COGNITIVE PERFORMANCE AS A FUNCTION OF SLEEP DISTURBANCE IN THE POSTPARTUM PERIOD

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New mothers often complain of impaired cognitive functioning, and it is well documented that women experience a significant increase in sleep disturbance after the birth of a child. Sleep disturbance has been linked to impaired cognitive performance in several populations, including commercial truck drivers, airline pilots, and medical residents, though this relationship has rarely been studied in postpartum women. In the present study 13 pregnant women and a group of 22 non-pregnant controls completed one week of actigraphy followed by a battery of neuropsychological tests and questionnaires in the last month of pregnancy (Time 1) and again at four weeks postpartum (Time 2). Pregnant women experienced significantly more objective and subjective sleep disturbance than the control group at both time points. They also demonstrated more impairment in objective, but not subjective cognitive functioning. Preliminary analyses indicated increased objective sleep fragmentation from Time 1 to Time 2 predicted decreased objective cognitive performance from Time 1 to Time 2, though small sample size limited the power of these findings. Implications for perinatal women and need for future research were discussed.

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Introduction

New mothers regularly complain of impaired cognitive functioning, often referred to in pop culture as “mommy brain” (Berdahl & Moon, 2013). Previous research examining objective decrements in cognitive functioning in postpartum women has returned mixed results when compared to their non-postpartum counterparts across various cognitive domains (Christensen, Leach, & Mackinnon, 2010; Crawley, Dennison, & Carter, 2003). There is consistent support for postpartum women showing impaired performance when looking specifically at higher-order cognitive tasks requiring executive functioning, particularly in the early postpartum weeks and months (Farrar, Tuffnell, Neill, Scally, & Marshall, 2014; Henry & Rendell, 2007; Henry & Sherwin, 2012). The mechanism behind such impairment is unknown. This issue is important because cognitive dysfunction is linked to reckless driving (Otmani, Pebayle, Roge, & Muzet, 2005), motor vehicle accidents (Larson & Merritt, 1991) and workplace accidents (Wadsworth, Simpson, Moss, & Smith, 2003; Wallace & Vodanovich, 2003) in other populations. Similar dysfunction in postpartum mothers might be a significant risk factor for accidental infant deaths, the fifth leading cause of infant mortality (Mathews & MacDorman, 2007; Riggs & Hobbs, 2011). In addition, decreased cognitive functioning is associated with depressed mood (Hammar & Ardal, 2009) and decreased quality of life (Teng, Tassniyom, & Lu, 2012), which can also negatively impact infants (Grace, Evindar, & Stewart, 2003). To date, few studies have investigated the possible relationship between postpartum sleep disturbance and cognitive impairment (Hunter,

Rychnovsky, & Yount, 2009; Insana, Williams, & Montgomery-Downs, 2013; K. Lee, Zaffke, & McEnany, 2000; Medina, Lederhos, & Lillis, 2009). This is surprising considering the well-established link between increased sleep disturbance and decreased cognitive functioning (Durmer & Dinges, 2005; Lim & Dinges, 2010). If sleep disruption is one mechanism driving postpartum cognitive impairment, it would have significant implications for education, prevention, and intervention among this population as well as informing public policy regarding maternal and paternal leave (Laughlin, 2011).

Postpartum Cognitive Functioning

Generally speaking, cognitive impairment *during pregnancy* has been studied more often and more thoroughly than in the *postpartum* period (Crawley et al., 2003). The predominant methodology has been to compare pregnant women to young adult, non-pregnant women, occasionally following them longitudinally into the postpartum period. Given the present study is focused on late pregnancy and early postpartum, only the literature that includes both pre- and post- childbirth were reviewed.

Subjective cognitive functioning. Self-reported impairment in cognitive functioning before and after childbirth has been consistently reported over time. In a review of the early literature in this area (eight articles from 1962 to 1999), Brett & Baxendale (2002) concluded there were consistent findings of self-reported disturbance in cognitive functioning through pregnancy and the postpartum period (with estimates of percentage of impacted women ranging from 50% to 80%). More recent studies have supported these results. For example, using a cohort design, Crawley (2002) used a modified version of the self-report Cognitive Failures Questionnaire (CFQ; Broadbent,

Cooper, FitzGerald, & Parkes, 1982), which asks about frequency of problems associated with memory and distractibility, to assess 13 pregnant women and 13 non-pregnant controls in the second trimester, third trimester, and 21 to 26 weeks postpartum. Women in the pregnancy group reported significantly more cognitive failures than the control group at all three time points. Additionally, when overtly asked about specific abilities, pregnant/postpartum women rated themselves significantly worse on retrospective memory, concentration, focused attention, and clarity of thought at all three time points. Within the pregnancy group, severity of all reported difficulties did not significantly differ across time points. Crawley et al., (2003) built on these findings by adding another time point and increasing power through a larger sample size. In a mixed model design, they surveyed a sample of pregnant women (n= 40) and matched controls (n = 24) in the second trimester, third trimester, one to two months postpartum, and 10 to 13 months postpartum. On a three item self-report questionnaire asking their belief in their own cognitive abilities in memory, focused attention, and divided attention, pregnant women reported their abilities in all three areas were significantly “worse than before” pregnancy, and remained “about the same” throughout both postpartum time points. The authors attributed these findings to a decline in perceived cognitive functioning in several domains beginning in mid-pregnancy and continuing consistently throughout the majority of the first postpartum year.

Objective cognitive functioning. Several studies have attempted to compare objective cognitive performance across several domains (e.g., processing speed, working memory, executive functioning, etc.) between pregnant/postpartum women and a control group. The results in these studies have been less consistent than those

examining subjective cognitive functioning, with some finding significant differences between groups and others resulting in minimal, non-significant results.

Henry & Rendell (2007) cited inadequate power due to small sample sizes as the primary reason for the inconsistent findings, prompting them to perform a meta-analysis on 14 of these studies, specifically targeting various components of memory (i.e., short-term memory, working memory, free recall, delayed free recall, recognition, and implicit memory). They found pregnant and postpartum women performed significantly worse than controls only in objective measures that required aspects of executive functioning, including free recall and the executive component of working memory. Though these findings are significant, they might be limited by lack of consistency in how the postpartum period was operationally defined. Specifically, of the nine studies that included postpartum assessments, the definition of postpartum varied greatly between studies, from 48 hours after birth (Eidelman, Hoffmann, & Kaitz, 1993; Harris, Deary, Harris, Lees, & Wilson, 1996), to six weeks (Crawley et al., 2003), two months (Casey, 2000) or four months (de Groot, Vuurman, Hornstra, & Lolles, 2006) postpartum. Further, several studies referred to any time between birth and 12 months as postpartum (Casey, Huntsdale, Angus, & Janes, 1999; de Groot, Hornstra, Roozendaal, & Jolles, 2003; Janes, Casey, Huntsdale, & Angus, 1999) or did not define this time point at all (Keenan, Yaldoo, Stress, Fuerst, & Ginsburg, 1998). Given the immediate weeks and months following childbirth consist of massive changes and rapid adjustment that stabilize in later postpartum months (Kennedy, Gardiner, Gay, & Lee, 2007; Tikotzky & Sadeh, 2009), it is possible there are changes in objective cognitive functioning occurring during the early postpartum days and weeks that are lost when

those weeks are not specified or left out entirely. The two studies included in the meta-analyses that were performed shortly after childbirth found clear, significant differences between postpartum women and controls in working memory, long-term memory, and information processing. One of these studies (Harris et al., 1996) followed the women longitudinally, also assessing them before (third month of pregnancy) and after (four weeks postpartum). These time points showed similar differences between pregnant/postpartum women and controls, though they did not reach significance. These findings potentially suggest the early postpartum period has greater breadth (i.e., more cognitive domains) and depth (i.e., greater degree) of cognitive impairment that gradually returns to baseline, though methodological variations between studies make this difficult to conclude for certain. Further, the majority of these studies used one or a combination of author-generated tasks rather than well-validated tests to test cognitive performance.

Attempting to overcome weaknesses of some of the prior studies, Henry & Sherwin (2012) assessed a fairly large sample of women with well-validated neuropsychological tests at specific points in late pregnancy and early postpartum. Fifty-five pregnant women matched with 21 non-pregnant women received a battery of tests measuring verbal memory, spatial ability, paragraph recall, executive function, and attention in the last trimester and again at 12 weeks postpartum. Pregnant/postpartum women performed worse than controls on tasks of verbal memory and executive functioning. Spatial ability was marginally worse in pregnant/postpartum women, and pregnant women's performance worsened marginally more than the control group from late pregnancy to the third month postpartum on spatial tasks. Most recently, Farrar et

al., (2014) further bolstered the executive functioning hypothesis proposed by Henry and Rendell (2007) by longitudinally assessing cognitive performance across pregnancy/postpartum via a computerized testing. The authors administered a neuropsychological battery consisting of four tests intended to measure executive functioning to 23 pregnant women in each trimester and again at three months postpartum. Twenty-four non-pregnant women followed the same protocol. They found a systematic decline in performance on a spatial memory task (spatial recognition test) at each time point in the pregnant women relative to the non-pregnant group. They did not find this trend in three other tests (delayed match to sample test, stockings of Cambridge test, and intra/extra dimensional shift test); consistent with Henry and Sherwin (2012), the authors suggested this might mean complex visuospatial working memory is more impacted than other tasks of executive functioning, including planning, strategizing, and set-shifting.

In summary, women subjectively report consistent, perceived deficits in several domains of cognitive functioning throughout pregnancy and the postpartum period compared to their non-pregnant counterparts. Research to date utilizing objective assessment does not substantially support cognitive impairment in pregnancy but suggests some decline in cognitive functioning during the first few postpartum weeks and months with the most substantial evidence found in tasks of executive functioning on computerized tests. More limited support has been found for tasks related to processing speed and working memory during early postpartum.

Increased Sleep Disturbance in Pregnancy and Postpartum.

Sleep disturbance has been found throughout the entire peripartum period, with subjective sleep quality being impacted throughout pregnancy and the early postpartum (Figures 1 and 2) and objective sleep disturbance occurring most noticeably in the first few postpartum weeks (Figures 3 and 4).

Subjective sleep. Similar to subjective cognitive functioning, self-reports of sleep using well-validated questionnaires indicate subjective sleep disturbance occurs throughout pregnancy and the postpartum period. For instance, three longitudinal studies utilizing the General Sleep Disturbance Scale (GSDS, Gay, Lee, & Lee, 2004; Goyal, Gay, & Lee, 2007; Lee & Gay, 2011; Lee, 1992) found women in the third trimester and first month postpartum scored 43 or higher, suggesting they were poor sleepers (See Figure 1). By the third month these scores decreased to the good sleeper range (i.e., less than 43). Further, several studies utilizing the Pittsburg Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989) and spanning from first trimester through the third postpartum month have regularly found average PSQI scores greater than five, suggesting significant sleep disturbance from the beginning of pregnancy through the third month postpartum (See Figure 2; Bei, Milgrom, Ericksen, & Trinder, 2010; Coo, Milgrom, & Trinder, 2014; Dørheim, Bondevik, Eberhard-Gran, & Bjorvatn, 2009; Kamysheva, Skouteris, Wertheim, Paxton, & Milgrom, 2010; Okun et al., 2011; Okun, Hall, & Coussons-Read, 2007; Skouteris, Germano, Wertheim, Paxton, & Milgrom, 2008).

Actigraphy. Given the sensitive nature of the transitioning a new baby into the home, actigraphy has often been used as a non-invasive method to objectively measure sleep and activity levels in an attempt to improve measurement fidelity while not greatly

increasing participant burden. Wulff and Siegmund (2000) used a within subjects design to longitudinally measure sleep with continuous actigraphy in seven first-time mothers and their infants in Germany for 84 continuous weeks, from the last month of pregnancy through the fourth month postpartum. Their results indicated sleep was worst for mothers and their infants during the first month postpartum.

Matsumoto, Shinkoda, Kang, and Seo (2003) found similar results using a mixed model design. They collected continuous actigraphy data from 10 pregnant women and 10 control women in Japan from the eighth month of pregnancy to the fourth month postpartum. From the last month of pregnancy to first month postpartum the pregnant women had a significant decrease in sleep duration and increase in sleep fragmentation relative to the control group. These variables improved over time for the postpartum women but were still not equivalent to controls by the fourth postpartum month.

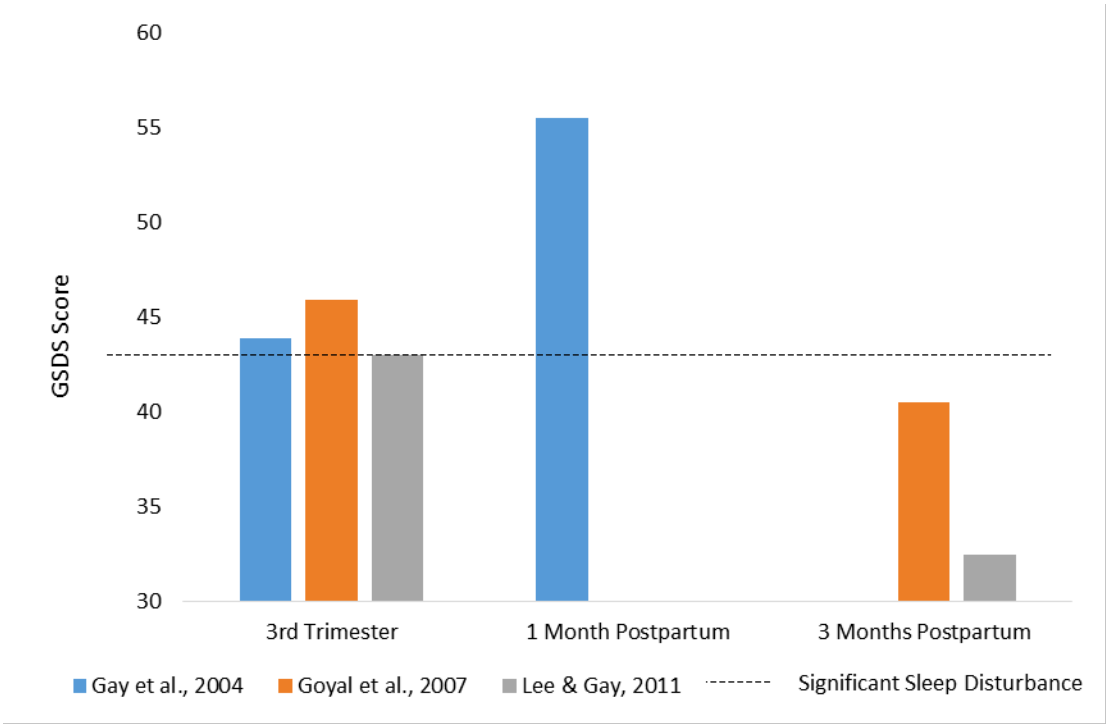

Figure 1. Scores on General Sleep Disturbance Scale during pregnancy/postpartum.

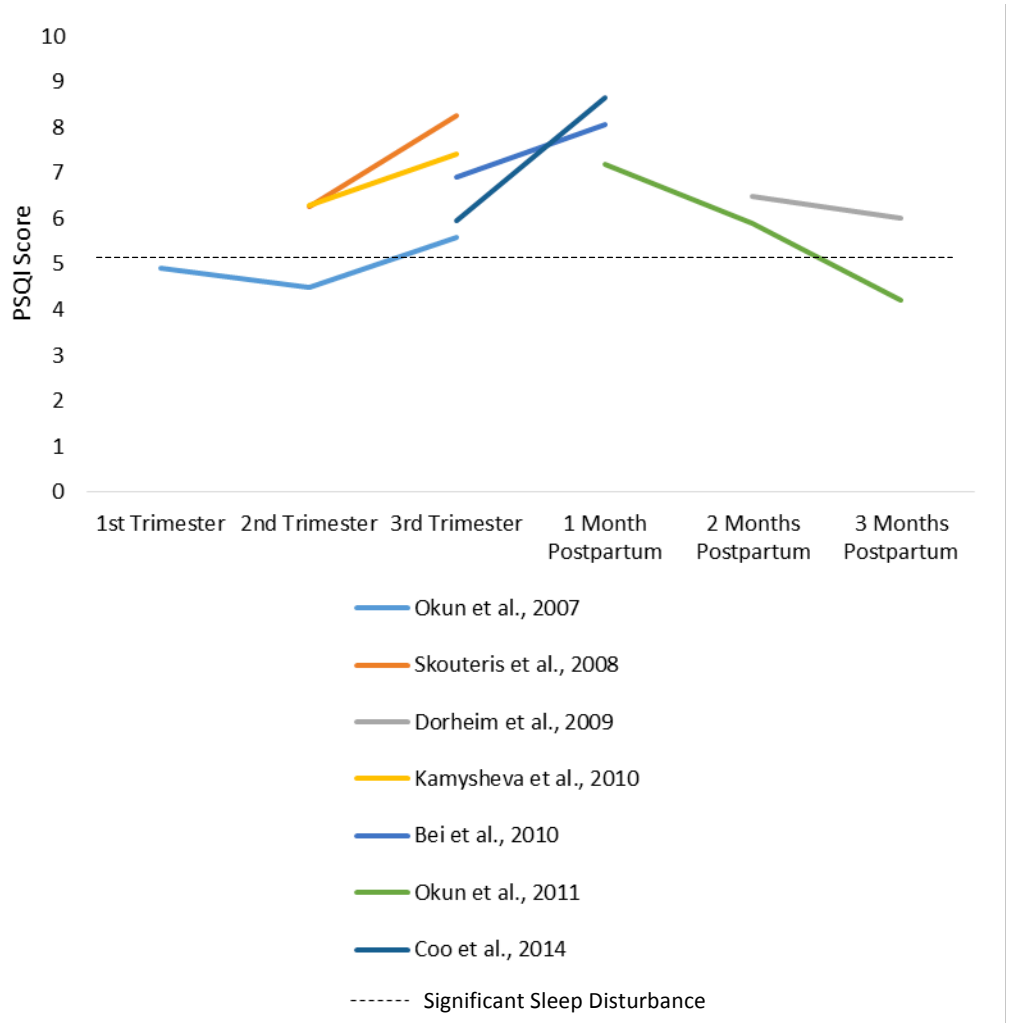

Figure 2. Scores on Pittsburg Sleep Quality Index during pregnancy/postpartum.

Gay et al. (2004) was able to use a larger sample size (*N* = 72), collecting 48 hours of actigraphy data in the last month of pregnancy and again during the first month postpartum. They also found that from pregnancy to postpartum sleep duration significantly decreased and sleep fragmentation significantly increased.

Signal et al. (2007) added to the previous literature by also examining sleep earlier in pregnancy. They longitudinally assessed 19 women with one week of actigraphy and sleep diaries at four time points: second trimester (typically the fifth or

sixth month of pregnancy), one week before delivery, and at the first and sixth weeks postpartum. These authors found no differences between sleep measures during pregnancy, but found significant worsening post-partum, with the first week postpartum being worse than the sixth week; the authors attribute this to gradual improvement over time. Such findings have been replicated multiple times in recent years. Bei et al. (2010) collected one week of actigraphy in the third trimester and again the first postpartum week in 44 women. Consistent with all other studies, they found a significant decrease in sleep duration and increase in sleep fragmentation from third trimester to one week postpartum. Montgomery-Downs, Insana, Clegg-Kraynok, & Mancini (2010) assessed 70 postpartum women and nine non-postpartum controls using continuous actigraphy from the first month to fourth month postpartum. They found that sleep fragmentation was worse in postpartum women than controls, and gradually improved from the first week to the last, again indicating improvement in sleep over the postpartum period. Unlike other studies that suggest significant disruption in sleep duration, they found that nocturnal sleep duration did not change over the course of four months and was comparable to that of non-postpartum controls. It should be noted, however, they did not assess sleep during pregnancy, and thus no inferences can be drawn from this study regarding transition from pregnancy to postpartum. Most recently, Coo et al. (2014) followed 29 pregnant women in Australia, collecting one week of actigraphy on three occasions: third trimester, 15 days postpartum, and 10 to 12 weeks postpartum. Similar to Montgomery-Downs et al. (2010), they found more impact on sleep fragmentation than sleep duration. Specifically, sleep duration declined significantly in the immediate postpartum but had recovered by three months postpartum. However,

sleep fragmentation sharply increased in the immediate postpartum and at three months postpartum remained significantly greater than sleep fragmentation during pregnancy.

Overnight sleep studies. Overnight sleep studies require significant participant burden (e.g., multiple electrodes attached, arrangement of nocturnal childcare, and often sleeping away from home) and are subsequently rarely performed in studies of sleep and pregnancy. Nishihara & Horiuchi (1998) conducted one of the few studies in this area, assessing 10 first-time mothers in Japan using an overnight sleep study during the last month of pregnancy and at three times during postpartum (the first, third, and sixth weeks). They found sleep duration and fragmentation were significantly worse at all three postpartum time points compared to pregnancy.

Lee et al (2000) were the first to follow women beginning prior to pregnancy. They assessed 29 women in their homes for two nights with overnight sleep studies during pre-pregnancy, once each trimester, and during the first and third months postpartum. There was a gradual decrease in sleep duration throughout pregnancy, though it was not significant. However, sleep duration significantly decreased from the third trimester to one month postpartum and improved slightly by the third month. Comparable results were seen for sleep fragmentation (i.e., a significant increase in sleep fragmentation from third trimester to one month postpartum and gradual improvement thereafter). There was no difference in these findings between first-time mothers and women with multiple children.

In summary, pregnant women experience worse subjective sleep quality than their non-pregnant counterparts throughout pregnancy and postpartum, with the most disturbance occurring shortly after the birth of the child. However, objective measures

such as actigraphy and overnight sleep studies have shown relatively undisturbed sleep in pregnancy (compared to non-pregnant controls) followed by a *slight* decrease in sleep duration and *significant* increase in sleep fragmentation after the birth of the child, subsequently improving over time. These findings have been consistent across several countries and using various methodologies.

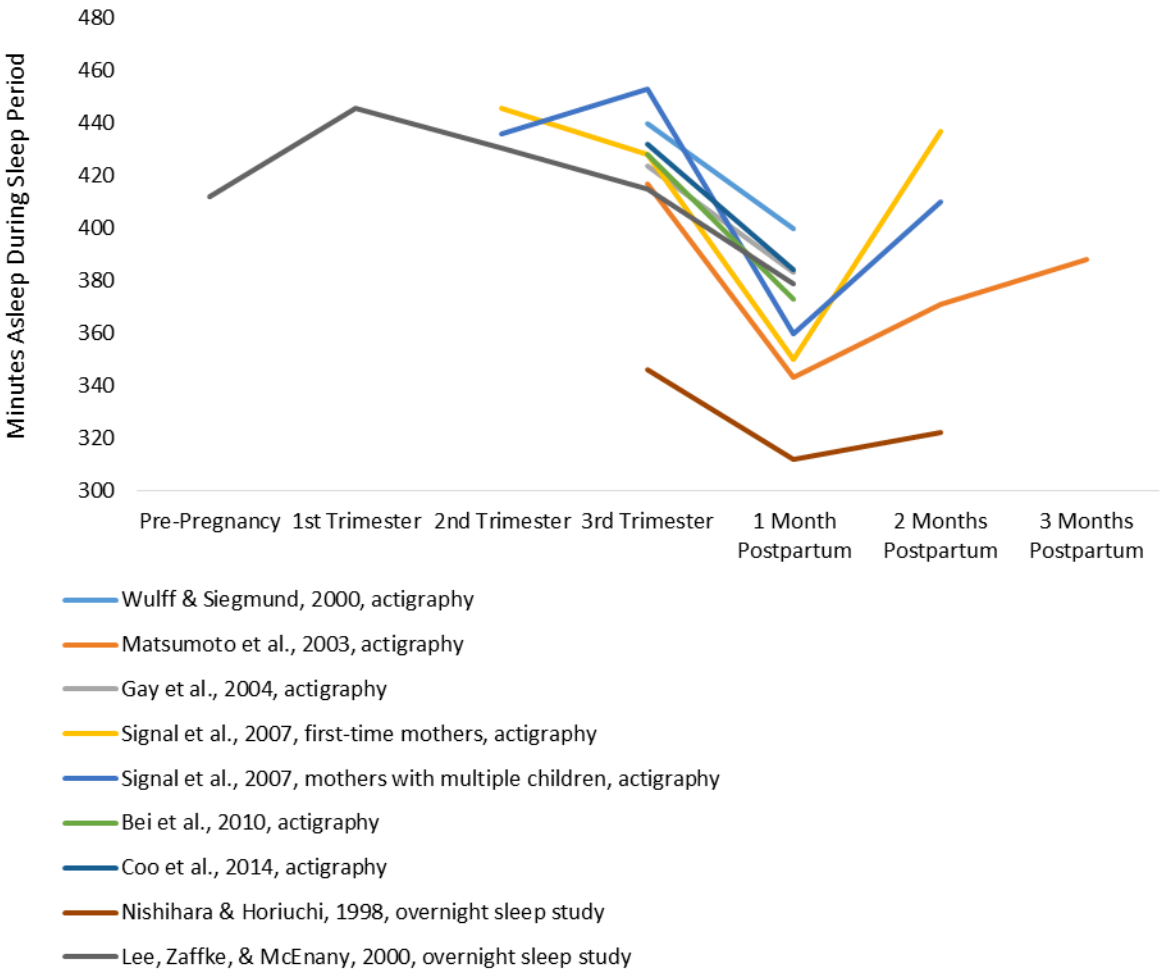

Figure 3. Nocturnal sleep time (sleep duration), in minutes, during pregnancy/postpartum.

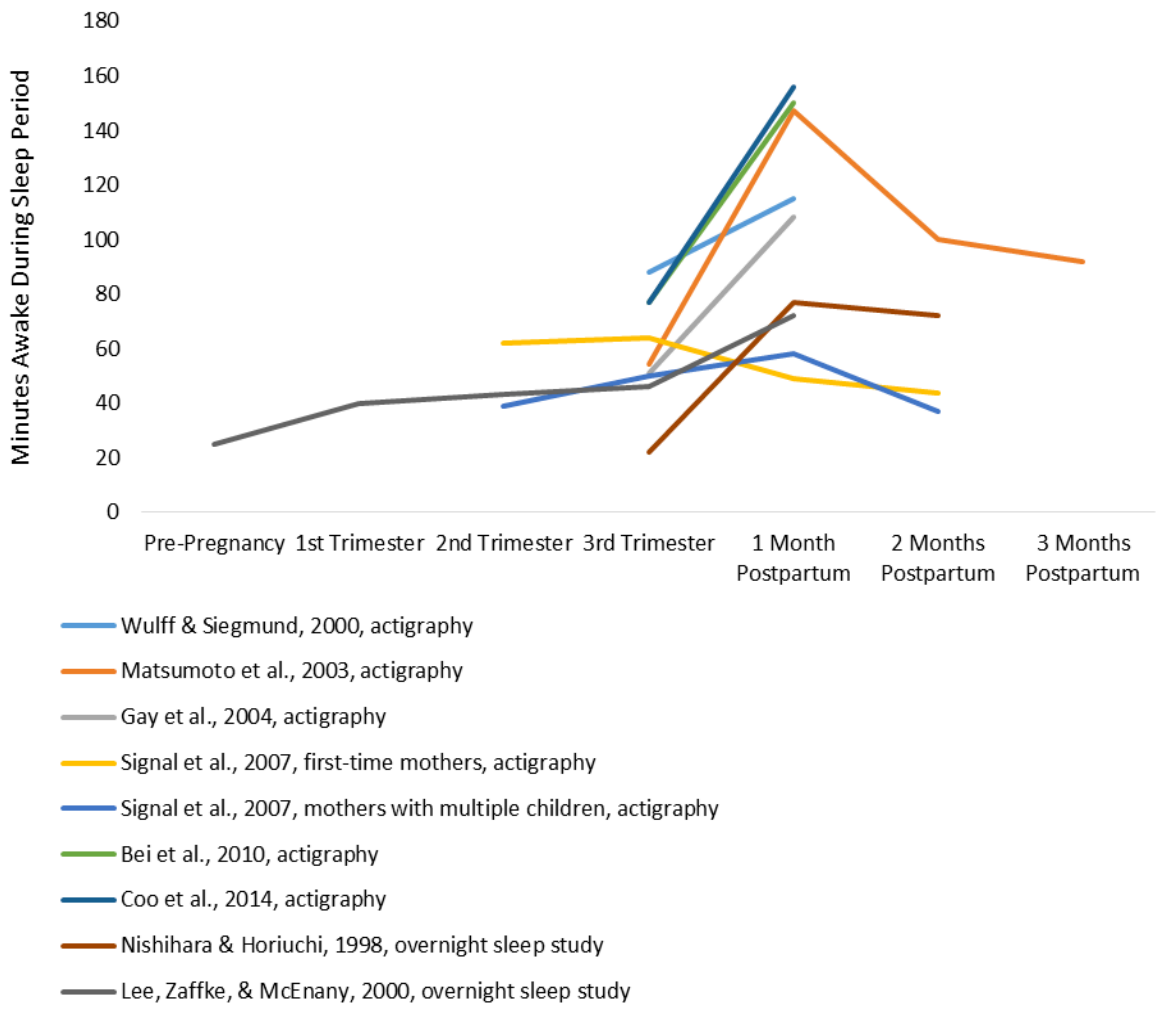

Figure 4 Nocturnal wake time (sleep fragmentation), in minutes, during pregnancy/postpartum.

Sleep and Cognitive Functioning

Subjective sleep and cognitive functioning. To date, the relationship between subjective sleep quality and cognitive performance in the general population has returned mixed results, with some studies finding a significant relationship (e.g., Amer, Hamza, El Akkad, & Abdel Galeel, 2013; Benitez & Gunstad, 2012; Nebes, Buysse, Halligan, Houck, & Monk, 2009) and others finding no such connection (Draganich & Erdal, 2014; Orff, Drummond, Nowakowski, & Perils, 2007). Research examining the relationship between subjective and objective sleep and subjective and objective

performance on overall daytime performance tasks have advised subjective sleep disturbance is a better predictors of subjective performance and objectively measured sleep is a better predictor of objective performance (Franzen, Siegle, & Buysse, 2008; Insana, Stacom, & Montgomery-Downs, 2011; Orff et al., 2007), suggesting these mixed findings might be due to using subjective sleep to predict objective cognitive performance. Few studies have explored the connection between subjective sleep and subjective cognitive functioning, and those studies have typically examined sleep disturbance within the context of self-reported insomnia symptoms. Ohayon & Lemoine (2004) surveyed a large sample (*N* = 5,622) of the general population aged 15 and older in France. They found those who endorsed enough symptoms to meet criteria for insomnia were more likely to report decreased overall cognitive efficiency (although questions asked were not available). Using a similar approach, Kronholm et al. (2009) surveyed 5,177 adults over the age of 30 using three author-generated questions related to sleep duration, fatigue, and exceptional tiredness and one author-generated question related to memory (i.e., “Is your memory: very good, good, satisfactory, poor, very poor?”). They also administered objective measures of cognitive performance by administering tasks of verbal fluency and memory (elements of the Consortium to Establish a Registry for Alzheimer’s Disease test battery). The authors found that self-reported sleep duration and report of insomnia symptoms were more predictive of self-reported memory than objective measures of verbal fluency and memory. Most recently, Wilkerson, Boals, and Taylor (2012) added to these studies by utilizing well-validated measures (rather than author-generated questions) of self-reported sleep disturbance and cognitive functioning using the Insomnia Severity Index (ISI; Morin, 1993) and the

CFQ. In a survey of undergraduate students (*N* = 941), it was found that insomnia severity predicted degree of self-reported cognitive failures, even after controlling for potential confounding variables of depression, negative affect, stress, and anxiety.

Objective sleep and cognitive functioning. The relationship between objective sleep disturbance and objective cognitive functioning has been heavily researched. The majority of the literature has been focused on objectively measured sleep duration, which is defined as total sleep time obtained during a single, nocturnal sleep period. Objectively measured sleep fragmentation, defined as amount of arousals and/or amount of time awake or mobile after initial sleep onset, has been examined less frequently as a contributor to cognitive changes.

Objective sleep duration. In a review of the sleep duration literature, Durmer and Dinges (2005) addressed three different potential types of disruption to sleep duration. Long-term sleep deprivation is defined as greater than 45 hours, short-term sleep deprivation as less than or equal to 45 hours, and partial sleep deprivation is sleeping less than seven hours per 24 hours for multiple nights. Only a handful of studies have thoroughly analyzed cognitive performance as a result of partial sleep deprivation, which most closely resembles postpartum sleep in terms of duration. Belenky et al. (2003) used a mixed model design, randomizing 66 adults to a three, five, seven, or nine hour sleep window for seven days. They found a dose-response effect for partial sleep deprivation on the psychomotor vigilance test (PVT), a measure of attention. In the five hour and seven hour groups, performance initially declined and then leveled off. In the three-hour group, performance consistently declined.

Interestingly, they did not report on assessments of executive functioning, so it is unclear if there would be a dose response within those tasks.

Using a similar design, Van Dongen, Maislin, Mullington, and Dinges (2003) expanded on these findings. Forty-eight adults were randomized to either three nights of total sleep deprivation, 14 days of partial sleep deprivation (four or six hours sleep window for fourteen days), or a control group (eight hour sleep window for 14 days). They also found a dose response and a cumulative effect for partial sleep deprivation using three measures of cognitive functioning: attention (PVT), working memory (digit span), and cognitive throughput (serial addition/subtraction), with both partial sleep deprivation groups exhibiting significant, cumulative, performance deficits compared to the control group on all tasks. By the end of the study, the four hour group reached performance levels comparable to two nights of total sleep deprivation in tasks of attention and working memory and performance levels comparable to one night of total sleep deprivation on throughput tasks. The six hour group reached performance levels comparable to one night of total sleep deprivation in tasks of attention and working memory.

Further supporting these findings using similar methodology, Casement, Broussard, Mullington, and Press (2006) randomized 22 adults to a four hour sleep window per night or a control group (eight hour sleep window) for a period of nine days. There was a significant difference in performance on a measure of higher-level working memory (retrieving an item from working memory), such that the control group exhibited learning by significantly improving on the task (i.e., learning or practice effect), while the four hour group did not improve over time (i.e., failure to learn).

***Objective sleep fragmentation*.** There is a paucity of research on sleep fragmentation and cognitive functioning, though the few studies that have examined this relationship have found a strong correlation. Bonnet (1985) used a within subjects design to study sleep fragmentation by briefly awakening each of eleven participants after every minute of electroencephalographic-defined sleep for two nights, following one night of undisturbed sleep. A prolonged (30 minute) addition task and a working memory task (digit symbol substitution) were administered each morning. After two nights, their performance was significantly worse than baseline on both tasks. The author noted the performance was comparable to 40 to 60 hours of total sleep deprivation. However, participants slept one hour less, on average, when sleep was fragmented compared to undisturbed sleep. This indicates findings might have been a result of decreased sleep duration rather than increased fragmentation.

In answer to this problem, Martin, Wraith, Deary, and Douglas (1997) have since shown that sleep fragmentation produces similar deficits with or without decreased sleep duration. They used a within subjects design to examine the daytime effects of sleep fragmentation while controlling for sleep duration in twelve healthy adults who underwent two nights of overnight sleep studies on two separate occasions. On one occasion they were allowed undisturbed sleep. On the other occasion, sleep fragmentation was induced every minute to increase heart rate and blood pressure without visibly awakening participants. As a result, participants experienced the same amount of total sleep time during undisturbed and fragmented nights, allowing any differences to be attributed to sleep fragmentation. Following fragmented nights, participants experienced significantly more objective sleepiness (measured by multiple

sleep latency tests), which has consistently been significantly related to cognitive impairment (Mitler, 1993; Stepanski, 2002).

More recently, Lim et al. (2011)conducted a naturalistic field study, following 700 healthy older adults who were monitored with actigraphy, a non-invasive method of monitoring rest-activity cycles, for 11 days, after which they completed 21 cognitive tasks in five domains. They found that increased sleep fragmentation, operationally defined as increased number of transitions between rest and activity, was associated with poorer global cognitive performance. Broken down by domain, increased sleep fragmentation was associated with greater deficits in perceptual speed (digit symbol substitution, number comparison, Stroop color naming, and Stroop word naming), visual spatial abilities (line orientation and progressive matrices), working memory (digit span forward, digit span backward, and digit ordering), and semantic memory (Boston naming and reading test). Given the very limited research on sleep fragmentation and cognitive performance, it is difficult to infer if the additional impacted domains found in the field study are due to valid, unique contributions of a naturalistic setting (e.g., more distractions than a lab environment, impacting already vulnerable concentration) or some other confounding variable (e.g., a third variable, such as an ill family member, impacting both sleep fragmentation and cognitive functioning).

In summary, subjective sleep quality is associated with subjective reports of perceived cognitive functioning, and objective sleep duration and sleep fragmentation cause significant impairment in objectively measured cognitive functioning in several domains. Regarding objective measures, controlled studies using randomization in a lab setting have found a cumulative, dose-response effects of decreased sleep duration on

tasks requiring attention and concentration as well as tasks of simple and higher-level working memory. Sleep fragmentation has been less researched, but shown to have a comparable effect to that of sleep duration, exhibiting a negative, linear relationship between sleep fragmentation and performance on and tasks of working memory, processing speed, visuospatial abilities.

Postpartum Sleep and Cognitive Functioning

Only two studies have attempted to thoroughly examine the relationship between sleep and cognitive functioning in postpartum women. Swain, O'Hara, Starr, and Gorman (1997) studied 30 first-time mothers, recruited from obstetrics and gynecology clinics, who completed sleep diaries during their *first three weeks postpartum*. Additionally, each week the women completed tasks designed to measure memory (immediate free recall, delayed free recall and recognition, and paired associate learning), attention and concentration (symbol cancellation, addition, digit-symbol substitution, card sorting, backward digit span, and Stroop color-word recognition task), and psychomotor performance (simple reaction time and tapping). Twenty-eight non-pregnant controls (i.e., women recruited from the same clinic who had a child at least five years of age and were not pregnant completed the same protocol. There was an effect of time for most individual tasks, indicating a practice effect in both groups. However, there was not a significant group effect for group in any of the three domains, indicating postpartum women performed comparably to that of controls. Using hierarchical regression to separately analyze postpartum and control groups, the authors found in the postpartum women, sleep duration of the previous night predicted performance on attention and concentration tasks and psychomotor tasks in the first

week and memory tasks in the second week. There was no relation between sleep duration and cognitive performance in the third week. In the control group there was no relationship between sleep duration and cognitive performance in any domain at any time point.

More recently, Insana et al (2013) studied 70 first-time mothers and nine non-pregnant controls, recruited via community advertisements, who wore actigraphy for *weeks 2-12 postpartum*. These women also self-administered the PVT each morning. The authors found that the postpartum group experienced PVT performance significantly worsened over time in the postpartum group compared to the controls, which they attributed to postpartum women experiencing more sleep fragmentation than the control group across weeks (i.e., compounded impact of prolonged sleep disturbance). In the postpartum women, small to moderate correlations were found between the total amount of sleep and attention for most postpartum weeks. They did not examine this relationship among the control group.

It is important to note both of these studies began in the postpartum period, thus lacking any information on sleep and cognitive functioning prior to the transitional postpartum period. If increased sleep disturbance due to the birth of a child is a primary mechanism driving postpartum cognitive disturbance it is important to control for significant group differences in sleep that might have existed during pregnancy. Further, despite having the information needed, both studies examined only sleep duration and subsequent cognitive performance, failing to mention sleep fragmentation, and neither gave an explanation for leaving out such analyses.

In addition, parity (the number of times a woman has given birth) has been separately linked with sleep disturbance and cognitive performance in the first postpartum month. Most studies support that primapara, though similar to multipara in sleep during pregnancy, seem to experience more subjective and objective sleep disturbance than multipara in the first six to eight weeks postpartum with little to no difference between the two groups by the third month and following (Dørheim et al., 2009; Lee et al., 2000; Montgomery-Downs et al., 2010; Signal et al., 2007; Weinraub et al., 2012). Parsons et al. (2004) demonstrated the same relationship with cognitive functioning. Although they exhibited comparable performance during pregnancy, first-time mothers performed significantly worse than mothers with multiple children on several measures of cognitive performance (as measured by the California Verbal Learning Test) at one month postpartum. To date, no study has investigated the relationship between parity, sleep disturbance, and cognitive performance in the same sample, though these separate findings lend further support to the notion that sleep might be a mechanism behind changes in cognitive functioning in this population.

The Current Study

Subjective sleep disturbance and subjective cognitive functioning decrements have been independently demonstrated throughout pregnancy and in early postpartum. To date, no studies have examined the relationship *between* subjective sleep and cognitive functioning during this timeframe in this population.

Objective sleep disturbances (decreased sleep duration and increased sleep fragmentation) and objective cognitive performance impairments have resulted in mixed findings, but independent decrements have most consistently been found in both in the

first postpartum weeks. Studies examining the *relationship between* objective sleep disturbance and objective cognitive functioning in the postpartum period have found sleep disturbance to be a significant predictor of several areas of cognitive functioning (e.g., attention, concentration, and memory). Unfortunately, none of these studies included baseline measures (i.e., before the postpartum period), and thus were unable to control for baseline differences between groups before childbirth, limiting interpretation of the independent contribution of postpartum objective sleep disturbance to objective cognitive functioning. Additionally, these studies did not examine tasks of executive functioning, a domain that has been shown in several studies to be impacted in pregnancy and the postpartum period.

The current study was designed to expand on previous research by longitudinally examining the relationship between subjective and objective sleep and subjective and objective cognitive functioning in late pregnancy and early postpartum. Sleep and neuropsychological performance data were collected from pregnant women in the last month of pregnancy (Time 1) and four to eight weeks postpartum (Time 2). A control group of adult, non-pregnant women completed the same protocol. Consistent with previous literature (Franzen et al., 2008; Insana et al., 2011; Orff et al., 2007), subjective sleep measures were analyzed primarily in relation to subjective cognitive functioning variables and objective sleep measures were analyzed with objective cognitive performance.

Aims and Hypotheses

Aim 1. Replicate previous studies showing pregnant women subjectively report worse sleep and cognitive functioning, compared to controls, at both time points.

Hypothesis 1. Pregnant women would subjectively report worse sleep quality and cognitive functioning than non-pregnant women at both time points.

Aim 2. Examine the relationship between subjective sleep and subjective cognitive functioning in pregnant women at both time points.

Hypothesis 2. Higher, self-reported sleep disturbance would significantly predict higher, self-reported cognitive failures in pregnant women at both time points.

Aim 3. Replicate previous studies showing pregnant women objectively experience worse sleep and cognitive performance, compared to controls, in early postpartum.

Hypothesis 3. There would be no significant group differences (pregnant vs. controls) in objective sleep (i.e., duration and fragmentation) or cognitive function (i.e., attention, working memory, and executive functioning) at Time 1, but that at Time 2, pregnant women would have worse sleep and cognitive function than controls.

Aim 4. Determine if an increase in objective postpartum sleep disturbance mediates the relationship between pregnancy and objective cognitive performance in early postpartum, after controlling for baseline cognitive functioning.

Hypothesis 4. Using only the objective sleep variables that were found to significantly change between Time 1 and Time 2 based on group membership (i.e., exhibit a group X time interaction), it was hypothesized that the objective sleep would mediate the relationship between group and cognitive performance change scores on the objective cognitive performance variables found to significantly change between Time 1 and Time 2 based on group membership (i.e., have a significant group X time interaction). See Figure 5 for representation.

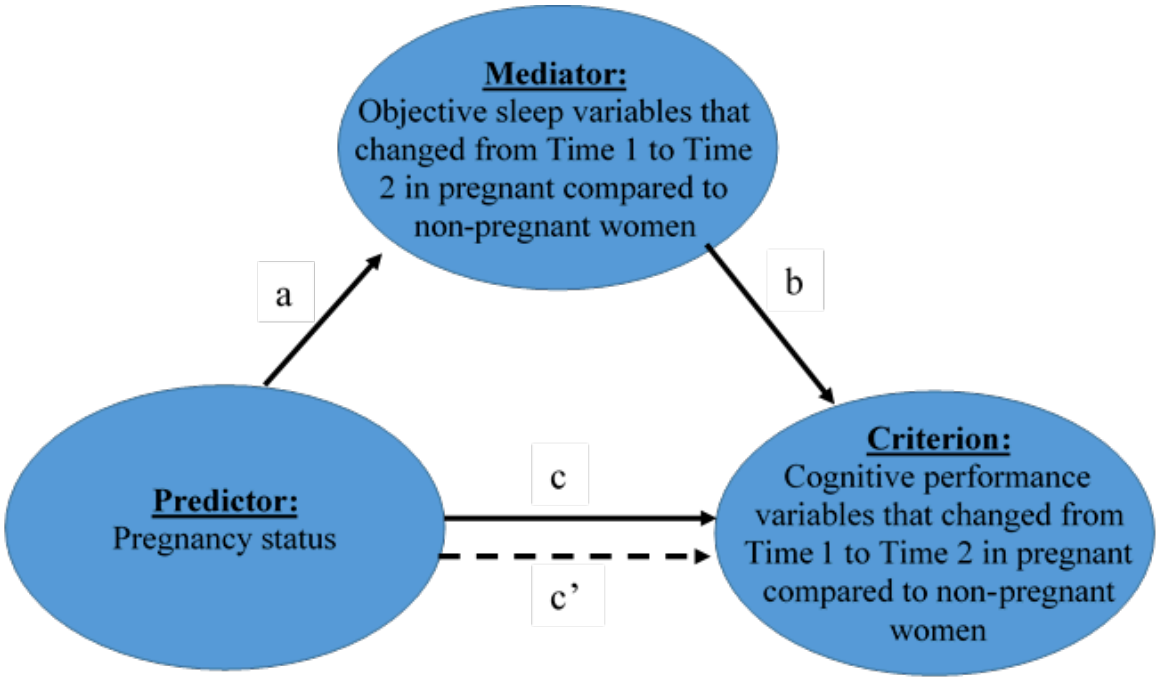

Figure 5. Proposed mediation model.

Methods

Participants

Women were recruited through medical offices, large universities, and online forums. Pregnant women were excluded based on multiple births (e.g., twins, triplets, etc.) or premature birth (i.e., birth prior to the 37th week of pregnancy), as these circumstances are often related to significant complicating factors (e.g., extended admission to the hospital for mother and/or infant) that are likely to continue into the fourth week postpartum. Further, in accordance with previous literature with similar samples, volunteers were excluded if they reported a history of depression, history of serious mental illness, or presence of a neurological disorder. Further, consistent with previous studies (e.g., Insana et al., 2013), if it was discovered during testing a

participant had current, probable depression, as indicated by > 13 on the Edinburgh Postnatal Depression Scale (Cox, Holden, & Sagovsky, 1987), she was excused from the study and referred as appropriate.

Measures

Measures varied by time point and pregnancy status. See Appendix for list of measures administered at each time point by group as well as a list of demographic questions asked.

General Sleep Disturbance Scale (GSDS). The GSDS is a 21-item self-report measure designed to evaluate the incidence and nature of sleep in the past week (Lee, 1992). Responses are given using an eight point likert scale ranging from 0 (never) to 7 (every day). Questions pertain to a variety of general sleep issues, including: problems initiating sleep (1 item), waking up during sleep (1 item), waking too early from sleep (1 item), quality of sleep (3 items), quantity of sleep (2 items), daytime sleepiness (7 items), and the use of substances to induce sleep (6 items). The GSDS has been validated multiple times in samples of pregnant/postpartum women, resulting in Cronbach alpha coefficients ranging from .77 to .85 (Gay et al., 2004; Goyal, Gay, & Lee, 2009).

Actigraphy. Actigraphy is a method for measuring sleep and activity patterns. In this study, sleep and wake patterns were measured using Respironics® Actiwatch Spectrum® (Philips Home Health Care Solutions, Bend, OR, USA) which are compact, wrist-worn, battery-operated activity monitors that look similar to a small wristwatch. The Actiwatch utilizes a motion sensor known as an "accelerometer" to monitor the occurrence and degree of motion. This type of sensor integrates the degree and speed

of motion and produces a small signal whose magnitude and duration depend on the amount of motion. This information is stored in memory and then will be downloaded for analysis. Actigraphy is highly correlated with polysomnography (PSG), the gold standard for objectively measuring sleep, in differentiating sleep from wakefulness. Actigraphy has often been used as a non-invasive measure of sleep in pregnant and postpartum women (Dørheim et al., 2009; Insana et al., 2011; Jenni, Deboer, & Achermann, 2006; Montgomery-Downs et al., 2010; Wulff & Siegmund, 2000). Comparisons between actigraphy and PSG have shown adequate overall agreement of in-bed recordings in healthy young adults, including women of child-bearing age (Ancoli-Israel et al., 2003). However, no data currently exists regarding validity of this measure in pregnant and postpartum women.

Actiware software utilizes an algorithm to autoscore individual time epochs as "sleep" or "wake." The highest resolution (15-second epochs) was used in order to remain consistent with previous analyses in normative samples of postpartum women (Montgomery-Downs et al., 2010). In accordance with previous literature (Gay et al., 2004; Matsumoto et al., 2003; Montgomery-Downs et al., 2010; Signal et al., 2007) several variables were calculated from the actigraphy data. For the present study, sleep duration was measured using total sleep time (TST) and sleep fragmentation was measured using wake after sleep onset (WASO) and the fragmentation index (FI, a more sensitive measure of movement during nocturnal sleep period). First, time in bed (TIB) for the nocturnal sleep period was calculated as minutes from the first epoch identified as rest to the final epoch identified as rest. TST was defined as the number of minutes scored as sleep during TIB. WASO was defined as the number of minutes

scored as awake during TST. FI was defined as the quantity of activity that occurred during time in bed. FI was calculated by adding together two percentages derived from the TIB period. First, the percentage of epochs scored as mobile during the entire TIB period were be calculated (i.e., (minutes of movement during TIB)/TIB). Second, within each sleep interval, a minute will manually be scored as movement if a single epoch (15 seconds) is scored as movement (activity > 40); this value is then used to find a percentage of mobile minutes during the specified sleep interval (i.e., manually calculated mobile minutes/minutes of sleep interval). These two percentages will be added together to create the fragmentation index. Each variable (TST, WASO, and FI) will be calculated for each night the participant wears the watch, then averaged across the week for that time point.

Sleep diary. Sleep diaries were utilized to support actigraphy data. Participants were asked to keep a sleep diary for each day an Actiwatch was worn. In accordance with previous studies (Montgomery-Downs, 2010; Swain et al., 1997), women were be asked to record when they went to bed for the night, when they woke up for the day, when they removed their Actiwatches, when they put their Actiwatches back on, and what time they napped (if a nap was taken).

Cognitive Failures Questionnaire (CFQ). The CFQ (Broadbent, Cooper, Fitzgerald, & Parkes, 1982) is a 25-item self-report inventory focusing on perception, memory, and motor function. Each item uses a 5-point likert scale from 1 (never) to 5 (very often). The items are summed, yielding a minimum score of 25 and a maximum score of 125. The measure was originally designed to assess participants' experience over the past six months. For the purposes of the current study, participants will be

asked specifically about the previous week. A similar, modified version of the CFQ (inquiring of last four weeks) has been used previously in postpartum samples (Crawley, 2002).

Automated Neuropsychological Assessment Metrics (ANAM^4). The ANAM^4 (2007) is a library of computer-based assessments designed to measure several aspects of neuropsychological performance. The current study included three subtests from the ANAM^4, rendering numerous variables computed for each test. Given the exploratory nature of the present study, a variety of variables were selected to create a comprehensive view of performance: number of trials with a correct response (Num Corr), average response time of all items (correct and incorrect; Mean RT), average response time for the correct responses (Mean RT Corr), and number of correct responses per unit of available response time (Throughput).

Code Substitution – Learning (Cds). Code substitution, designed to measure attention and processing speed, requires the participant to compare a digit-symbol pair with a set of defined digit-symbol pairs (i.e., the key). The participant presses designated buttons to indicate whether a given pair represents a correct or incorrect pairing relative to the key. In the learning phase the defined pairs are presented on the screen along with the digit-symbol pairs in question.

Code Substitution – Immediate Memory (Cdi). The Immediate Memory phase of Code Substitution, designed to measure cognitive processing efficiency, begins immediately after the Learning phase. The participant is presented with learned digit-symbol pairs and is again presses the designated buttons to indicate whether the given pair represents a correct or incorrect pairing without the key present.

Stroop Task (Strp). The Stroop Task, designed to measure executive functioning, presents three blocks of trials. In the first block, the words RED, GREEN, and BLUE are presented individually in black type on the display. The user is instructed to press a corresponding key for each word (1 for RED, 2 for GREEN, 3 for BLUE). In the second block, a series of XXXX-s is presented on the display in one of the three colors (XXXX, XXXX, XXXX). The user is instructed to press the corresponding key based on color. In the third block, a series of individual words (RED, GREEN, BLUE) are presented in a color that does not match the name of the color depicted by the word. The user is instructed to press the response key assigned to the color of the word rather than the actual word. For the purposes of the present study only the third block, Stroop Task – Interference, was used.

Procedure

This study was approved by the University of North Texas (UNT) Human Subjects Research IRB. Once a participant was identified she met with a researcher either in her home or in a laboratory room on the campus of UNT. Consent was obtained and participants were asked to provide general demographic information, including age, race, ethnicity, marital status, household income, and education level. For pregnant women, baseline information was collected during the last 5 weeks of pregnancy. Non-pregnant women were recruited and began the study during the same time period. Participants were be asked to wear an Actiwatch for one week. To assist in recognizing nocturnal sleep periods, participants were asked to press a button on the side of the watch (“event marker”) twice per day: once when they attempted to go to sleep in the evening, and once when they woke up in the morning. They were also

asked to keep a daily sleep diary on the days an Actiwatch was worn. Following the week of actigraphy, women completed self-report measures and participated in a neuropsychological test battery (Time 1). All testing and surveys were administered in the morning (i.e, between 8:00 am and 11:00 am) to control for circadian factors associated with cognitive performance (Henry & Sherwin, 2011). For pregnant women, this procedure was repeated at four to eight weeks postpartum (Time 2). At Time 2 pregnant women also provided information about working status, partner working status, duration of maternity/paternity leave, type of birth, infant's sleep environment (daytime vs. nighttime), and feeding method. For non-pregnant women, the procedure was repeated approximately four to twelve weeks following the baseline assessment.

Results

All statistical analyses were performed using SPSS version 22.0. Prior to analyses data were screened for normality, missing data, and outliers (Tabacnick and Fidell; 2007). Due to software malfunctions, ANAM data were missing for one control participant at Time 1 and one pregnant participant at Time 2. Additionally, due to defective actiwatches, actigraphy data were missing for three pregnant participants at Time 2. There were no problematic univariate or multivariate outliers and no variables required transformations.

Participants

Data were collected from January 2014 until April 2015. One hundred seventeen women initially expressed interest in the study. Twenty-four pregnant women met criteria and were initially consented into the study, with 13 completing both time points. Thirty-six non-pregnant women met inclusion criteria and were consented with 22

completing both time points. See Figure 6 for attrition details. Only participants who completed both time points were included in analyses. Participants ranged in age from 18 to 34 and were primarily Caucasian (71.88%). See Table 1 for sample characteristics by group.

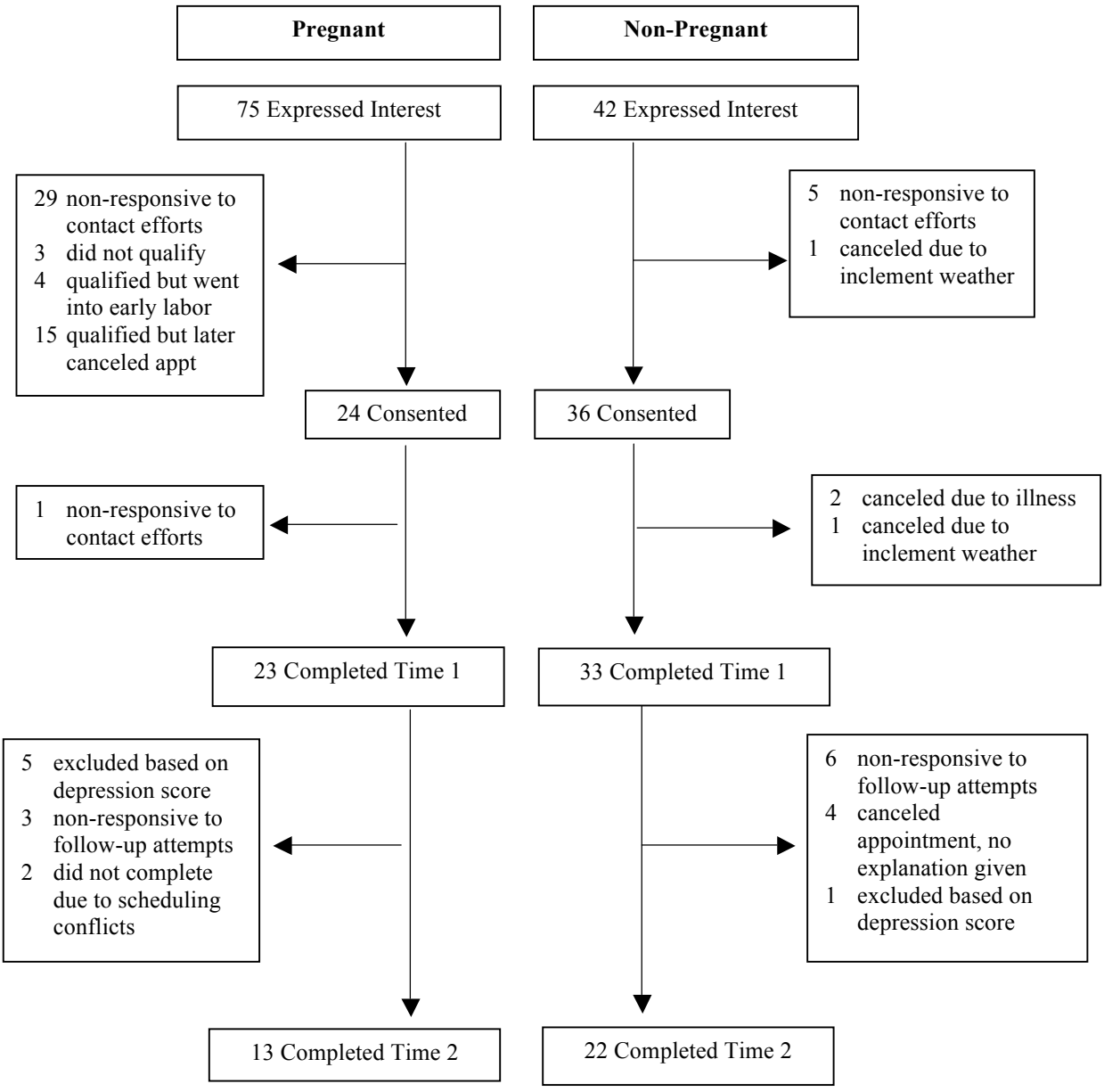

Figure 6. Attrition rates by group.

Table 1

Sample characteristics for pregnant women and non-pregnant controls

	Pregnant	Non-pregnant	*t*	x^2	*p*
Age, *M (SD)*	28.99 (3.37)	20.15 (1.84)	8.71		< .001
Ethnicity, *n*				1.6	0.205
Hispanic/Latina	1	12			
Non-hispanic/Non-latina	10	21			
Unanswered	2				
Race, *n*				2.48	0.481
American Indian/Alaska Native	0	0			
Asian	0	1			
Black/African American	1	3			
White/Caucasian	11	12			
More than one race	1	4			
Marital status, *n*				21.67	<.001
Married	8	1			
Living with partner (unmarried)	5	4			
Single	0	17			
Number of children, *n*				15.97	<.001
None	3	19			
One or more	10	2			
Education, *n*				19.62	<.001
High school diploma	2	0			
Some college	1	20			
Associates/certification	2	2			
Bachelors	7	0			
Masters	1	0			
Employed, *n*				1.86	0.172
Full-time	9	10			
Part-time	4	3			
Not currently employed	13	7			
Individual income, *M (SD)*	44910 (37741)	13260 (10020)	2.56		0.02
Household income, *M (SD)*	98784 (61360)	58545 (49216)	1.75		0.094

Correlations Between Target Variables

Preliminary correlations were run to examine relationships between age, mood, and subjective and objective sleep and cognitive functioning at baseline. Throughput was used as the primary measure of objective cognitive functioning for each test as it incorporates multiple other factors (i.e., number correct and response time). As displayed in Table 2, age was significantly positively related to FI and WASO and negatively related to the Stroop task. Therefore, Age was considered as a covariate in analyses that included these variables. Not surprisingly, WASO, and FI were significantly associated with each other as were the Throughput variables.

Table 2
Correlations between age, sleep, and cognitive functioning among entire sample at baseline

						Throughput		
	GSDS	CFQ	TST	FI	WASO	Cds	Cdi	Stroop
Age	0.20	-0.07	-0.04	*0.34	*0.41	-.028	-0.31	*-0.36
GSDS		0.12	-0.21	0.11	0.01	0.10	0.00	-0.10
CFQ			0.17	-0.01	-0.06	-0.24	-0.256	0.28
TST				-0.20	-0.05	-0.25	-0.12	0.05
FI					**0.87	-0.17	-0.30	-0.25
WASO						-0.22	-0.32	-0.26
Cds							**0.86	**0.45
Cdi								0.30

Note: * = $p < .05$; ** = $p < .01$; GSDS = General Sleep Disturbance Scale; CFQ = Cognitive Failures Questionnaire; TST = Total Sleep Time; FI = Fragmentation Index; WASO = Wake After Sleep Onset; Throughput = number of correct responses per unit of available response time; Cds = Code Substitution – Learning; Cdi = Code Substitution – Immediate Memory; Stroop = Stroop Task - Interference

Hypothesis Testing

Hypothesis 1. Pregnant women would subjectively report worse sleep quality and cognitive functioning than non-pregnant women at both time points.

A Group (Pregnant vs. Non-pregnant) X Time (Time 1 vs. Time 2) MANOVA was run with two dependent variables: GSDS and CFQ. There was a trend for a Group effect (Wilk's Λ = .925, F[2, 65] = 2.64, p = .079), and but no Time effect (Wilk's Λ = .960, F[2, 65] = 1.37, p = .261) or Group X Time interaction (Wilk's Λ = .967, F[2, 65] = 1.11, p .337). As can be seen in Table 3, consistent with Hypothesis 1, follow-up univariate analyses revealed pregnant women reported significantly worse GSDS scores when collapsed across time points (p = .026). Examination of each time point showed that pregnant women reported worse sleep at both Time 1 (d = 0.23) and Time 2 (d = 0.89). However, inconsistent with Hypothesis 1 there was no effect of Group on CFQ score.

Hypothesis 2. Higher self-reported sleep disturbance would significantly predict higher self-reported cognitive failures in pregnant women at both time points.

Regression analyses revealed no relationship between GSDS score and CFQ score among pregnant women at Time 1 (F(1, 11) = 1.70, p = 0.22,) or at Time 2 (F(1, 11) = 1.86, p = 0.20). Exploratory analyses were run to explore this relationship at Time 1, including all participants who completed that time point (n = 22) rather than only those who completed both time points (n = 13). Independent samples t-tests revealed women who only completed the first time point had significantly greater CFQ scores (M = 59.80) than women who completed both time points (M = 31.46). Including all pregnant participants who completed Time 1 in the analysis for that time point resulted in a larger

range of scores on the GSDS (14 to 83, increased from 14 to 78, normally distributed) and CFQ (2 to 90, increased from 2 to 45, normally distributed) being included in the analysis. A significant regression equation was found, $F(1, 21) = 5.02$, $p = 0.04$, accounting for approximately 16% of the variance in the model (Adjusted $R^2 = .155$). Specifically, worse self- reported sleep predicted worse self-reported cognitive failures in pregnant women, with CFQ scores increasing .40 points for each point increase in GSDS score.

Hypothesis 3. There would be no significant group differences (pregnant vs. controls) in objective sleep or cognitive function at Time 1, but at Time 2, pregnant women would have worse sleep and cognitive function than controls.

To analyze objective sleep, a Group (Pregnant vs. Non-pregnant) X Time (Time 1 vs. Time 2) MANOVA was run with three dependent variables from actigraphy: TST, FI, and WASO. There was a significant Group effect (Wilk's $\Lambda = .636$, $F[3, 61] = 11.62$, $p < .001$), but no Time (Wilk's $\Lambda = .943$, $F[3, 61] = 1.22$, $p = .308$) or Group X Time interaction effects (Wilk's $\Lambda = .961$, $F[3, 61] = .817$, $p = .489$). As can be seen in Table 4, follow-up univariate analyses revealed significant group effects on the two sleep fragmentation variables (FI, $p < .001$; WASO, $p < .001$), but not TST ($p = .642$). Examination of each time point showed that pregnant women experienced more sleep fragmentation than non-pregnant women at both Time 1 (FI, $d = 0.73$; WASO, $d = 1.01$) and Time 2 (FI, $d = 1.35$; WASO, $d = 2.17$). This effect remained after controlling for Age (Wilk's $\Lambda = .811$, $F[3, 60] = 4.67$, $p = .005$).

Given the dearth of research to date on objective cognitive performance in postpartum women (i.e., only two studies supporting decline in executive functioning

Table 3

Subjective measures of sleep and cognitive functioning by pregnancy group and time point

		Time 1			Time 2			Between Groups Main Effect			Within Subjects Main Effect			Group X Time Interaction		
		M	*SD*	*N*	*M*	*SD*	*N*	*F*	*p*	*d*	*F*	*p*	*d*	*F*	*p*	*d*
GSDS	Non-Pregnant	38.96	14.73	22	39.18	12.56	22	5.19	**.026**	0.28	2.27	.137	0.19	2.09	.153	0.18
	Pregnant	42.00	11.74	13	52.77	17.66	13									
	Total	40.09	19.17	35	44.23	15.87	35									
CFQ	Non-Pregnant	34.05	14.89	22	35.31	15.09	22	.001	.979	0.00	.908	.314	0.12	.397	.531	0.08
	Pregnant	31.46	11.96	13	37.69	21.52	13									
	Total	33.09	13.75	35	36.2	17.48	35									

Note: GSDS = General Sleep Disturbance Scale; CFQ = Cognitive Failures Questionnaire.

Table 4

Objective measures of sleep by pregnancy group and time point

		Time 1			Time 2			Between Groups Main Effect			Within Subjects Main Effect			Group X Time Interaction		
		M	*SD*	*N*	*M*	*SD*	*N*	*F*	*p*	*d*	*F*	*p*	*d*	*F*	*p*	*d*
TST	Non-Pregnant	416.83	57.49	22	400.47	68.84	22	2.18	.642	0.19	.766	.385	0.11	.025	.874	0.02
	Pregnant	421.70	58.91	13	410.38	52.32	10									
	Total	418.64	57.20	35	403.57	63.45	32									
FI	Non-Pregnant	16.54	5.35	22	17.31	6.36	22	17.15	**.000**	0.52	2.61	.111	0.20	1.34	.251	0.15
	Pregnant	21.58	8.21	13	26.27	6.91	10									
	Total	18.41	6.90	35	20.11	7.68	32									
WASO	Non-Pregnant	37.61	14.85	22	38.13	18.92	22	35.73	**.000**	0.75	2.88	**.**095	0.21	2.52	.117	0.20
	Pregnant	58.63	25.26	13	74.36	14.02	10									
	Total	45.42	21.62	35	49.45	24.30	32									

Note: TST = Total Sleep Time; FI = Fragmentation

and tentative support for decline in working memory and processing speed), multiple Group (Pregnant vs. Non-pregnant) X Time (Time 1 vs. Time 2) ANOVAs were run. As shown in Table 5, when collapsed across time points, the pregnant group performed worse on several variables within code substitution learning (Mean RT, p = .001; Mean RT Correct, p = .001; Throughput, p = .001), code substitution immediate memory (Throughput, p = .028), and Stroop task (Num Corr, p = .005, Mean RT, p = .015; Mean RT Correct, p = .018; Throughput, p = .010). However, as shown in Table 6, after controlling for Age on the Stroop task, there were no longer group differences (p > .05 for all variables). There were no significant Time (although there were trends for Throughput on Stroop task [p = .068], indicating both groups improved from Time 1 to Time 2) or Group X Time interaction effects.

Hypothesis 4. Using only the objective sleep variables that were found to significantly change between Time 1 and Time 2 based on group membership (i.e., exhibit a group X time interaction), it was hypothesized that the objective sleep would mediate the relationship between group and cognitive performance change scores on the objective cognitive performance variables found to significantly change between Time 1 and Time 2 based on group membership (i.e., have a significant group X time interaction). See Figure 5 for representation.

There were no significant Group X Time interactions for objective sleep variables. MANOVA and follow-up ANCOVA analyses revealed pregnant women experienced more sleep fragmentation (FI and WASO) than non-pregnant women when collapsed across time points, even after controlling for age. Similarly, there were no significan

Table 5

Objective measures of cognitive functioning by pregnancy group and time point

		Time 1			Time 2			Between Groups Main Effect			Within Subjects Main Effect			Group X Time Interaction		
		M	*SD*	*N*	*M*	*SD*	*N*	*F*	*p*	*d*	*F*	*p*	*d*	*F*	*p*	*d*
Cds Number Correct	Non-Pregnant	70.43	1.33	21	69.36	2.44	22	.329	.569	0.07	1.77	.188	0.17	1.02	.317	0.13
	Pregnant	70.23	1.36	13	70.08	1.56	12									
	Total	70.35	1.32	34	69.62	2.17	34									
Cds Reaction Time (*M*)	Non-Pregnant	1060.39	211.61	21	945.95	178.43	22	11.27	**.001**	0.42	.576	.451	0.09	1.80	.185	0.17
	Pregnant	1170.23	207.67	13	1201.93	289.06	12									
	Total	1102.38	213.91	34	1036.30	252.05	34									
Cds RT Correct (*M*)	Non-Pregnant	1058.83	211.50	21	942.07	176.19	22	11.52	**.001**	0.42	.610	.438	0.10	1.853	.178	0.17
	Pregnant	1169.62	206.71	13	1201.26	292.86	12									
	Total	1101.19	213.62	34	1033.55	253.28	34									
Cds Throughput	Non-Pregnant	57.38	11.00	21	62.98	10.74	22	11.19	**.001**	0.42	.919	.341	0.12	1.30	.258	0.14
	Pregnant	51.49	8.83	13	51.00	11.40	12									
	Total	55.13	10.49	34	58.76	12.26	34									
Cdi Number Correct	Non-Pregnant	34.29	2.49	21	34.91	1.74	22	2.82	.098	0.21	1.46	.231	0.15	.034	.855	0.02
	Pregnant	33.15	3.53	13	34.00	1.81	12									
	Total	33.85	2.93	34	34.59	1.79	34									
Cdi Reaction Time (*M*)	Non-Pregnant	1091.63	397.05	21	923.46	217.42	22	3.04	.086	0.22	2.524	.117	0.20	.120	.731	0.04
	Pregnant	1213.15	445.54	13	1105.13	317.44	12									
	Total	1138.09	413.91	34	987.58	267.28	34									
Cdi RT Correct (*M*)	Non-Pregnant	1077.59	360.17	21	908.35	200.87	22	3.22	.078	0.22	3.21	.078	0.22	.119	.731	0.04
	Pregnant	1192.22	412.75	13	1077.67	276.95	12									
	Total	1121.42	379.17	34	968.11	240.81	34									
Cdi Throughput	Non-Pregnant	57.73	16.45	21	66.10	14.21	22	5.03	**.028**	0.28	2.90	.094	0.21	.172	.680	0.05
	Pregnant	50.51	15.72	13	55.59	16.98	12									
	Total	54.97	16.32	34	62.39	15.83	34									
Strp Number Correct	Non-Pregnant	31.38	4.31	21	33.41	3.91	22	8.26	**.005**	0.36	2.29	.135	0.19	.033	.857	0.02
	Pregnant	28.15	4.81	13	29.75	6.61	12									
	Total	30.15	4.71	34	32.12	5.24	34									
Strp Reaction Time (*M*)	Non-Pregnant	841.16	218.03	21	746.17	170.19	22	6.29	**.015**	0.31	2.011	.161	0.18	.008	.929	0.01
	Pregnant	993.63	260.65	13	909.90	385.99	12									
	Total	899.46	243.25	34	803.96	272.77	34									
Strp RT Correct (*M*)	Non-Pregnant	841.59	225.62	21	737.84	157.33	22	5.91	**.018**	0.30	2.66	.108	0.20	.001	.978	0.00
	Pregnant	1000.58	267.17	13	893.31	407.94	12									
	Total	902.38	250.91	34	792.71	277.33	34									
Strp Throughput	Non-Pregnant	71.62	15.21	21	78.36	14.59	22	7.05	**.010**	0.33	3.45	.068	0.23	.029	.866	0.02
	Pregnant	60.34	14.80	13	68.43	19.98	12									
	Total	67.30	15.83	34	74.85	17.08	34									

Note: Cds = Coding Substitution Learning; Cdi = Coding Substitution Immediate Memory; Strp = Stroop Task - Interference; Number Correct = number of trials with a correct response; Reaction Time = average response time of all items (correct and incorrect); RT Correct = average response time for the correct response; Throughput = number of correct responses per unit of available response time.

Table 6

Stroop interference task by group adjusted for age

					Between Groups Main Effect		
		Adjusted M	*Adjusted SE*	*N*	*F*	*p*	*d*
Strp Number Correct	Non-Pregnant	31.29	1.05	21	0.04	.85	0.02
	Pregnant	30.85	1.61	13			
Strp Reaction Time (*M*)	Non-Pregnant	852.69	55.02	21	0.00	.98	0.00
	Pregnant	850.22	84.77	13			
Strp RT Correct (*M*)	Non-Pregnant	844.44	56.63	21	0.00	.95	0.01
	Pregnant	852.80	87.26	13			
Strp Throughput	Non-Pregnant	71.68	3.50	21	0.04	.840	0.08
	Pregnant	70.06	5.39	13			

Note: Strp = Stroop Task - Interference; Number Correct = number of trials with a correct response; Reaction Time = average response time of all items (correct and incorrect); RT Correct = average response time for the correct response; Throughput = number of correct responses per unit of available response time

Group X Time interactions for cognitive functioning variables. ANOVA analyses revealed pregnant women performed worse than non-pregnant women when collapsed across time on all three tasks (code substitution, learning, code substitution immediate memory, and Stroop interference), though this effect was no longer present for the Stroop task after controlling for age. Therefore, there were not enough appropriate variables to examine the relationship between pregnancy status and objective sleep and cognitive functioning over time in the full mediation analysis as described in the hypotheses and pictured in Figure 5. Exploratory analyses were run for each pathway using the objective variables that seemed most impacted by group for sleep (i.e., WASO) and cognitive functioning (i.e., Throughput for all three tasks). There was a trend for the effect of pregnancy status on increased WASO from Time 1 to Time 2 (Figure 7, pathway a), $F(1, 30) = 3.074$, $p = .090$. Increased WASO from Time 1 to Time 2 significantly predicted a worsening of performance as measured by change in Throughput from Time 1 to Time 2 (Figure 7, pathway b) on the Stroop task, $F(1, 29) = 4.90$, $p = .035$, but not code substitution learning, $F(1, 29) = .013$, $p = .911$ or code

substitution immediate memory, $F(1, 29) = 1.63$, $p = .212$. Pregnancy status significantly predicted a worsening of Throughput performance from Time 1 to Time 2 (Figure 7, pathway c) for code substitution learning, $F(1, 31) = 4.68$, $p = .038$, but not code substitution immediate memory, $F(1, 31) = .670$, $p = .419$, or Stroop task, $F(1, 31) = .123$, $p = .73$.

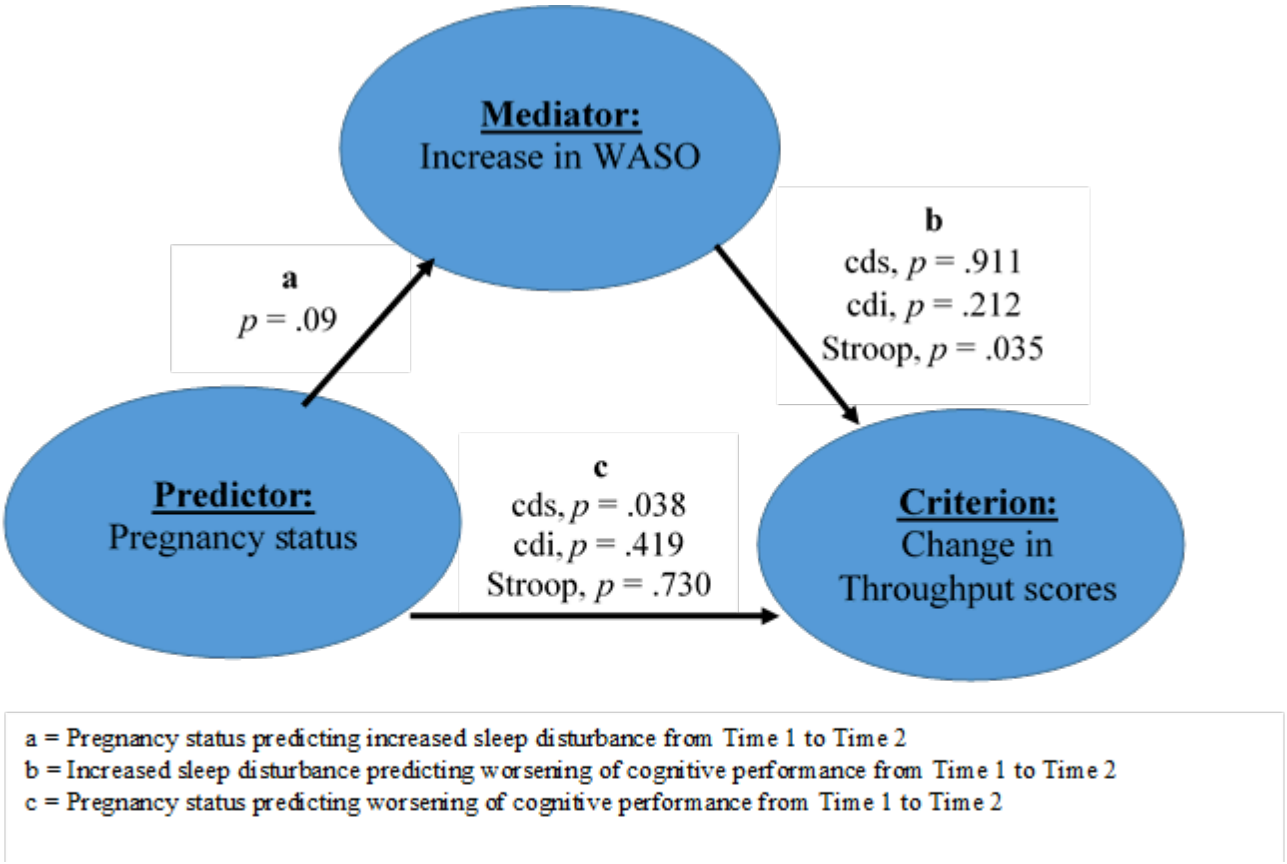

Figure 7. Exploratory analyses of pregnancy, wake after sleep onset, and change scores on code substitution learning, code substitution immediate memory, and Stroop task

Discussion

The current study examined the relationship between subjective and objective sleep and cognitive functioning in late pregnancy and early postpartum. As expected, pregnant women reported significantly worse sleep in the last month of pregnancy and at four to eight weeks postpartum than non-pregnant women. However, contrary to

expectation, pregnant women reported a similar level of cognitive failures to that of non-pregnant women at both time points. Further, self-reported sleep disturbance was not predictive of self-reported cognitive failures among pregnant women who completed both time points. Regarding objective measures, pregnant women experienced more nocturnal sleep fragmentation than non-pregnant women at both time points, though the two groups did not differ in nocturnal sleep duration. Indeed, pregnant women slept slightly *more* than non-pregnant women at both time points (though these differences were minimal). When examining accuracy and efficiency of performance on three tasks designed to measure attention and processing speed, working memory, and executive functioning, pregnant women performed significantly worse than non-pregnant women at both time points, though there were no longer group differences on the executive functioning task after controlling for age. Exploratory analyses indicate increased objective sleep fragmentation from Time 1 to Time 2 was predictive of objective cognitive functioning on the executive functioning task at Time 2 among women who completed both time points.

Subjective Sleep and Cognitive Functioning

The subjective sleep disturbance experienced by pregnant women neared clinical significance (i.e., GSDS > 43) in the last month of pregnancy and exceeded significance at four to eight weeks postpartum. This is consistent with results of previous studies using similar, well-validated measures of self-reported sleep (Bei et al., 2010; Coo et al., 2014; Gay et al., 2004; Goyal et al., 2007; Lee & Gay, 2011; Okun et al., 2007). However, contrary to much of the literature (Brett & Baxendale, 2001; Crawley, 2002), pregnant women did not endorse more cognitive failures than non-pregnant

women at either time point. Crawley (2002) and Crawley, Grant, and Hinshaw (2008) have suggested results showing self-reported cognitive decline in pregnancy and the postpartum period might be a result of a social stereotype (e.g., “pregnancy brain” and “mommy brain”) being made salient during the course of the study. In the present study, women completed the measure of perceived cognitive failures in the midst of multiple other questionnaires and behavioral tasks as part of a week-long data collection period examining several other variables, including sleep and mood. Given the women were not informed of any of the study hypotheses and the study focused on several factors besides cognitive functioning, it is feasible the cultural expectations associated with the social stereotype were not made salient and subsequently not reflected in their self-report of cognitive failures.

To the author’s knowledge, this is the first study to examine the relationship between subjective sleep and subjective cognitive functioning in this population. Studies that have looked at these two variables using objective measures (i.e., actigraphy with sleep diaries and neuropsychological tests) in this population have found medium to large correlations (i.e., r = .36 - .66) between sleep duration and cognitive performance (Insana et al., 2013; Swain et al., 1997). In the present study, there were medium correlations between subjective sleep and subjective cognitive functioning when examining women who completed both time points (last month of pregnancy, r = .37; four to eight weeks postpartum, r = .38), though these did not reach significance. However, when including all pregnant women who completed the study in the last month of pregnancy, there was a much larger range of scores included in analyses resulting in medium to large effect size (r = .44) with greater sleep disturbance

significantly predicting greater perceived cognitive failures at this time point. As seen in Figure 6, 50% (*n* = 5) of the attrition rate was due to non-responsiveness or scheduling conflicts, which might have been related to forgetfulness or other problems related to cognitive failures. It is possible that if all women had returned for the second time point this relationship would also have been seen at four to eight weeks postpartum.

Objective Sleep and Cognitive Functioning

The significant sleep fragmentation experienced by women at four to eight weeks postpartum is consistent with many qualitative and quantitative studies showing increased time awake throughout the night after the birth of a child (Bei et al., 2010; Coo et al., 2014; Gay et al., 2004; Lee et al., 2000; Matsumoto et al., 2003; Nishihara & Horiuchi, 1998; Signal et al., 2007; Wulff & Siegmund, 2000). Most of these studies reported a significant increase in fragmentation from the last month of pregnancy through early postpartum. Indeed, in the present study there was an increase in minutes awake, though the differences did not reach significance. Rather, the sleep fragmentation evidenced in the pregnant group relative to the control group was not exclusive to the postpartum period, but also seen in pregnancy. The similarities in sleep duration between groups is consistent with recent research examining sleep in this population via actigraphy (Coo et al., 2014; Montgomery-Downs et al., 2010). However, it was surprising there was virtually no difference between sleep duration in the pregnant group from the first to second time points.

Group differences were found on tasks of attention and processing speed (code substitution learning: average response time, average response time for correct responses, number of correct responses per unit of available response time), working

memory (code substitution immediate memory: number of correct responses per unit of available response time) and executive functioning (Stroop interference task: number of trials with correct response, average response time, average response time for correct items, and number of correct responses per unit of available response time). The group differences in Stroop task were no longer evident after considering age. However, it is possible these results are misleading. Though age was controlled for due to its correlation with Stroop interference task performance at baseline, the age range was restricted to young adulthood (pregnant group, *M* = 28.99; non-pregnant group *M* = 20.15). Further, age was negatively correlated with performance Stroop interference task; it would be more expected for individuals in their upper-twenties to perform better than women in their early twenties on a task of executive functioning (Johnson, Blum, & Giedd, 2009). It is possible the restricted age range and the counter-intuitive correlation direction are why previous similar studies have not included age in analyses when comparing pregnant to non-pregnant young adult women (Farrar et al., 2014; Insana et al., 2013; Swain et al., 1997).

The lack of group by time interactions on neither sleep nor cognitive performance was surprising given past research that has found worsening cognitive performance (Farrar et al., 2014; Henry & Rendell, 2007; Henry & Sherwin, 2012) and decreased sleep duration with increased sleep fragmentation (Bei et al., 2010; Coo et al., 2014; Gay et al., 2004; Lee et al., 2000; Matsumoto et al., 2003; Nishihara & Horiuchi, 1998; Signal et al., 2007; Wulff & Siegmund, 2000) during this time period in pregnant women. Lack of these findings, particularly regarding sleep, might be due to timing of the first testing period. Studies have typically identified late pregnancy as the last trimester,

which includes the 24th to 40th week of pregnancy. Due to feasibility concerns, the present study defined late pregnancy as the last month of pregnancy, including women who were between the 35th and 40th week of pregnancy. There have been no in depth studies examining sleep disturbance within the third trimester, but it is possible it is more disturbed in the final weeks of pregnancy, reducing the effect that might have existed if data were collected earlier in pregnancy. Power could also be contributing to the non-significant interactions, given results of all variables were in the expected direction and there was a small sample size due to significant attrition from Time 1 to Time 2. These results did show small effect sizes (d > .2 < .5) for the group by time interaction on WASO, with FI (d = .15) and CDS (d = .14) also approaching this magnitude effect.

Without such interactions it is difficult to thoroughly examine the relationship between sleep and cognitive performance. Exploratory analyses revealed increased time awake throughout the night was predictive of worsening performance on a task of executive functioning from last month or pregnancy to four to eight weeks postpartum, though this relationship was not evident between sleep and tasks of attention and processing speed or working memory.

Limitations

A major limitation of this study was the high attrition rate of 38%, which was further impacted by malfunctioning equipment at the second time point, particularly among the pregnant group. This is higher than the 24%-36% found in previous studies (Bei et al., 2010; Signal et al., 2007). This loss of participants not only limited the power of statistical analyses but might have changed the overall characteristics of groups

across times. Women who did not complete the second time point had a broader range of self-reported sleep disturbance and cognitive failures than those who were ultimately included in analyses, indicating findings may not be a comprehensive representation of this population. Additionally, the sample primarily consisted of Caucasian women with some college (or more) education, thus results may not be generalizable to women of other races and cultures or women with less education.

Further, as briefly discussed above, women in late pregnancy were experiencing worse sleep fragmentation than controls, which is inconsistent with previous studies showing objective sleep is relatively unmarked in the third trimester, followed by significant changes following the birth of the child (Figures 3 and 4). It is possible that including women in the last month of pregnancy produced a qualitatively different sample with significantly worse sleep than would be found in a sample including women earlier in the third trimester, resulting in a floor effect with limited room for worsening among the pregnant sample.

Implications and Future Directions

Despite these limitations, the findings in this study make a novel contribution to perinatal sleep research. This is the first study to examine subjective and objective measures of sleep and cognitive functioning in pregnancy and the postpartum period. Previous research has emphasized the need for evidence-based postpartum sleep intervention (Sharkey, 2013), and recent pilot studies for such interventions, including cognitive behavioral therapy for insomnia, have shown promising results (Swanson, Flynn, Adams-Mundy, Armitage, & Arnedt, 2013). The significant subjective and objective sleep disturbance and their tentative link to impairment in subjective and

objective cognitive functioning add support to the importance of development and implementation of such evidence-based interventions. This is particularly important to women today as the number of women working throughout pregnancy and in early postpartum has grown exponentially in recent years (Laughlin, 2011), limiting many of the more obvious options for assisting with peripartum sleep disturbance, such as sleeping in or scheduling naps.

Similar studies examining a larger, more diverse sample of women with multiple time points, beginning earlier in pregnancy and extending later in postpartum will be important to substantiate these findings. Further, given the scarcity of research examining the relationship between sleep and cognitive functioning in new mothers, there are many factors yet to be explored, including the role of delivery-type, social support, breastfeeding, maternity leave, and partner involvement, as well as how these variables relate to each other in new fathers.

APPENDIX

Measures:

	Pregnancy		Postpartum
	Initial (week before Time 1)	Time 1 36-40 wks	Time 2 4-8 weeks
Initial Demographics/Health Survey	X		
Pregnancy Information	X[1]		
One week of actigraphy		X	X
One week of sleep diaries		X	X
General Sleep Disturbance Scale		X	X
Insomnia Severity Index		X	X
Epworth Sleepiness Scale		X	X
Multidimensional Assessment of Fatigue		X	X
Cognitive Failures Questionnaire		X	X
Virtual Apartment Stroop, with and without distractors		X	X
ANAM - Code substitution - Stroop task		X	X
Perceived Stress Scale		X	X
Quality of Marriage Index		X	X
Edinburgh Pre/Postnatal Depression Scale		X	X
Birth Information			X[1]
Baby/Mother Information			X[1]

[1]Pregnant/Postpartum women only

Initial Demographics/Health Survey

Please fill in the blank or circle the appropriate response

Date: _____	
Birthdate: _____	
Ethnicity	Hispanic or Latino Not Hispanic or Latino
Race	American Indian/Alaska Native Asian Native Hawaiian or Other Pacific Islander Black or African American White More than one race
Current height:	___ft ____ in
Current weight:	_____lbs
Marital status:	Married Living with partner (unmarried) Single Divorced/Separated Widowed
Number of children:	_____
Ages of children:	_____
Number of children living with you:	_____
Highest education level:	_____
Spouse/partner's highest education level (if applicable):	_____
Are you currently employed? If Yes, What is your occupation? What type of work? How many hours/week? What days/times?	Yes No _____ Full-time OR Part-time _____ hours _____ OR Variable
Are you currently a student? If Yes, What degree are you seeking? Full-time or part-time? How many hours/week? What days/times?	Yes No _____ Full-time OR Part-time _____ hours _____ OR Variable
Individual income (annually):	_____
Household income (annually):	_____

If you have had any of the following health problems, indicate the date of onset.

If there is more than one disease choice available, please circle the one that applies to you (e.g., Hyperthyroid).

Then put the number of years and months you've had each problem and if it is a current health problem:

	Tell us what disease and	Duration		
	date of onset	Years	Months	Current
Heart Disease (ex: irregular heart beats, heart attack)				Y / N
Cancer				Y / N
AIDS/HIV				Y / N
High Blood Pressure				Y / N
Neurological Disease (ex: seizures, Huntington's, Multiple Sclerosis)				Y / N
Breathing Problems (ex: COPD, asthma, emphysema)				Y / N
Urinary Problems (ex: kidney disease/stone, recurring UTIs)				Y / N
Diabetes (please circle: type I, type II, gestational)				Y / N
Chronic Pain (ex: back pain, fibromyalgia, arthritis)				Y / N
Gastrointestinal (ex: ulcers, irritable bowel, Crohn's)				Y / N
Autoimmune (ex: lupus, Guillain-Barre, psoriasis)				Y / N
Endocrine (ex: hypo/hyper thyroid, adrenal)				Y / N
Migraines/Chronic Headaches				Y / N
STDs (please specify:_____)				Y / N
Mental Health Disorder (e.g., depression, anxiety)				Y / N
Other:				Y / N

List ***ALL* medications** *(prescription, over the counter, and natural products)* taken in the **past 7 days. Please include hypnotic/sleep medications** and **stimulants medications (e.g., provigil, adderall, no-doze)**

Medicine	Purpose	Frequency	How long have you been taking this medication?	Time of day
Example: Claritin	Allergies	Daily	6 months	7am & 8pm

(If taking more than 5 medications please write on another piece of paper and return with packet.)

In the past 7 days,		
How many alcoholic drinks did you have (12oz beer, 1oz hard liquor, 5oz wine)?		_____
- How many nights did you drink alcohol to help fall asleep?		_____
How many cigarettes did you smoke?		_____
How many times did you use smokeless tobacco?		_____
How many caffeinated drinks did you have (12oz soda, 8oz coffee)?		_____
How many stimulants (caffeine, illicit drugs) did you use to stay awake or alert?		_____
- What stimulants did you use:		

In past 7 days how often have you used the following illicit drugs?		
Cocaine		_____
Marijuana		_____
Steroids		_____
Ecstasy		_____
Amphetamines	(e.g., speed, crystal, meth, crank, ice)	_____
Sedatives	(e.g., Rohypnol, Amytal, Seconal, Demoral)	_____
Opiates	(e.g., opium, morphine, codeine, heroine)	_____
Hallucinogens	(e.g., LSD, Peyote, Mushrooms)	_____
Inhalants	(e.g., glues, gasoline, paint thinners)	_____

In the past 6 months,	
… how many times did you visit a physician? (Do NOT include visits while in the hospital or the hospital emergency room)	____visits
… how many times did you go to a hospital emergency room?	____times
… how many times did you visit a psychologist, psychiatrist, or other mental health clinician?	____visits
… how many times did you visit a physical therapist or other rehabilitative practitioner?	____visits
… how many different times did you stay in a hospital overnight or longer?	____times
… how many total NIGHTS did you spend in the hospital?	____nights

Pregnancy Information

Please fill in the blank or circle the appropriate response

Expected due date:	_____
How far along in pregnancy:	_____ weeks
Is your first pregnancy: If No, How many previous pregnancies? How many previous live births?	Yes No _____ _____
Have there been any medical complications during this pregnancy? If Yes, Please briefly elaborate:	Yes No _____

Birth Information

Please fill in the blank or circle the appropriate response

Name of infant: _____	
Date of birth of infant: _____	
Sex of infant:	Male Female
Type of delivery: Length of delivery:	Caesarean Vaginal _____ hours
Where did you deliver:	Hospital Birthing center Home Other (please specify) _____
Number of weeks into pregnancy at delivery:	____
Where there any delivery complications? (If yes, please specify)	_____
Length of hospital/birthing center stay for infant:	_____
Length of hospital/birthing center stay for mother:	_____

Baby/Mother Information

Please fill in the blank or circle the appropriate response

Mother's current weight: Baby's current weight:	____lbs ____lbs ____ oz
Feeding method (circle all that apply):	Breastfeeding Breast milk - pumping Breast milk - milk bank or other source Formula
Feeding frequency (per 24 hours)	_____ to _____ times
Besides you and your infant, who else lives in your home? Names are not needed, simply state how they are related to you (e.g., spouse, son)	_____
Does anyone else (including spouse/partner) help out with the infant during the *DAY* If yes, please elaborate:	Yes No _____
Does anyone else (including spouse/partner) help out with the infant during the *NIGHT* If yes, please elaborate:	Yes No _____
Have you returned to work? If Yes, What type of work? How many hours/week? What days/times? If No, When will you to return to work?	Yes No Full-time Part-time _____ hours _____ OR Variable When infant is _____ wks old OR I am not returning to work
Is your maternity leave paid? If partial, please briefly elaborate:	Yes No Partially NA _____

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