast with existing research suggesting a positive correlation between IL-1β and depression. Therefore, is this accounted for by the current study's non-clinical status? Or rather, does the nature of the sleep restriction lead to elevations of IL-1β under certain circumstances and IL-6 under others? Thus, further elucidating and teasing apart the mechanism driving the effect is warranted.

In terms of the neurocognitive variables, this class of variable resulted in significant limitations. Primarily, there is very little research on the Joggle Research platform that detail its psychometric properties, with respect to both internal and external validity. Despite the lack of available psychometric research, the discrete subtests embedded within it are generally regarded as exhibiting strong psychometric properties. Although consisting of well-researched subtests, we question whether the program and platform itself exhibited adequate external validity in capturing the participants' neurocognitive functioning in both the NSR and ESR groups. From the viewpoint of existing literature, we would have expected that some findings align with well-documented trends, such as an increase in reaction time. Rather than find this effect, the opposite effect emerged, further calling into question the instrument's validity. From an observational standpoint, it was noted that relative to the psychological measures,

participants exhibited a greater tendency to request clarification for the task at hand. Although this did not uniformly happen, it may be that participants had difficulty comprehending some of the subtests. Taken together, these limitations severely hinder our ability to have confidence in our interpretations, particularly in gauging whether we were actually detecting the intended constructs,.

In all, if future research includes the Joggle Research platform, we recommend that additional and convergent measures also be included, as a means for expanding our understanding of its psychometric properties, while also serving as an opportunity to establish convergence and/or discriminant validity between the measures. As indicated, its discrete subtests generally show sound psychometric properties, yet the platform itself currently lacks adequate psychometric research.

Final Comments

In all, the current study yielded several large effect sizes and a relatively smaller number of significant effects, which resulted from the small sample size and conservative corrections implemented to control for familywise error rates. Despite this, the small sample size was sufficient in detecting large effect sizes across all three classes of variables. Although some of our hypotheses were not supported, several of the current study's findings add to the literature in providing a comparison of the effects of volitional and non-volitional sleep restriction among a female sample. Because we grouped our participants on the basis of whether they were naturally sleep restricted or experimentally sleep restricted, we were able to gauge how different forms of sleep restriction differentially impacted these participants, thereby contributing to the extant literature's

ecological validity, which has primarily examined sleep deprivation manipulations while also excluding females.

Given that some of the current study's large effect sizes run counter to what has been described in the literature, and that our study did include a small sample size, we believe that significantly more research is needed in order for us to elucidate our understanding of the link between sleep restriction and its various consequences. We acknowledge that developing a cohesive picture is muddled by the sheer number of confounding variables, yet also believe that this is a worthwhile endeavor. Evidently, sleep loss is pernicious to one's health, but the interindividual differences in how biological, psychological, and neurocognitive functioning are impacted has yet to be entirely understood. We believe that advances within the field of psychoneuroimmunology will necessitate a greater appreciation for the ties between biological and psychological functioning, as well as what these specific interindividual differences entail. As a means for doing so, the current study examined the biological, psychological, and neurocognitive consequences of sleep restriction among a sample of young women who were either naturally or experimentally sleep restricted.

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Appendix A

Group Comparisons on Screening Measures

		Total Minutes Slept		PSQI		ISI	
Group	*n*	*M*	*SD*	*M*	*SD*	*M*	*SD*
NSR	11	392	25	5.18	1.33	8.55	4.25
ESR	9	445	36	3.44	2.46	3.38	1.5

Appendix B

Group Comparisons on Demographic Variables

		Age		BMI		Race (*n*)			
Group	*n*	*M*	*SD*	*M*	*SD*	*Caucasian*	*African American*	*Hispanic*	*Asian*
NSR	11	19.64	1.03	25.00	7.59	5	3	2	1
ESR	9	19.67	1.41	24.49	5.38	5	0	1	3