Received: 18 June 2020 | Revised: 1 September 2020 | Accepted: 4 September 2020

DOI: 10.1111/jsr.13204

Journal of Sleep Research | ESRS

REGULAR RESEARCH PAPER

Pregnant women do not display impaired memory formation across one night of sleep

Katharina Zinke[1] | Vanessa Lehnert[1] | Andreas Fritsche[2,3,4] | Hubert Preissl[2,3,5] | Manfred Hallschmid[1,2,3]

[1]Institute of Medical Psychology and Behavioural Neurobiology, University of Tübingen, Tübingen, Germany

[2]German Center for Diabetes Research (DZD), Tübingen, Germany

[3]Institute for Diabetes Research and Metabolic Diseases, Helmholtz Center Munich at the University of Tübingen, Tübingen, Germany

[4]Division of Endocrinology, Diabetology and Nephrology, Department of Internal Medicine, University of Tübingen, Tübingen, Germany

[5]Department of Pharmacy and Biochemistry, Interfaculty Centre for Pharmacogenomics and Pharma Research, University of Tübingen, Tübingen, Germany

Correspondence
Katharina Zinke and Manfred Hallschmid, Institute of Medical Psychology and Behavioural Neurobiology, University of Tübingen, Otfried-Müller-Str. 25, 72076 Tübingen, Germany.
Emails: katharina.zinke@uni-tuebingen.de; manfred.hallschmid@uni-tuebingen.de

Funding information
This work was supported by grants from the German Federal Ministry of Education and Research (BMBF) to the German Center for Diabetes Research (DZD e.V.; 01GI0925) and from the Deutsche Forschungsgemeinschaft (SFB 654 – Plasticity and Sleep).

Abstract

Forgetfulness is a common complaint of pregnant women, who also often report impaired nocturnal sleep. Considering sleep's well-known beneficial role in consolidating newly encoded memory content, we hypothesized that pregnant women would display detrimental changes in objective sleep measures and associated memory deficits. We compared the consolidation of declarative as well as procedural memory across sleep in 21 healthy, third-trimester pregnant women versus 20 matched non-pregnant controls. Subjects encoded and were tested on visuospatial and procedural memory tasks before and after, respectively, a night of sleep spent at home. The emergence of gist-based memories was tested with the Deese-Roediger-McDermott (DRM) paradigm. Sleep was polysomnographically recorded and subjective sleep quality was assessed with questionnaires. Although pregnant in comparison to non-pregnant women reported markedly impaired subjective sleep quality and efficiency, quantitative changes were limited to increases in wakefulness after sleep onset and reductions in rapid eye movement (REM) sleep. Retention of newly learned memory contents, which is believed to reflect sleep-associated memory consolidation, was comparable between groups, as was the formation of gist-based memories. The findings indicate that subjective deteriorations in sleep quality experienced by pregnant women are not necessarily linked to objective impairments. They raise the possibility that sufficient slow wave sleep towards the end of pregnancy allows for normal sleep-related memory consolidation. Although these results were obtained in a small number of pregnant women in very good health and should be corroborated in larger samples, they challenge the assumption of poor sleep and impaired memory as hallmarks of the "pregnancy brain".

KEYWORDS

cognitive function, forgetfulness, pregnancy, sleep, slow wave sleep

1 | INTRODUCTION

Pregnant women commonly complain of increased forgetfulness, disorganization and attentional deficits (Christian et al., 2019; Davies et al., 2018). Up to 80% of pregnant women have been found to report such subjective signs of cognitive decline (Brett & Baxendale, 2001), which are referred to in lay media as symptoms of the "baby brain" or "pregnancy brain." Studies on objective measures of cognitive function during pregnancy support this assumption but point towards inconsistencies. For example, although women in the first and third trimester of pregnancy compared to controls showed impaired performance in immediate and delayed verbal episodic memory tasks, procedural memory was unaffected (Wilson et al., 2011a). A recent meta-analysis concluded that third-semester-pregnant in comparison to non-pregnant women display impaired general cognitive functioning (standard mean difference [SMD] = 1.28, random effects model), memory (SMD = 1.47) and executive functions (SMD = 0.46; Davies et al., 2018). Such cognitive impairments have been hypothesized to emerge from structural changes such as reductions in grey matter volume (Hoekzema et al., 2016) that may be linked to hormonal adjustments (Brown & Schaffir, 2019), with possible contributions of pregnancy-related affective changes (Ouellette & Hampson, 2019).

Sleep is known to benefit the consolidation of newly encoded memory contents (Diekelmann & Born, 2010), raising the question of whether compromised memory functions during pregnancy are related to deteriorations in sleep quality and quantity. Pregnant women frequently report reduced quality and efficiency of nocturnal sleep, more awakenings and even insomnia, as well as intensified sleepiness and napping during the day (Feinstein et al., 2020; Lee & Gay, 2004; Tsai et al., 2012; Wilson et al., 2011b). These complaints worsen towards late pregnancy and have been related to long-term declines in sleep satisfaction (Richter et al., 2019). However, investigations relying on objective measures of sleep and wakefulness, such as polysomnography (PSG) and actigraphy, are rare. Moreover, whereas sleep efficiency has consistently been shown to be reduced, especially towards late pregnancy, changes in total sleep time (TST) and the amount of time spent in different sleep stages vary across studies (Driver & Shapiro, 1992; Lee et al., 2000; Wilson et al., 2011b). A longitudinal polysomnographic study observed increases in TST, but more awakenings and less slow wave sleep (SWS), during the first trimester, whereas sleep in the third trimester was mostly characterized by lower amounts of SWS (Lee et al., 2000). Another study found women to be more affected in the third than the first trimester, with poorer sleep efficiency, more wake after sleep onset, less stage 4 sleep and reduced rapid eye movement (REM) sleep duration compared to controls (Wilson et al., 2011b).

Impairments in sleep quality and quantity might predispose pregnant women to shortcomings in sleep-associated memory formation. To our knowledge, this assumption has only been tested in one previous study (Wilson et al., 2013), which, however, relied on memory tasks commonly used in clinical rather than sleep-experimental settings and tested women's sleep in the laboratory. In that study, verbal declarative memory consolidation was impaired in both first- and third-trimester women compared to controls, whereas there were no differences in visual declarative and procedural memory. Pregnant women also showed shorter TST, more wake after sleep onset and less SWS and REM sleep, but these alterations were mostly unrelated to memory performance (Wilson et al., 2013). We investigated the consolidation of newly encoded memory contents across a night of polysomnography-recorded sleep during late pregnancy; we relied on memory tasks known to detect beneficial effects of sleep on memory formation and provided naturalistic sleeping conditions by recording in the women's own homes. We expected poor sleep during the third trimester of pregnancy to be associated with deficits in sleep-related memory consolidation processes.

2 | METHODS

2.1 | Participants

Twenty-one third-trimester pregnant women (mean age ± SEM, 29.4 ± 1.2 years; the experimental night took place at 33.2 ± 0.5 weeks of gestation, with a range between 29 and 37 weeks) and 20 matched non-pregnant, nulliparous controls (29.0 ± 1.1 years) participated in the study. Pregnant and non-pregnant women were matched for age ($p > .783$), usual bedtime ($p > .887$) and usual wake-up time ($p > .768$). Most of the pregnant women were expecting their first child; only three had already given birth to one older child. According to a short questionnaire filled in at enrollment, all participants were physically and mentally healthy, non-smoking, had at least a high-school degree and had a regular sleep–wake cycle (no shift workers). All participants were free of medication except for six control women taking contraceptives, one pregnant woman taking medication against hypertonus (already before pregnancy), and one pregnant woman taking a pain reliever on the test day. Gestational diabetes was excluded by means of an oral glucose tolerance test. Pregnant women were recruited within a joint project with the local foetal MEG centre investigating the link between metabolic function and foetal outcomes, and controls were recruited through advertisements posted via the university mailing list. All participants gave written informed consent prior to participation. They received monetary compensation (40 €) for volunteering in the study. All study procedures were approved by the local ethics committee.

2.2 | Procedure

All participants were tested according to the same procedure to assess sleep-associated memory consolidation (i.e., encoding and retrieval of different memory tasks were assessed before and, respectively, after a single night of sleep spent at home). At least 2 days before the actual experimental night, an adaption night took place. For this purpose, participants received a dummy recording

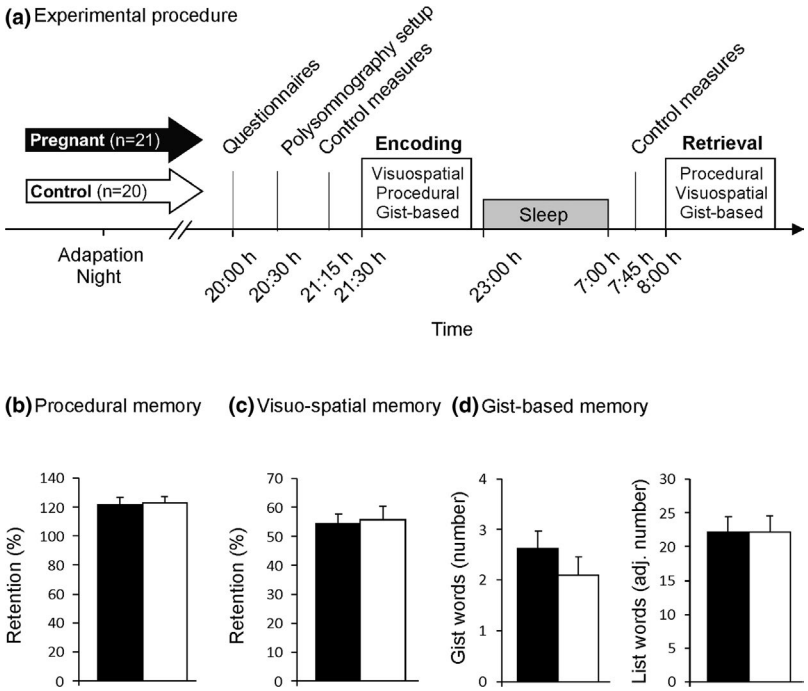

FIGURE 1 Experimental procedure (a) and results of the memory tasks (b–d). Pregnant (black bars) and non-pregnant control women (white bars) performed a procedural memory, a visuospatial declarative memory and a gist-based memory task before (encoding) and after (retrieval) a night of polysomnography-recorded sleep spent at their homes. Memory scores are indicated in absolute numbers at recall or in percentage of encoding performance (retention) as appropriate. Statistical comparison of task performance yielded no significant differences in retrieval, learning or retention across sleep between pregnant women and controls (all $p > .26$). All data are means ± SEM

system with electrodes and were instructed to wear this apparatus for one night to adapt to sleeping with electrodes. The experimental night (see Figure 1a) was timed according to the women's individual bedtimes and supervised by an experimenter who also administered the cognitive tasks. About 3 h before going to bed, the participants answered questionnaires about their sleep and current mood and were prepared for the polysomnographic recordings with a mobile PSG device. After the assessment of control parameters, participants encoded three memory tasks presented on a notebook computer in a fixed order (visuospatial declarative memory, procedural memory and gist-based memory). Afterwards, participants prepared for bed and their sleep was recorded until spontaneous awakening. The morning visit was scheduled according to the participant's usual wake-up time; the participant was asked to summon the experimenter if she woke up considerably earlier. Thus, around 45 min after awakening and the assessment of control variables, retrieval performance on the three memory tasks was tested (in the fixed order of procedural memory, visuospatial declarative memory, gist-based memory).

2.3 | Memory tasks

2.3.1 | Procedural memory consolidation

We used a well-established sequential finger-tapping task known to profit from sleep to assess procedural memory consolidation (Walker et al., 2002). Participants were required to press four keys on a keyboard with their non-dominant hand, repeating a five-element sequence shown on a computer screen (for example 4–1–3–2–4 or 2–4–1–3–2) as fast and as accurately as possible for 30 s. Encoding consisted of 12 blocks of 30 s of tapping the sequence with 30 s of rest in between. The number of sequences tapped in each 30 s, as well as errors, was recorded. At retrieval, participants performed three blocks of the learned sequence after a warm-up block. The main dependent variable was the mean number of correct sequences tapped during retrieval. Retention of procedural memory was calculated as the percentage of the mean number of correct sequences tapped during retrieval, with the mean number of correct sequences tapped during the last three blocks of encoding set to 100%.

2.3.2 | Visuospatial declarative memory

To assess visuospatial declarative memory, we used an object-location memory task resembling the game “concentration” that is known to be sensitive to sleep-associated memory consolidation (Diekelmann et al., 2011). The task required participants to learn the location of 15 pairs of identical cards showing coloured pictures of different animals and everyday objects presented on a computer screen. During encoding, one card of each card pair was presented, followed by the presentation of both cards. The whole set of card pairs was presented twice in different orders. Immediately after these two runs, recall of the spatial locations was tested using a cued recall procedure with feedback (i.e., the first card of each pair was presented and the participant had to indicate the location of the second card by clicking on the location with a computer mouse). The cued recall procedure was repeated until the subject reached a criterion of 60% correct responses. Because sleep has been shown in experiments using verbal tasks to stabilize declarative memory contents against interfering influences (Ellenbogen et al., 2006; for conflicting evidence see Pöhlchen et al., 2020), we included an interference learning block after the nocturnal retention interval. The interference learning and

recall procedure were identical to the procedure described above (using the same 15 card pairs but with a different location for the second card of each pair), except that there was only one cued recall run for all subjects. Then, retrieval of the originally learned card pairs followed, using the same cued recall procedure as during the encoding phase but without feedback. We used correctly recalled card pairs at retrieval as a measure of memory and calculated retention from encoding to retrieval as percentages, with correctly recalled card pairs at the end of encoding set to 100%.

2.3.3 | Gist-based declarative memory

We used the Deese-Roediger-McDermott paradigm (DRM; Deese, 1959; Roediger & McDermott, 1995) to assess verbal and gist-based declarative memory. A shortened version of this task has previously been shown to be sensitive to sleep-associated consolidation of gist memories (Diekelmann et al., 2010; Payne et al., 2009) and also to reflect sleep-independent but pregnancy-related alterations in gist memories (Berndt et al., 2014). During encoding, the participants heard eight different word lists (spoken by a prerecorded male voice at a rate of one word per 3 s) through headphones and were asked to remember as many words as possible. Each list consisted of 12 semantically associated words (e.g., "night", "dark", "shade", etc.), lacking the word with the strongest common association (i.e., the critical lure word, e.g. "black"). Each word list was separated by a 30-s pause. During retrieval, participants were asked to recall all the words they still remembered and write them down. They were asked not to guess and to name only words they were sure were included in one of the lists. The main dependent measure for gist-based memory was the number of critical lures recalled by the participant (maximum of eight). Additionally, veridical word memory was analyzed using the number of correctly recalled list words (maximum of 96) adjusted by the number of intrusions (falsely recalled unrelated words).

2.4 | Sleep and control measures

2.4.1 | Polysomnography

Sleep was continuously recorded during the night using standard polysomnography, including electroencephalogram (EEG; from Fz, C3, Cz, C4, Pz, referenced to linked electrodes attached to the mastoids and a ground electrode at FPz), electrooculogram (EOG; from electrodes placed below the left and above the right canthi) and electromyogram (EMG; from electrodes over the left and right musculus mentalis) recordings. Recordings were conducted with a portable amplifier system (SOMNOscreenTM plus EEG 32, Somnomedics GmbH), which enabled undisturbed sleeping conditions during recordings in the subject's home. All signals were sampled at a rate of 256 Hz and filtered between 0.3 and 35 Hz (for EEG and EOG), and between 10 and 100 Hz (for EMG), respectively. A 50-Hz notch filter was applied to all channels. Two raters manually determined sleep stages off-line for subsequent 30-s recording epochs following standard criteria (Rechtschaffen & Kales, 1968). TST and the time spent in the different sleep stages (wake, stages 1, 2, 3, 4, and REM sleep) were calculated in minutes and percentage of TST. SWS was defined as the sum of time in stages 3 and 4 sleep. Sleep onset was defined with reference to lights off by the first occurrence of a stage-1 sleep epoch followed by stage-2 sleep.

Considering the relevance of sleep spindles and sleep-related changes in EEG power for memory consolidation (Rasch & Born, 2013) and, in particular, the distinct roles of slow and fast spindles (Mölle et al., 2011), we conducted spindle and power analyses using the SpiSOP toolbox (Weber, 2018) with algorithms previously described (Mölle et al., 2002). Individual frequency peaks for slow and fast spindles were visually identified for each participant from power spectra of all non-rapid eye movement (NREM) epochs (stages 2, 3 and 4). For each EEG channel, the NREM epochs signal was filtered with a band-pass of ±1.5 Hz around the individual spindle frequency peaks. Subsequently, using a sliding window of 0.2 s, the root mean square (RMS) was computed and the resulting signal was smoothed. A spindle was detected when the smoothed RMS signal exceeded an amplitude threshold of one standard deviation of the filtered signal for 0.5–3 s. For each participant, spindle density (per 30-s epoch) was determined separately for slow spindles (at Fz) and fast spindles (mean of C3, Cz, C4). For power spectra analyses, artifact-free NREM and REM sleep epochs were divided into consecutive 10-s segments (0.5 s overlap), which were tapered using a Hanning window. This signal was fast Fourier-transformed and resulted in power spectra with a frequency resolution of 0.1 Hz. The power spectra were then averaged across all segments (Welch's method). Mean power density (normalized by the effective noise bandwidth, averaged across all channels) was determined for the following frequency bands: slow wave activity (SWA, 0.5–4 Hz) and general sigma activity (11–15 Hz) during NREM sleep epochs, and theta activity (4–7 Hz) during REM sleep epochs, respectively.

2.4.2 | Subjective sleep measures

On the morning after the PSG-recorded night, the women were asked to report the times they fell asleep and woke up, how often they woke up and how restful their sleep was during the night (on a scale from 1, "very restful", to 5, "not restful"). General sleep quality during the last 4 weeks was assessed using the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989), with values higher than 5 indicating impaired sleep quality. General sleepiness during the day was assessed using the Epworth Sleepiness Scale (ESS; Johns, 1991), with values higher than 8 indicating elevated sleepiness.

2.4.3 | Control measures

At the beginning of the encoding and retrieval session, participants indicated their acute level of sleepiness on the Stanford Sleepiness Scale (SSS; Hoddes et al., 1973) from 1 (active, alert) to 7 (very

sleepy). To control for possible general differences in memory abilities, we assessed word fluency indicative of retrieval abilities using a standardized test (RWT; Aschenbrenner et al., 2000) and working memory performance indicative of encoding abilities using the digit span subtest of the Wechsler Intelligence Test (von Aster, 2006). Vigilance was measured using a 5-min version of the psychomotor vigilance test (PVT; Roach et al., 2006); the speed of key presses (mean of 1/reaction time) served as a measure of vigilance.

2.4.4 | Statistical analyses

Two sleep recordings of pregnant women and one recording of a control participant failed due to technical problems, so that sleep analyses are based on samples of 19 women per group. All values are presented as means ± SEM. The main analyses were based on Student's *t*-tests and Mann–Whitney *U*-tests as appropriate; a *p*-value of <.05 was considered significant.

3 | RESULTS

3.1 | Sleep

In the experimental night, women in the control group slept on average for 430.7 min and spent most of the time asleep in stage 2 sleep (47.1%), SWS (21.7%) or REM sleep (18.5%; Table 1). Pregnant women did not significantly differ from controls in TST, time spent in SWS (in minutes and relative amounts) or intensity of slow wave activity (all $p > .46$). Alterations of objective sleep measures in pregnant compared to control women were limited to an increase in time spent awake after sleep onset (exceeding that of control participants by around 2.5 times), almost 20% less REM sleep, and a moderate reduction in fast spindle density in NREM sleep (Table 1). Bedtimes and wake-up times did not differ between pregnant and non-pregnant women (23:28 ± 0:09 h vs. 23:38 ± 0:12 h and, respectively, 7:46 ± 0:17 h vs. 7:30 ± 0:15; all $p > .50$).

Pregnant compared to non-pregnant women reported impaired sleep in the experimental night as well as in the preceding four weeks (Table 2). When asked about the experimental night, pregnant women compared with controls reported shortened sleep (by about 50 min; $t(39) = -2.04$, $p = .048$), more awakenings (about two vs. one; $U = 322.50$, $p = .002$) and feeling less rested ($U = 309.00$, $p = .007$). They also indicated decreased general sleep quality before participation (higher values in the PSQI; $U = 334.50$, $p = .001$), whereas general sleepiness during the day (ESS) was mostly unaffected ($p = .17$).

3.2 | Memory

We did not find differences between pregnant women and controls in encoding or retrieval of any of the three memory tasks (all $p > .35$).

TABLE 1 Polysomnographic data

	Pregnant women ($n = 19$)	Controls ($n = 19$)		
	mean ± SEM	mean ± SEM	*p*	*d*
Stages (in min)				
TST	418.8 ± 16.7	430.7 ± 10.7	.552	0.20
WASO	40.0 ± 9.0	15.2 ± 5.2	**.012**	**0.78**
Stage 1	40.9 ± 3.5	38.9 ± 4.2	.457	0.12
Stage 2	184.4 ± 9.3	203.1 ± 6.9	.113	0.53
SWS	88.4 ± 6.7	92.3 ± 6.4	.674	0.14
REM	63.7 ± 5.1	79.5 ± 3.7	**.017**	**0.81**
Stages (in % of TST)				
WASO	9.0 ± 2.0	3.4 ± 1.1	**.017**	**0.80**
Stage 1	9.7 ± 0.8	9.0 ± 0.9	.529	0.21
Stage 2	44.2 ± 1.6	47.1 ± 1.0	.127	0.51
SWS	21.6 ± 1.5	21.7 ± 1.5	.980	0.01
REM	15.1 ± 0.9	18.5 ± 0.7	**.006**	**0.94**
Slow spindles in NREM (Fz)				
Mean frequency (Hz)	10.7 ± 0.2	10.9 ± 0.2	.591	0.18
Density (per 30 s)	1.9 ± 0.1	2.1 ± 0.1	.281	0.36
Fast spindles in NREM (C3, Cz, C4)				
Mean frequency (Hz)	13.3 ± 0.1	13.4 ± 0.1	.455	0.25
Density (per 30 s)	2.5 ± 0.1	2.7 ± 0.1	**.036**	**0.73**
Power density in NREM (V^2/Hz, mean all electrodes)				
SWA (0.5–4 Hz)	86.4 ± 7.7	85.7 ± 8.4	.919	0.02
Sigma (11–15 Hz)	2.5 ± 0.2	2.7 ± 0.2	.593	0.18
Power density in REM (V^2/Hz, mean all electrodes)				
Theta (4–7 Hz)	5.4 ± 0.5	5.0 ± 0.4	.530	0.20

Abbreviations: NREM, non-rapid eye movement sleep; REM, rapid eye movement sleep; SEM, standard error of the mean; SWA, slow wave activity; SWS, slow wave sleep; TST, total sleep time; WASO, wake after sleep onset.

Significant *p*- and respective *d*-values are given in bold.

In the procedural memory task, neither the mean number of correct sequences in the last three blocks of encoding (15.9 ± 1.0 vs. 17.1 ± 0.7) nor the mean number of correct sequences at retrieval (19.5 ± 1.6 vs. 20.7 ± 0.9) differed significantly between groups. Similarly, in the visuospatial declarative memory task, women of both groups needed comparable numbers of runs until the learning criterion was reached during encoding (3.8 ± 0.4 vs. 4.4 ± 0.8) and correctly remembered about 38% of the card locations at retrieval in

TABLE 2 Subjective sleep measures

	Pregnant women ($n = 21$)	Controls ($n = 20$)		
	mean ± SEM	mean ± SEM	*p*	*d*
Subjective sleep during experimental night				
Sleep duration (in min)	405.7 ± 19.6	455.3 ± 13.9	**.048**	**0.65**
Number of awakenings	1.9 ± 0.3	0.9 ± 0.3	**.002**	**0.80**
Restfulness (1, "very restful"; 5, "not restful")	2.7 ± 0.2	1.9 ± 0.2	**.007**	**0.98**
General sleep quality				
Sleep quality (PSQI)	5.8 ± 0.5	3.3 ± 5.8	**.001**	**0.79**
Sleepiness (ESS)	9.1 ± 0.8	7.7 ± 9.1	.174	0.44

Abbreviations: ESS, Epworth Sleepiness Scale; PSQI, Pittsburgh Sleep Quality Index; SEM, standard error of the mean.

Significant *p*- and respective *d*-values are given in bold.

TABLE 3 Control measures

	Pregnant women ($n = 21$)	Controls ($n = 20$)		
	mean ± SEM	mean ± SEM	*p*	*d*
Sleepiness (SSS)				
Encoding	3.1 ± 0.2	3.1 ± 0.3	.989	<0.01
Retrieval	2.4 ± 0.2	2.5 ± 0.2	.685	0.13
Word fluency (RWT, number of words)				
Encoding	15.0 ± 1.0	16.2 ± 1.2	.449	0.24
Retrieval	17.2 ± 1.2	16.7 ± 0.9	.727	0.11
Working memory (digit span)				
Encoding - forward	7.1 ± 0.3	6.4 ± 0.2	.072	0.58
Encoding - backwards	5.7 ± 0.3	5.6 ± 0.3	.672	0.13
Retrieval - forward	7.3 ± 0.3	6.3 ± 0.2	**.020**	**0.76**
Retrieval - backwards	6.3 ± 0.3	6.0 ± 0.3	.364	0.29
Vigilance (speed in PVT in 1/s)				
Encoding	3.2 ± 0.1	3.3 ± 0.1	.119	0.50
Retrieval	3.2 ± 0.1	3.3 ± 0.1	.120	0.42

Abbreviations: PVT, Psychomotor Vigilance Test; RWT, Regensburger Wortflüssigkeitstest; SEM, standard error of the mean; SSS, Stanford Sleepiness Scale.

Significant *p*- and respective *d*-values are given in bold.

the morning. Most importantly, memory retention across the night (Figure 1b-d) was comparable between groups in the procedural memory task (121.7 ± 4.8 vs. 122.9 ± 4.4%; $p > .86$) as well as in the visuospatial declarative memory task (54.6 ± 3.3 vs. 55.8 ± 4.6%; $p > .82$). There was no difference in the mean number of gist-based memories (pregnant vs. control, 2.6 ± 0.3 vs. 2.1 ± 0.4; $p > .26$) or adjusted recall of veridical memories in the DRM task (22.1 ± 2.4 vs. 22.2 ± 2.4; $p > .98$). Statistical correlations between sleep parameters and measures of memory performance, which were mostly non-significant, did not indicate a clear pattern of interrelationships (see Table S1). With a sample size of 21 pregnant and 20 non-pregnant women our study was sufficiently powered (post-hoc achieved power 1 - $\beta = 0.88$) to detect a large effect ($d = 1.0$, for a *t*-test between groups) on overnight memory retention, comparable to the impairment in memory functioning in third-trimester-pregnant versus non-pregnant women obtained in meta-analyses (Davies et al., 2018) that, notably, also included experiments on sleep-associated memory consolidation (Wilson et al., 2013).

3.3 | Control measures

Results of the control variables (Table 3) did not indicate differences between groups in momentary sleepiness (SSS) or word fluency (RWT) at the test sessions. Working memory performance measured by means of the backwards digit span did not differ either, but pregnant women performed better on the forward digit span task during retrieval ($t(39) = 2.42$, $p = .020$) and a similar trend was evident during encoding

($t(39) = 1.85$, $p = .072$, all other $p > .11$). Because forward digit span performance at encoding showed a mild positive correlation with adjusted list-word recall in the DRM task ($r = .31$, $p = .039$), we submitted the latter result to an analysis of variance with forward digit span performance as a covariate and found that the reported null effect remained stable ($p > .45$). Vigilance (PVT) did not differ between groups.

On an exploratory basis, we analysed the sleep and memory measures without the results of the three multiparous pregnant women. Although this analysis did not change the overall pattern of results, the difference between groups in subjective sleep duration did not reach significance anymore (pregnant vs. controls, 415.8 ± 21.3 vs. 455.3 ± 13.9 min, $t(36) = 1.58$, $p = .124$). Rerunning the analyses excluding the six women of the control group who were on contraceptives did not change the results, except that the decreases in the relative amount of REM sleep and in fast spindle density in NREM sleep found in pregnant compared with non-pregnant women were now restricted to trends (15.1 ± 0.9 vs. 17.6 ± 0.9% REM, $t(31) = 1.96$, $p = .059$; 2.5 ± 0.1 vs. 2.7 ± 0.1 density/30 s, $t(19.7) = 1.72$, $p = .102$, degrees of freedom adjusted due to unequal variances) and the difference in REM sleep duration did not reach significance anymore (63.7 ± 5.1 vs. 74.0 ± 3.6 min, $t(31) = 1.54$, $p = .134$).

4 | DISCUSSION

We investigated whether pregnant women, who often report cognitive shortcomings as well as sleep impairments, exhibit deficits in sleep-associated memory function. We found that, in comparison to matched controls, our well-characterized sample of healthy third-trimester pregnant women reported decreased subjective sleep duration and more awakenings. Contrary to expectations, however, objective sleep measures did not indicate substantial alterations in overall sleep duration and sleep architecture, with the exception of lower amounts of REM sleep and extended time spent awake after sleep onset in pregnant compared to non-pregnant women. Moreover, the sleep-associated consolidation of declarative and procedural memory tasks known to benefit from sleep turned out to be comparable between pregnant women and controls. In accordance with this result, we did not detect pregnancy-related alterations in the amount of SWS or the intensity of slow wave activity, both of which are known to foster sleep-associated memory consolidation (Diekelmann & Born, 2010; Klinzing et al., 2019). Findings of SWS impairments during pregnancy have been mixed and may even be exaggerated because most previous studies tested women's sleep in an unfamiliar sleep laboratory (Driver & Shapiro, 1992; Lee et al., 2000; Wilson et al., 2011b, 2013). Based on our results, we conclude that this sleep stage is largely preserved in healthy, third-trimester pregnant women sleeping in their home environment and, thus, may enable normal sleep-related memory consolidation.

The subjective reports of lower sleep quality, reduced sleep duration and more frequent awakenings in pregnant women are in line with findings in other investigations (Lee & Gay, 2004; Tsai et al., 2012; Wilson et al., 2011b). Still, only the increased number of awakenings was reflected in polysomnographic measures (i.e., in the increased amount of wake after sleep onset). The remaining objective sleep parameters did not yield evidence for substantial alterations (i.e., no differences between pregnant women and controls in total sleep duration, sleep depth [as indicated by the amounts of stage 1 sleep and SWS] or sleep physiology). Thus, sleep architecture was largely preserved in third-trimester pregnancy in the home environment. The fact that changes in objective measures of sleep did not quite match the extent of subjective impairments is not surprising, considering that subjective and objective measures of sleep have been shown to correlate relatively poorly (Baker et al., 1999). It is also conceivable that general expectations of poor sleep during pregnancy may distort subjective reports or that pregnant women who experience more pronounced subjective sleep impairments are more prone to participate in sleep studies such as ours than women with mild complaints. We did find reduced amounts of REM sleep and slightly reduced spindle activity in the pregnant women, which is in line with previous findings (Brunner et al., 1994; Wilson et al., 2011b, 2013). In conjunction with the increase in wakefulness, these changes might stem from generally elevated arousal levels (Hertz et al., 1992). However, reductions in REM sleep during pregnancy have not been unanimously observed (e.g., Schorr et al., 1998) and our exploratory analyses excluding the subsample of healthy women on contraceptives from the control group indicated that these alterations may not be as robust as increases in the time spent awake after sleep onset. Although the conclusion that the observed differences in REM sleep may have been largely driven by extended REM sleep in the control participants on contraceptives is clearly speculative because of the small size of this subsample in our study, it is supported by a previous report (Burdick et al., 2002). The exploratory analyses also indicated that our results in general were not biased by the addition of a negligible number of multiparous women to the sample of mainly nulliparous participants.

In the main memory tasks as well as in most control tasks, performance of the pregnant women was comparable to that of controls. In conjunction with the comparable amount and intensity of SWS, this outcome suggests that the vital role of sleep, and SWS in particular, for sleep-associated memory consolidation is intact during late pregnancy. A study on sleep-associated memory consolidation during pregnancy likewise found comparable visual declarative and procedural memory consolidation but also an impairment in the retention of verbal memory (Wilson et al., 2013). Using a well-established verbal declarative memory task known to benefit from sleep, we could not corroborate this observation. Our results are in line with the assumption that pregnancy-related cognitive impairments in otherwise healthy women are relatively mild, especially when measured objectively in the laboratory (Christensen et al., 2010; Onyper et al., 2010). Fittingly, even when signs of respective cognitive shortcomings emerge in larger samples, performance mostly remains within normal ranges (Davies et al., 2018). However, we cannot draw conclusions on the development of memory functions and sleep over the course of

pregnancy or exclude that pregnancy-related impairments affect aspects of memory not investigated here (e.g., prospective memory) (Rendell & Henry, 2008). Memory dysfunctions might also be restricted to pregnant women with additional mental impairments such as depressive symptoms (Ouellette & Hampson, 2019; Skouteris et al., 2008). Finally, for ethical reasons we did not include a wake control condition and thus did not assess memory formation across (nocturnal) wakefulness.

In conclusion, although many healthy pregnant women experience subjective impairments of sleep quality during the third trimester of their pregnancy, objective sleep quality and physiology are relatively well preserved and may allow for normal sleep-related memory consolidation. These findings challenge the assumption of poor sleep and impaired memory as hallmarks of the "pregnancy brain".

ACKNOWLEDGEMENTS

We thank all subjects for participating in the study. We are grateful to M. Weiß for continued support during recruitment of participants and D. Lehmann for recruiting participants and collecting data during an early stage of the project. Open access funding enabled and organized by Projekt DEAL.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

KaZ and MH designed the research; KaZ, VL, AF and HP performed research; KaZ analysed data; KaZ and MH wrote the paper; all authors read and approved the final manuscript.

ORCID

Katharina Zinke https://orcid.org/0000-0003-2595-2668
Manfred Hallschmid https://orcid.org/0000-0002-0352-1106

REFERENCES

Aschenbrenner, S., Tucha, O., & Lange, K. W. (2000). *Regensburger Wortflüssigkeits-Test: RWT*. Hogrefe, Verlag für Psychologie.

Baker, F. C., Maloney, S., & Driver, H. S. (1999). A comparison of subjective estimates of sleep with objective polysomnographic data in healthy men and women. *Journal of Psychosomatic Research*, *47*(4), 335–341. https://doi.org/10.1016/S0022-3999(99)00017-3

Berndt, C., Diekelmann, S., Alexander, N., Pustal, A., & Kirschbaum, C. (2014). Sleep fragmentation and false memories during pregnancy and motherhood. *Behavioural Brain Research*, *266*, 52–57. https://doi.org/10.1016/j.bbr.2014.02.030

Brett, M., & Baxendale, S. (2001). Motherhood and memory: A review. *Psychoneuroendocrinology*, *26*(4), 339–362. https://doi.org/10.1016/S0306-4530(01)00003-8

Brown, E., & Schaffir, J. (2019). "Pregnancy brain": A review of cognitive changes in pregnancy and postpartum. *Obstetrical & Gynecological Survey*, *74*(3), 178–185. https://doi.org/10.1097/OGX.0000000000000655

Brunner, D. P., Münch, M., Biedermann, K., Huch, R., Huch, A., & Borbély, A. A. (1994). Changes in sleep and sleep electroencephalogram during pregnancy. *Sleep*, *17*(7), 576–582. https://doi.org/10.1093/sleep/17.7.576

Burdick, R. S., Hoffmann, R., & Armitage, R. (2002). Short note: Oral contraceptives and sleep in depressed and healthy women. *Sleep*, *25*(3), 347–349. https://doi.org/10.1093/sleep/25.3.347

Buysse, D. J., Reynolds, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. *Psychiatry Research*, *28*(2), 193–213. https://doi.org/10.1016/0165-1781(89)90047-4

Christensen, H., Leach, L. S., & Mackinnon, A. (2010). Cognition in pregnancy and motherhood: Prospective cohort study. *British Journal of Psychiatry*, *196*(2), 126–132. https://doi.org/10.1192/bjp.bp.109.068635

Christian, L. M., Carroll, J. E., Teti, D. M., & Hall, M. H. (2019). Maternal sleep in pregnancy and postpartum part I: Mental, physical, and interpersonal consequences. *Current Psychiatry Reports*, *21*(3), 20. https://doi.org/10.1007/s11920-019-0999-y

Davies, S. J., Lum, J. A., Skouteris, H., Byrne, L. K., & Hayden, M. J. (2018). Cognitive impairment during pregnancy: A meta-analysis. *Medical Journal of Australia*, *208*(1), 35–40. https://doi.org/10.5694/mja17.00131

Deese, J. (1959). On the prediction of occurrence of particular verbal intrusions in immediate recall. *Journal of Experimental Psychology*, *58*(1), 17–22. https://doi.org/10.1037/h0046671

Diekelmann, S., & Born, J. (2010). The memory function of sleep. *Nature Reviews - Neuroscience*, *11*(2), 114–126. https://doi.org/10.1038/nrn2762

Diekelmann, S., Born, J., & Wagner, U. (2010). Sleep enhances false memories depending on general memory performance. *Behavioural Brain Research*, *208*(2), 425–429. https://doi.org/10.1016/j.bbr.2009.12.021

Diekelmann, S., Büchel, C., Born, J., & Rasch, B. (2011). Labile or stable: Opposing consequences for memory when reactivated during waking and sleep. *Nature Neuroscience*, *14*(3), 381–386. https://doi.org/10.1038/nn.2744

Driver, H. S., & Shapiro, C. M. (1992). A longitudinal study of sleep stages in young women during pregnancy and postpartum. *Sleep*, *15*(5), 449–453. https://doi.org/10.1093/sleep/15.5.449

Ellenbogen, J. M., Hulbert, J. C., Stickgold, R., Dinges, D. F., & Thompson-Schill, S. L. (2006). Interfering with theories of sleep and memory: Sleep, declarative memory, and associative interference. *Current Biology*, *16*(13), 1290–1294. https://doi.org/10.1016/j.cub.2006.05.024

Feinstein, L., McWhorter, K. L., Gaston, S. A., Troxel, W. M., Sharkey, K. M., & Jackson, C. L. (2020). Racial/ethnic disparities in sleep duration and sleep disturbances among pregnant and non-pregnant women in the United States. *Journal of Sleep Research*, *29*(399), e13000. https://doi.org/10.1111/jsr.13000

Hertz, G., Fast, A., Feinsilver, S. H., Albertario, C. L., Schulman, H., & Fein, A. M. (1992). Sleep in normal late pregnancy. *Sleep*, *15*(3), 246–251. https://doi.org/10.1093/sleep/15.3.246

Hoddes, E., Zarcone, V., Smythe, H., Phillips, R., & Dement, W. C. (1973). Quantification of sleepiness: A new approach. *Psychophysiology*, *10*(4), 431–436. https://doi.org/10.1111/j.1469-8986.1973.tb00801.x

Hoekzema, E., Barba-Müller, E., Pozzobon, C., Picado, M., Lucco, F., García-García, D., Soliva, J. C., Tobeña, A., Desco, M., Crone, E. A., Ballesteros, A., Carmona, S., & Vilarroya, O. (2016). Pregnancy leads to long-lasting changes in human brain structure. *Nature Neuroscience*, *20*, 287–296. https://doi.org/10.1038/nn.4458

Johns, M. W. (1991). A new method for measuring daytime sleepiness: The Epworth sleepiness scale. *Sleep*, *14*(6), 540–545. https://doi.org/10.1093/sleep/14.6.540

Klinzing, J. G., Niethard, N., & Born, J. (2019). Mechanisms of systems memory consolidation during sleep. *Nature Neuroscience*, *22*(10), 1598–1610. https://doi.org/10.1038/s41593-019-0467-3

Lee, K. A., & Gay, C. L. (2004). Sleep in late pregnancy predicts length of labor and type of delivery. *American Journal of Obstetrics*

and Gynecology, *191*(6), 2041–2046. https://doi.org/10.1016/j.ajog.2004.05.086

Lee, K. A., Zaffke, M. E., & Mcenany, G. (2000). Parity and sleep patterns during and after pregnancy. *Obstetrics & Gynecology*, *95*(1), 5.

Mölle, M., Bergmann, T. O., Marshall, L., & Born, J. (2011). Fast and slow spindles during the sleep slow oscillation: Disparate coalescence and engagement in memory processing. *Sleep*, *34*(10), 1411–1421. https://doi.org/10.5665/SLEEP.1290

Mölle, M., Marshall, L., Gais, S., & Born, J. (2002). Grouping of spindle activity during slow oscillations in human non-rapid eye movement sleep. *Journal of Neuroscience*, *22*(24), 10941–10947. https://doi.org/10.1523/JNEUROSCI.22-24-10941.2002

Onyper, S. V., Searleman, A., Thacher, P. V., Maine, E. E., & Johnson, A. G. (2010). Executive functioning and general cognitive ability in pregnant women and matched controls. *Journal of Clinical and Experimental Neuropsychology*, *32*(9), 986–995. https://doi.org/10.1080/13803391003662694

Ouellette, S. J., & Hampson, E. (2019). Memory and affective changes during the antepartum: A narrative review and integrative hypothesis. *Journal of Clinical and Experimental Neuropsychology*, *41*(1), 87–107. https://doi.org/10.1080/13803395.2018.1485881

Payne, J. D., Schacter, D. L., Propper, R. E., Huang, L.-W., Wamsley, E. J., Tucker, M. A., Walker, M. P., & Stickgold, R. (2009). The role of sleep in false memory formation. *Neurobiology of Learning and Memory*, *92*(3), 327–334. https://doi.org/10.1016/j.nlm.2009.03.007

Pöhlchen, D., Pawlizki, A., Gais, S., & Schönauer, M. (2020). Evidence against a large effect of sleep in protecting verbal memories from interference. *Journal of Sleep Research*, e13042, https://doi.org/10.1111/jsr.13042

Rasch, B., & Born, J. (2013). About sleep's role in memory. *Physiological Reviews*, *93*(2), 681–766. https://doi.org/10.1152/physrev.00032.2012

Rechtschaffen, A., & Kales, A. (1968). *A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects*. US Department of Health, Education and Welfare.

Rendell, P. G., & Henry, J. D. (2008). Prospective-memory functioning is affected during pregnancy and postpartum. *Journal of Clinical and Experimental Neuropsychology*, *30*(8), 913–919. https://doi.org/10.1080/13803390701874379

Richter, D., Krämer, M. D., Tang, N. K. Y., Montgomery-Downs, H. E., & Lemola, S. (2019). Long-term effects of pregnancy and childbirth on sleep satisfaction and duration of first-time and experienced mothers and fathers. *Sleep*, *42*(4), zsz015. https://doi.org/10.1093/sleep/zsz015

Roach, G. D., Dawson, D., & Lamond, N. (2006). Can a shorter psychomotor vigilance task be used as a reasonable substitute for the ten-minute psychomotor vigilance task? *Chronobiology International*, *23*(6), 1379–1387. https://doi.org/10.1080/07420520601067931

Roediger, H. L., & McDermott, K. B. (1995). Creating false memories: Remembering words not presented in lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*(4), 803–814. https://doi.org/10.1037/0278-7393.21.4.803

Schorr, S. J., Chawla, A., Devidas, M., Sullivan, C. A., Naef, R. W. 3rd, & Morrison, J. C. (1998). Sleep patterns in pregnancy: A longitudinal study of polysomnography recordings during pregnancy. *Journal of Perinatology*, *18*(6 Pt. 1), 427–430.

Skouteris, H., Germano, C., Wertheim, E. H., Paxton, S. J., & Milgrom, J. (2008). Sleep quality and depression during pregnancy: A prospective study. *Journal of Sleep Research*, *17*(2), 217–220. https://doi.org/10.1111/j.1365-2869.2008.00655.x

Tsai, S.-Y., Lin, J.-W., Kuo, L.-T., & Thomas, K. A. (2012). Daily sleep and fatigue characteristics in nulliparous women during the third trimester of pregnancy. *Sleep*, *35*(2), 257–262. https://doi.org/10.5665/sleep.1634

von Aster, M. (2006). *Wechsler Intelligenztest für Erwachsene: WIE; Übersetzung und Adaption der WAIS-III*. Harcourt Test Services.

Walker, M. P., Brakefield, T., Morgan, A., Hobson, J. A., & Stickgold, R. (2002). Practice with sleep makes perfect: Sleep-dependent motor skill learning. *Neuron*, *35*(1), 205–211. https://doi.org/10.1016/S0896-6273(02)00746-8

Weber, F. D. (2018). SpiSOP: One tool for all basic sleep EEG analysis [Web resource]. Retrieved from http://www.spisop.org/

Wilson, D. L., Barnes, M., Ellett, L., Permezel, M., Jackson, M., & Crowe, S. F. (2011a). Compromised verbal episodic memory with intact visual and procedural memory during pregnancy. *Journal of Clinical and Experimental Neuropsychology*, *33*(6), 680–691. https://doi.org/10.1080/13803395.2010.550604

Wilson, D. L., Barnes, M., Ellett, L., Permezel, M., Jackson, M., & Crowe, S. F. (2011b). Decreased sleep efficiency, increased wake after sleep onset and increased cortical arousals in late pregnancy: Decreased sleep efficiency in late pregnancy. *Australian and New Zealand Journal of Obstetrics and Gynaecology*, *51*(1), 38–46. https://doi.org/10.1111/j.1479-828X.2010.01252.x

Wilson, D. L., Barnes, M., Ellett, L., Permezel, M., Jackson, M., & Crowe, S. F. (2013). Reduced verbal memory retention is unrelated to sleep disturbance during pregnancy: Memory consolidation and sleep in pregnancy. *Australian Psychologist*, *48*(3), 196–208. https://doi.org/10.1111/j.1742-9544.2012.00076.x

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Zinke K, Lehnert V, Fritsche A, Preissl H, Hallschmid M. Pregnant women do not display impaired memory formation across one night of sleep. *J. Sleep Res*. 2020;00:e13204. https://doi.org/10.1111/jsr.13204