Baby-brain phenomena is a subjective experience: absence of evidence for cognitive deficit in new mothers at one-year postpartum.

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Abstract

The experience and even existence of so-called “baby-brain” in the postpartum period is uncertain, with only a few scientific studies that have reported inconsistent results. Here we investigate cognition in 86 women (43 first-time mothers one year postpartum, and 43 non-mothers). Mothers and non-mothers showed no significant differences on measures of objective cognition (verbal memory, short-term memory, working memory, processing speed or theory of mind). Despite the absence of objective differences, mothers self-reported significantly worse subjective memory than non-mothers. To interpret the difference between objective and subjective measures of memory, we investigated relationships between subjective memory, objective memory, and wellbeing. Mothers, but not non-mothers, showed a positive correlation between subjective and objective measures of memory, indicating mothers are more ‘in-tune’ with their memory performance than non-mothers. Mothers also demonstrated a positive relationship between subjective memory and wellbeing (sleep, anxiety and depression), where better wellbeing correlated with higher subjective memory. This relationship was not apparent in non-mothers. The results suggest that poorer sleep, higher anxiety and higher depression are related to reports of poorer subjective memory in mothers. Our results refute the phenomena of “baby-brain” deficits at one year postpartum, with no evidence of cognitive differences between mothers and non-mothers.

"My once-sharp mind keeps coming up blank. A year ago, when I was pregnant, I passed it off as pregnancy brain. After my daughter was born, I used the sleep-deprived, postpartum-brain-fog excuse. But now, I'm not so sure. Did having a baby do lasting damage to my brain? How long can I keep blaming hormones for my mental inadequacies?"[1]

- Teal Burrow (2019)
Making sense of mommy brain: a new mother wants to know if she's losing her mind, or if it's all in her head

"Baby-brain" is a colloquial term that refers to cognitive decline experienced by women during the transition to motherhood (pregnancy and the postpartum period), and is self-reported by approximately 80% of expectant mothers[2]. Despite the overwhelming number of anecdotal reports of forgetfulness in pregnancy, empirical research has revealed that cognitive deficits, if they exist, are objectively subtle and remain within the normal ranges of general cognitive functioning and memory, noticeable to women themselves, but unlikely to cause significant disruption to daily life (e.g. reduced job performance[2,3]). In addition to the question of whether baby-brain exists in the perinatal period, it is also unknown *when* baby-brain ceases – does baby-brain end at child-birth? Or does it continue within the postpartum period? The anecdotal description above suggests that many women continue to experience subjective deterioration of cognitive function well into the postpartum period.

Subtle memory deficits have been consistently found during pregnancy[2,4,5], including objective deficits in working memory, recall, processing speed, and general cognition, as well as decrements in ratings of subjective memory. However, there is considerably fewer studies investigating cognition in the postpartum period, and evidence for differences in cognitive performance between postpartum versus non-postpartum women is mixed. When assessing the extant literature as a whole, it is clear that the number of studies showing non-significant changes or differences in cognitive function in the postpartum period [6-19] outweigh those showing significant cognitive deficits[20-23], relative to women outside the postpartum period.

The endurance of cognitive deficits into the postpartum period therefore remains unclear in the scientific literature. Poor understanding about the time-course of cognitive changes in early motherhood represents a shortcoming in maternal healthcare, and has implications for how women's cognitive abilities in the postpartum period are perceived by society, employers, and themselves. One challenge to understanding the presence and magnitude of cognitive changes across the postpartum period is that early motherhood is a dynamic period in a woman's life, involving considerable physiological and environmental changes. These physiological and environmental experiences change dynamically across the postpartum period, being highly variable in the early postpartum, and stabilising in later postpartum months[24-26]. Thus, cognitive results obtained in the early first few weeks or months postpartum may not accurately predict cognitive outcome in the late postpartum period, or beyond.

One important question, as highlighted by the anecdotes above, is how long do 'baby-brain' related cognitive changes persist into the postpartum period. Women often report subjective experiences

of cognitive difficulties related to pregnancy and parenthood that do not necessarily resolve upon the birth of the child[8,9,13,15,27,28]. Indirect evidence from neuroimaging studies suggests that the maternal brain undergoes dynamic plastic changes during pregnancy and the postpartum period which may be indicative of cognitive changes. Cortical grey matter undergoes plastic changes across pregnancy and the postpartum period; with one study reporting reduction in cortical grey matter volume during pregnancy, which is maintained two and six years postpartum[29,30]. This result appears to align with anecdotal reports of baby-brain related cognitive deficits in the postpartum period.

On the other hand, there is more neuroimaging evidence to support the contention that cognition may actually *improve* in the postpartum period. A number of studies have reported that within the first six months postpartum, cortical grey matter actually increases between the early and later postpartum period[31-35]. We have found that differences in brain structure and function related to motherhood are present even in older age, and are accompanied by higher scores in verbal episodic memory [36,37]. This pattern of results suggests that postpartum cognitive changes, if they exist, may actually result in improved cognitive performance for mothers relative to non-mothers. However, while neural changes during the postpartum period may be suggestive of cognitive changes, it is not always the case that neural changes are linearly associated with overt cognitive changes (see for example the literature on cognitive compensation[38,39]). It is therefore necessary to directly measure cognition in the postpartum period.

Thus, the goal of the current study was to investigate whether subjective and objective differences in cognition between mothers and non-mothers are evident late in the postpartum period. To this end, we measured differences in subjective and objective cognition between first-time mothers (one year postpartum), and age- and education-matched women who had never been pregnant. Consistent with the anecdotal and self-report literature[8,9,13,15,27,28], we hypothesised that mothers would self-report worse subjective memory than non-mothers but out-perform non-mothers in objective tests of cognitive performance.

Methods

Participants

Our sample comprised 86 women, 43 first-time mothers approximately one-year postpartum (~12±2 months) and 43 women who had never been pregnant (for longer than eight weeks). Eleven mothers and one non-mother had a previous pregnancy that did not result in live birth (less than eight weeks gestation). All participants were aged over 18 years and right-handed. Inclusion criteria for the study included fluency in English, not currently pregnant (all participants completed a pregnancy test), no history of head injury, neurological disorder, epilepsy or stroke, and completion of an MRI safety survey for subsequent MRI scanning. MRI results are not reported here.

Procedure

After providing informed consent, all participants completed a psychosocial and cognitive battery, including paper and computer-based tasks and questionnaires. Demographic information and medical and obstetric history (including information about pregnancy, birth, breast-feeding, and time spent in primary care) was collected via clinical interview. Participants completed the prospective memory (PRMQ), depression (BDI), anxiety (BAI), attachment (MPAS) and self-efficacy (MEQ) questionnaires at a time of their convenience on their own devices (e.g. laptop, phone) via a Qualtrics survey, before attending their testing session (acronyms defined below). This protocol was approved by Monash University Human Research Ethics Committee (Project ID: 19455) and conducted in accordance with the relevant guidelines.

Cognitive Tasks

Verbal Memory: *Hopkins Verbal Learning Test (HVLT)*

Participants completed the HVLT as a paper-based neuropsychological assessment with the researcher. The HVLT[40] consists of three trials of free-recall of a 12-item word list, composed of four words from each of three semantic categories. Participants were instructed to listen carefully and attempt to memorise the words as the examiner read the word list. The participant's free recall of the list was recorded. The same procedure was repeated for two more trials. After a 20-25 minute delay, free recall was recorded again. Following delayed recall, the participant was read 24 words and asked to say "yes" after each word that appeared on the recall list (12 targets) and "no" after each word that did not (12 distractors). Higher scores indicate better verbal memory performance.

Short-Term Working Memory: *Digit Span Forward and Backward*

The computerised digit span task was completed using Inquisit 5, based on Woods, et al. [41]. Participants sat upright in front of a computer (2017 Macbook Pro, 15-inch), with their fingers placed on the laptop trackpad. Participants heard a sequence of auditory digits, where each digit was presented for one second, after which the participant was asked to recall the digit sequence by selecting digits in the same order presented (digit span forward) or in reverse order (digit span backward) by selecting each number from a number wheel with a mouse click. Fourteen trials were presented, with task difficulty modulated based on performance, such that if the response was correct, the sequence became one digit longer. If the response was incorrect, the same level was presented a second time; if a consecutive error occurred, the participant moved back down to a lower level. The digit span backward began after all 14 trials of the digit span forward were complete. The participant's two-error maximal length was recorded (the longest sequence of digits correctly recalled before two consecutive errors were made) for the forward and backward conditions. The task is available at:

https://www.millisecond.com/download/library/v6/digitspan/digitspan_auditory/digitspan_auditory/digitspan.manual

Processing Speed: *Symbol-Digit Modalities Task (SDMT)*

The SDMT was completed as a paper-based task under the instruction of the researcher. The SDMT[42] required individuals to quickly and accurately identify nine different symbols corresponding to the numbers 1 through 9, and to write the correct number under the corresponding symbol. Participants were given 90-seconds to manually fill the blank space under each symbol with the corresponding number. The number of symbol-digit pairs correctly identified comprises the SDMT score, where a higher score indicated faster processing speed.

Theory of Mind: *Reading the Mind in Films Task (RMFT)*

The adult version of the Reading the Mind in Films Task asked participants to infer the emotions of actors based on facial expressions and dramatic context. The RMFT was completed as a computer-based task using Inquisit 5, based on Golan, et al. [43]. Participants sat upright in front of a computer (2017 Macbook Pro, 15-inch), with their fingers placed on the laptop trackpad. Participants were presented with 22 film clips (plus one practice) and asked to select one of four possible adjectives to describe the emotion of one of the characters (e.g., smug, awkward, concerned). In each scene, the participant selects the emotion or mental state of the protagonist at the end of the scene. A handout with definitions for all the target and distractor words in the items included was prepared for participants' use before and during the task. The task is available at: https://www.millisecond.com/download/library/readingthemindinfilmstask/

Subjective Memory: *Prospective and Retrospective Memory Questionnaire (PRMQ)*

The PRMQ[44] consisted of 16 questions scored on a 5-point Likert scale: Very Often, Quite Often, Sometimes, Rarely, Never. Participants self-reported the frequency with which they made particular types of memory errors across six subscales reflecting different aspects of memory, including prospective and retrospective memory, short-term and long-term memory, and self- and environmentally-cued memory. Higher scores indicated worse self-reported memory performance.

Psychosocial Measures

Sleep: *Pittsburgh Sleep Quality Index (PSQI)*

The PSQI is a self-report questionnaire which assesses sleep quality and disturbances over a 1-month time interval. Nineteen individual items generate seven "component" scores: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. The sum of scores for these seven components yielded one global score,

where higher scores indicate worse self-reported sleep, and global scores greater than five indicate "poor" sleep[45]. Participants completed the PSQI using Inquisit 5, available at: https://www.millisecond.com/download/library/psqi/

Depression and Anxiety: *Beck Depression Inventory (BDI)/ Beck Anxiety Inventory (BAI)*

The BDI and BAI are self-report questionnaires which assess depression[46] and anxiety[47], respectively. Twenty-one items were assessed on a four point Likert scale (0=Not at All to 3=Severely – It bothered me a lot). Higher scores indicate greater severity of depressive/anxious symptoms.

Attachment: *Maternal Postnatal Attachment Scale*

The Maternal Postnatal Attachment Scale is a nineteen item questionnaire assessing attachment by asking questions on a 5 point Likert Scale (0=Never to 4=Very Frequently). Higher scores indicate greater attachment.

Self-Efficacy: *Maternal Self-Efficacy Questionnaire (MEQ)*

The MEQ[48] assesses self-efficacy with a ten item questionnaire on a 4 point Likert Scale (0=Not good at all, to 3=Very Good). Higher scores indicate greater self-efficacy.

Data Analysis

All 86 participants completed all tasks and questionnaires, with no missing data. Variables that were not normally distributed (HVLT, Digit Span Forward and Backward, SDMT, RMFT, PRMQ, PSQI, BDI, BAI) were log-transformed before further analysis. Comparisons between groups were completed with independent samples *t*-tests, with alpha set to .05 as a threshold for statistical significance, and effect sizes were calculated with Cohen's *d*[49]. Multiple comparisons were Bonferroni-corrected by dividing alpha by the number of tests run (e.g. for six tests, $\alpha = .05/6 = .008$). The applied α level for each statistical analysis is provided with the results Tables. To determine whether the *t*-test were impacted by between-group differences in sleep, depression and anxiety, we conducted additional *t*-tests analyses using residual values after regressing out global scores on the PSQI, BDI and BAI.

To explore the relationship between subjective and objective measures of memory between groups, we conducted two *post hoc* analyses. Firstly, we explored the hypothesis that mothers' subjective ratings of their memory may be inaccurate by comparison to their objective scores. We refer to this as 'memory fidelity'. Secondly, we explored the hypothesis that mothers with lower psychosocial wellbeing judge their memory performance more negatively than mothers with better wellbeing. To investigate these *post hoc* hypotheses, we created summary scores of objective memory and wellbeing. For the *objective memory* summary score, we conducted a principal components analysis (PCA) of the measures of objective memory (HVLT, Digit Span Forward, Digit Span Backward). For the *wellbeing* summary score, we conducted a separate PCA on the three psychosocial measures (PSQI, BDI, BAI).

These two PCAs were conducted in Matlab 2019b, using a singular value decomposition algorithm ('pca' function). Based on Kaiser's recommendation, PCs with eigenvalues >1 were retained for further analysis[50]. Retained PCs were then correlated with global scores on the Prospective and Retrospective Memory Questionnaire (PRMQ). The alpha level for the objective memory and wellbeing analyses were corrected for the number of comparisons (mothers and non-mothers) within each analysis; $\alpha = .05/2 = .025$. Differences in correlations found for mothers and non-mothers were assessed using Fisher's z[51,52].

Results

Detailed demographic information is given in Table 1. Mothers and non-mothers did not differ in age or education. Mothers showed significantly worse sleep and higher depression than non-mothers.

Table 1: *Demographic information for Mothers and Non-Mothers, including independent samples t-test comparisons between groups for age, education, sleep, depression and anxiety.*

	Mean(SD) Mothers	**Mean(SD) Non-Mothers**	***t*-value**	**Cohen's *d***	***p*-value**
N	43	43	-	-	-
Age (years)	32.5 (3.3)	31.4 (4.0)	1.43	0.31	.16
Education (years)	17.9 (2.6)	17.6 (2.6)	0.64	0.14	.53
Sleep (Pittsburgh Sleep Quality Index)	7.4 (3.2)	4.7 (2.5)	4.37	0.94	<.001
Depression (Beck Depression Inventory)	8.4 (5.5)	4.9 (4.3)	3.63	0.78	<.001
Anxiety (Beck Anxiety Inventory)	11.0 (7.8)	8.3 (6.4)	1.32	0.28	.19
Months Postpartum	11.6 (1.7)	-	-	-	-
Conception (Natural/IVF/Insemination)	36 / 6 / 1	-	-	-	-
Multiple Pregnancy (Singleton/Twins)	42 / 1	-	-	-	-
Delivery Method (Vaginal/Caesarean)	30 / 13	-	-	-	-
Breastfeeding (Currently/Weaned)	29/14	-	-	-	-
Total Breastfeeding Duration (Months)	10.0 (3.8)	-	-	-	-
Breastfeeding Duration (Weaned)	6.5 (4.3)	-	-	-	-
Sex of Baby (F/M/Both-Twins)	22 / 20 / 1	-	-	-	-

Objective & Subjective Cognition

Mothers did not significantly differ from non-mothers on any of the cognitive tasks tested (all p>.05; see Table 2). This result did not change when adjusting for sleep, anxiety and depression (all p>.05). Performance on the cognitive tasks did not show a significant relationship with maternal factors (breastfeeding duration, percentage of time spent in primary care, attachment or self-efficacy; all p>.05;

Supplementary Table 1). Performance on cognitive tasks did not differ between mothers based on the sex of their child (male/female), or delivery method (vaginal/caesarean; Supplementary Table 2).

Table 2: *Independent samples t-test comparisons between cognitive performance of mothers and non-mothers, before (raw) and after (adjusted) regressing out the effects of sleep, anxiety and depression. Bonferroni-corrected alpha (.05/6)= .008.*

	Mean(SD) Mothers (*n*=43)	**Mean(SD) Non-Mothers** (*n*=43)	***t***	**Cohen's *d* (*p*-value)**	**Cohen's *d* (*p*-value) Adjusted**
Hopkins Verbal Learning Test, Free-Recall	31.3 (3.1)	30.7 (3.8)	0.84	0.18 (*p*=.41)	0.28 (*p*=.21)
Hopkins Verbal Learning Test, Delayed-Recall	11.1 (1.1)	10.7 (1.5)	1.46	0.32 (*p*=.15)	0.34 (*p*=.12)
Digit Span Forward	7.1 (1.1)	7.6 (1.2)	-1.93	-0.42 (*p*=.057)	-0.32 (*p*=.14)
Digit Span Backward	6.4 (0.9)	6.8 (1.3)	-1.37	-0.30 (*p*=.17)	-0.17 (*p*=.43)
Symbol Digit Modalities Task	58.3 (7.4)	61.8 (10.0)	-1.69	-0.37 (*p*=.095)	-0.17 (*p*=.44)
Reading the Mind in the Films	66.3 (9.8)	64.9 (11.5)	0.87	0.19 (*p*=.39)	0.12 (*p*=.58)

Mothers reported significantly worse subjective memory than non-mothers, $t(84)=2.40$, $p=.020$ and Cohen's $d= 0.52$. This result was no longer significant when adjusting subjective memory score for sleep, anxiety and depression (Cohen's $d=0.19$, $p=.38$). All subscale effects also lose significance when adjusting for sleep, anxiety and depression (see Supplementary Table 3).

Exploring the discrepancy between objective and subjective cognition

We undertook a *post hoc* analysis to explore why mothers and non-mothers showed differences in subjective memory, without significant differences in objective memory. We tested two potential explanations for the incongruence of subjective and objective memory measures for the mother group. First, we considered the possibility that the mother group may be inaccurate in their self-reports of memory, whereas the non-mother group may be more accurate. In other words, this analysis of memory *fidelity* tested whether mothers underestimate their own memory performance on subjective measures. In our second *post hoc* analysis, we considered whether a pessimistic self-report was indicative of negative wellbeing. To this end, we explored the relationship between subjective memory and measures of wellbeing (sleep, anxiety and depression) in mothers and non-mothers.

Relationships between Objective and Subjective Measures of Memory

To investigate the relationship between objective memory performance and self-reported subjective memory, we created an *objective memory* summary score by conducting a principal component analysis (PCA) of the total scores for the Hopkins Verbal Learning Test, Digit Span Forward, and Digit Span Backward. Table 3 reports the loading coefficients, eigenvalues, and explained variance of the three obtained principal components (PCs). The coefficients of the first component

(explaining 62.38% of the variance) positively load onto all three of the objective measures of memory, with higher values indicating better memory performance (Figure 1a). We then correlated the first PC with the subjective memory score (Prospective & Retrospective Memory Questionnaire [PRMQ]) to investigate the relationship between objective memory performance and self-reported subjective memory.

Table 3: *Objective Memory Principal Component Coefficient Loadings, and relationships between Prospective and Retrospective Memory Questionnaire score (PRMQ) and each component for mothers and non-mothers. Alpha = .05/2 = .025*

	PC1	**PC2**	**PC3**
Verbal Memory (HVLT)	0.46	0.89	-0.03
Short-Term Memory (Digits Forward)	0.63	-0.30	0.72
Working Memory (Digits Backward)	0.63	-0.35	-0.70
Variance Explained (%)	62.38	25.62	12.00
Eigenvalue	**1.87**	0.77	0.36
Correlation with PRMQ (Mothers)	**0.40 (*p*=.008)**	-	-
Correlation with PRMQ (Non-Mothers)	-0.12 (*p*=.43)	-	-

Mothers showed a significant positive relationship between subjective and objective measures of memory (*rho*=.40, *p*=.008; Figure 1c, purple), such that mothers who thought (subjectively) that they had better memory, performed (objectively) better. No such relationship was obtained between subjective and objective memory for non-mothers (*rho*=-.12, *p*=.43; Figure 1c, blue). These relationships are significantly different from one another (Fisher's *z*=2.4, *p*=.007), indicating that mothers are more 'in tune' with their memory performance than non-mothers.

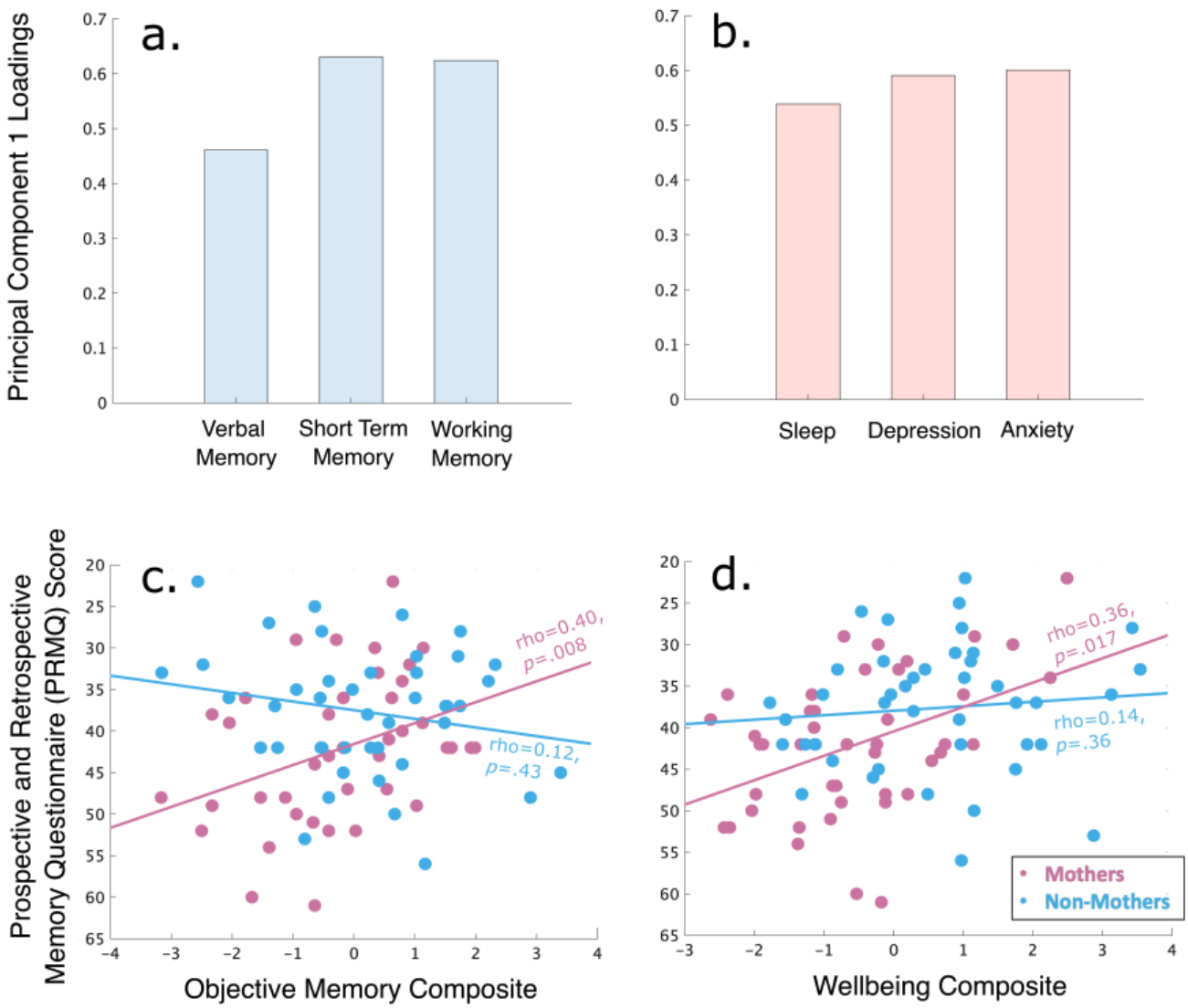

Figure 1: a) *Component loadings (PCA coefficients) for the first principal component combining verbal memory (HVLT), short-term memory (digit span forward) and working memory (digit span backward) into one objective memory composite score* **b)** *Component loadings (PCA coefficients) for the first principal component combining sleep (Pittsburgh Sleep Quality Index), depression (Beck Depression Inventory) and anxiety (Beck Anxiety Inventory) into one wellbeing composite score*. **c)** *Relationships between subjective memory (PRMQ score) and objective memory (first principal component of Hopkins Verbal Learning Task, Digit Span Forward, Digit Span Backward) for mothers (purple) and non-mothers (blue). Higher PRMQ scores indicate worse subjective memory, and higher objective memory values indicate better objective memory performance.* **d)** *Relationships between subjective memory (PRMQ score) and wellbeing ((first principal component of Pittsburgh Sleep Quality Index, Beck Anxiety Inventory and Beck Depression Inventory) for mothers (purple) and non-mothers (blue). Higher scores on the PRMQ depict worse subjective memory, and higher wellbeing scores indicate poorer sleep, and higher levels of depression and anxiety.*

Relationships between Wellbeing and Subjective Memory

To investigate the relationship between wellbeing and subjective memory, we created a summary score of *wellbeing* by conducting a PCA on three psychosocial measures: Pittsburgh Sleep Quality Index, Beck Anxiety Inventory and Beck Depression Inventory. Table 4 reports the loading

coefficients, eigenvalues, and explained variance of the three obtained PCs. The coefficients for the first component (explaining 66.73% of the variance) positively load onto all three of the measures of wellbeing (sleep, anxiety and depression), with higher values indicating poorer wellbeing (Figure 1b). We then correlated the first PC with the subjective memory score (PRMQ) to investigate the relationship between wellbeing and subjective memory.

Mothers showed a significant relationship between subjective memory scores and wellbeing, such that lower wellbeing was correlated with worse subjective memory (*rho*=.36, *p*=.017; Figure 1d, purple). Interestingly, the relationship between subjective memory and the wellbeing composite was not significant in non-mothers, (*rho*=.14, *p*=.36; Figure 1d, blue). These relationships were not significantly different from one another (Fisher's *z*=1.06, *p*=.15).

Table 4: *Wellbeing Principal Component Coefficient Loadings, and relationships between Prospective and Retrospective Memory Questionnaire score (PRMQ) and each component for mothers and non-mothers. Alpha = .05/2 = .025*

	PC1	**PC2**	**PC3**
Sleep (PSQI)	0.55	0.83	-0.13
Anxiety (BAI)	0.60	-0.28	0.75
Depression (BDI)	0.59	-0.49	-0.65
Variance Explained (%)	66.73	19.15	14.12
Eigenvalue	**2.00**	0.58	0.42
Correlation with PRMQ (Mothers)	**0.36 (*p*=.017)**	-	-
Correlation with PRMQ (Non-Mothers)	0.14 (*p*=.36)	-	-

Discussion

In this study, we investigated whether there is objective evidence for 'baby-brain'-like cognitive decrements in mothers at one year postpartum. We tested whether mothers one-year postpartum differed from non-mothers on objective and subjective cognitive measures. We hypothesised that mothers would self-report worse subjective memory than non-mothers, but predicted that mothers would out-perform non-mothers in objective tests of cognition. We obtained significant differences in subjective memory between mothers and non-mothers, in the absence of a difference in objective memory. These differences disappeared when we adjusted for differences in sleep, depression and anxiety, suggesting that subjective memory is likely impacted by differences in wellbeing. To further explore potential explanations for the incongruence between subjective and objective memory in mothers, we tested two *post hoc* hypotheses; firstly, that mothers show poorer memory fidelity than non-mothers, and underestimate their memory performance on self-report measures. As predicted, we found a positive relationship between objective and subjective measures of memory in mothers, but not in non-mothers. In the second *post hoc* analysis, we tested the hypothesis that mothers with lower

psychosocial wellbeing judge their memory performance more negatively than mothers with better wellbeing. As predicted, we found a positive correlation between subjective memory and wellbeing, where better wellbeing was associated with higher subjective reports of memory. This relationship was not obtained in the non-mother group. Our results challenge the existence of an objective "baby-brain" cognitive deficit in mothers at one year postpartum.

Objective Cognition

Mothers and non-mothers did not differ on any objective measure of cognition: verbal episodic memory (HVLT), working memory maintenance (digits forward) or manipulation (digit backwards), psychomotor speed (SDMT), or theory of mind (RMFT). These results did not change when adjusting for between-group differences in sleep, anxiety and depression. These results are consistent with previous studies of cognition in the postpartum period, which also report no differences between mothers and controls on measures of short-term memory[7,8,19], working memory[7,9,12,15,19-21], and processing speed[6,11,12,15,23]. Notably, the current study provides the first comparison of theory of mind task performance between mothers and non-mothers at any timepoint across pregnancy and the postpartum period, with no differences in performance between groups.

In contrast to the meta-analysis by Henry and Rendell [5], which showed subtle verbal memory deficits in postpartum women, we found no differences in verbal memory (free- or delayed-recall) between mothers and non-mothers. This result is consistent with more recent studies[12,13,15,18]. Glynn [21] and de Groot, et al. [23] both found verbal memory deficits in primiparous (first-time mothers) and multiparous postpartum mothers (Glynn: three months postpartum; de Groot: eight months postpartum). However, interpretation of memory decrements in these studies was complicated by the fact that both studies also included parous women in their control groups (Glynn: 30% of control group were mothers; de Groot: 58% of control group were mothers), and did not control for group differences in sleep or mood. Thus, on the basis of those results, it remains possible that the obtained cognitive decrements merely reflected poorer cognitive performance by the mothers in the early postpartum, where sleep and mood disturbances are common[53,54]. Indeed, the use of "non-pregnant" control groups, which include women who are mothers, rather than 'non-parous' groups, may contribute to the mixed findings in the literature. Studies of cognition in rodents suggest that previous reproductive experience confers cognitive benefits which are long-lasting, perhaps even permanent[3,55]. In humans, reproductive experience is associated with life-long changes to brain structure[37,56-59] and function[36], and improved cognition, including verbal memory[37,59]. Verbal memory also improves longitudinally across the postpartum period (3-12 months), with postpartum mothers showing more evidence of semantic clustering (recalling related words together) than when they were pregnant[16]. Mickes et al.[16] argued that mothers may increase the use of organisational strategies to support verbal memory, suggesting a potential cognitive mechanism for verbal memory recovery in the postpartum period.

Most studies of postpartum cognition also do not control for poor sleep, depression and anxiety, which are known to be both more prevalent in early parenthood[53,54] and related to poorer cognitive outcomes outside of a parenthood context[60]. Studies also vary in the time postpartum that mothers are tested, varying from a few days[10] to two years after birth[26]. The first weeks and months following birth involve considerable physical, hormonal, and psychosocial changes and rapid adjustment, which stabilise in later postpartum months[24,25]. So, it is likely that the presence and magnitude of cognitive effects of motherhood are influenced by the time of testing postpartum. This argument is compatible with evidence from neuroimaging studies, which suggest that structural brain changes associated with the early postpartum period are variable in direction and magnitude across the transition to motherhood[29,31-35]. On the basis of extant evidence, it appears that structural reorganisation that occurs during pregnancy and at least the first six months postpartum, appears to stabilise by two years postpartum. Here, we show that cognitive differences between mothers and non-mothers are not significant by one year postpartum, and that sleep and mood are not playing a role in objective cognition by one year postpartum.

Our results are consistent with longitudinal studies of postpartum cognition. Christensen, et al. [12] conducted the largest, and most rigorously controlled study of postpartum cognition to date; a prospective longitudinal study, following women before conception, to pregnancy, and into the postpartum period. Of the 806 women tested at baseline, 76 women were pregnant at one of the two follow-up sessions (four and eight years later), 188 had become mothers, and 542 had remained nulliparous. No significant differences on any cognitive task were found as a function of pregnancy or motherhood. We conclude that the mixed results in the postpartum cognitive literature may be due to three relevant methodological factors; 1) some studies include parous women in their control groups, 2) some studies control for the effects of sleep, depression, anxiety, 3) studies vary in the time postpartum that mothers are tested.

Subjective Memory

Despite showing no significant differences from non-mothers on objective measures of memory or cognition, mothers self-reported significantly worse memory than non-mothers. These findings support our hypotheses, and are consistent with previous studies[8,9,15,21,27] and meta-analyses[5] showing subjective memory deficits in the postpartum period. In the present study, and others[8,9,13,15,27,28], significant differences between mothers and non-mothers in subjective memory are present in the absence of any objective memory differences. This discrepancy suggests that mothers are consistently reporting perceived memory deficits without an objective memory deficit. This discrepancy begs the question - *why* do mothers and non-mothers show differences in subjective, but not objective memory? If the difference in subjective memory isn't because mothers are recalling less, then what is driving this consistent self-perceived deficit? One possible interpretation is the *fidelity* of self-reported memory – whether subjective reports of memory performance align with objective performance.

Relationships between Objective and Subjective Measures of Memory

Mothers showed a significant positive relationship between subjective and objective measures of memory, such that higher self-reported memory was associated with higher objective memory performance. No such relationship was found between subjective and objective measures of memory in non-mothers, suggesting that mothers may be more 'in-tune' with their memory performance than non-mothers. Here, we use the term 'memory fidelity' to refer to the alignment between subjective and objective memory. Subjective memory fidelity in mothers may be a consequence of increased self-awareness in motherhood[61]. We speculate that mothers' increased awareness of their memory performance may arise from two factors; a greater daily cognitive load (i.e., an increase in the number of items and tasks to remember in daily life), and an increased attention to memory lapses. The postpartum period is a time of rapid behavioural adaptation, with novel challenges, tasks and patterns to attend to and recall. For example, leaving the house with a one-year-old in tow, requires a new mother to remember a host of items – nappy bag, dummy, a favourite toy, snacks, a change of clothes, a bottle – the list goes on. With an increased cognitive load, there become more opportunities to forget an item or task. Memory errors in the postpartum period also carry heavier consequences (e.g., an unsettled baby, a sleepless night, in the extreme – harm to the baby), making memory lapses more salient. Pregnancy and early motherhood may make women more attuned to their functioning, through a higher sensitivity to minor memory or concentration lapses, which perhaps would have otherwise been ignored, or considered inconsequential before pregnancy[61]. We speculate that the increased cognitive load of daily life in early motherhood represents a cognitive challenge, with higher consequences for memory lapses, which encourages mothers to evaluate and re-evaluate their subjective memory regularly, making them more in tune with their memory performance. This continuous re-evaluation may also be related to the societal expectation of "baby-brain" in motherhood[62], contributing to a confirmation bias towards expected cognitive changes in pregnancy and the postpartum period.

Lower Maternal Wellbeing Related to Lower Subjective Memory

The second explanation that we explored to account for mothers' lower subjective memory is poorer maternal wellbeing. We hypothesised that mothers who experienced poorer wellbeing (poorer sleep, higher symptoms of depression or anxiety) might be more inclined to think negatively of their memory performance, and report lower subjective memory. We found a relationship between mothers' self-reported memory and wellbeing, where poorer wellbeing was associated with lower subjective memory ratings. Similar relationships between subjective memory and disturbances in sleep and mood have been shown in the first year postpartum[7-9,15], and in the transition to menopause[63]. The mismatch between subjective and objective memory is also related to depression and anxiety outside of the postpartum period, where people with more severe depression and anxiety rate their memories as more impaired, even after controlling for differences in objective cognitive performance[64]. Our results

suggest that measuring and controlling for differences in sleep, depression, and anxiety is essential when assessing cognition in the postpartum period, and providing appropriate support for new mothers who are experiencing poor wellbeing.

Future Directions

Whilst we did not observe any differences in objective cognitive performance between mothers and non-mothers, we cannot rule out the possibility that motherhood may induce cognitive changes, apparent to mothers themselves, but so subtle that they do not affect current laboratory-based tests. That is, either there are subtle cognitive deficits noticeable to mothers in their everyday lives which can be overcome in testing conditions (with fewer distractions, and greater concentration), or mothers are not experiencing deficits, but instead self-report forgetfulness which they perceive due to cultural expectation and anecdotal experience of the "baby-brain" stereotype. In Australia, there is a strong societal narrative regarding baby-brain and its impact on maternal cognition[2,12,65]. Crawley, et al. [66] argue that the pregnancy-related decline in memory performance has been exaggerated in the scientific literature, and that subjective reports of "baby-brain" result from cultural expectations of a cognitive deficit in pregnancy. These expectations are perpetuated by media, pop culture, and even in the advice of medical caregivers[67]. The baby-brain stereotype may be so established and internalised that it becomes a somewhat "self-fulfilling prophecy", where mothers' perception of their memory are seen through the lens of expected deficits[13,28]. For example, an everyday lapse in memory may be falsely attributed to postpartum status because of the context provided, and is then perpetuated by confirmation bias[68], where evidence in support of forgetfulness is disproportionately attended to, remembered, and discussed. This cycle works to incorrectly verify "baby-brain", maintaining the stereotype that motherhood is accompanied by memory decline. It is crucial that new and expectant mothers receive accurate information to appropriately guide their self-perception in the transition to motherhood.

Furthermore, it is important to note the cross-sectional design of this study when interpreting the results. The cross-sectional design means that we can only interpret *differences* between mothers and non-mothers, not *changes* across pregnancy and the postpartum period[69,70]. This also means that we cannot rule out the possibility that mothers in our sample experienced an objective decline compared to their own pre-pregnancy baseline performance. However, well-controlled longitudinal studies also found no differences in objective cognition between mothers and non-mothers across pregnancy and the postpartum period[12,15,18].

Conclusion

We show significant differences in subjective memory between mothers and non-mothers, in the absence of objective differences. In interpreting the discrepancy between subjective and objective memory in the postpartum period, we found evidence that mothers have greater self-reported memory 'fidelity', suggesting mothers may be more in tune with their memory performance than non-mothers, and that mothers with lower wellbeing (sleep, anxiety and depression) perceive worse subjective

memory. Our results, alongside past literature, challenge the existence of “baby-brain” at one-year postpartum. Our results have implications for how new mothers are perceived by society, and how they think about themselves and their own cognitive ability. Especially when subjective perception of cognitive ability is so strongly affected by expectation, it is critical that we do not overestimate, exaggerate, or extrapolate deficits in pregnancy to the postpartum period. We must encourage new mothers to be less willing to attribute every-day memory lapses to their postpartum status. We urge health-care providers to explain these findings to new and expectant mothers, that cognitive deficits in the postpartum period are not inevitable, and instead focus on providing appropriate care and support for mothers who express difficulties with poor sleep, or low mood.

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Conflict of Interest

The authors have no conflicts of interest to declare

Availability of data

All data supporting the results of this study are presented in the tables and supplements of the manuscript.

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