Discrepancies in maternal reports of infant sleep vs. actigraphy by mode of feeding.

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Abstract

Objectives: Many studies of infant sleep rely solely on parentally-reported data, assuming that parents accurately report their infant's sleep parameters. The objective of this paper is to examine whether night-time sleep parameters of exclusively breastfed or exclusively formula-fed infants differ, and whether correspondence between parental reports and objective measures varies by feeding type.

Methods: Mother-infant dyads intending to breastfeed or formula-feed exclusively for 18 weeks were recruited. Mothers were multiparas and primiparas, aged between 18 and 45 years. Infants were full-term, normal birthweight singletons. Maternal report and actigraphic data on infant sleep were collected fortnightly, from four to 18 weeks postpartum. Data were analysed cross-sectionally using t-tests and GLM analysis to control for interaction between feed-type and sleep location.

Results: Actigraphy-assessed infant sleep parameters did not vary by feed-type but parentally reported sleep parameters did. Maternal report and actigraphy data diverged at 10 weeks postpartum and discrepancies were associated with infant feeding type. Compared to actigraphy, maternal reports by formula-feeding mothers (controlling for infant sleep location) over-estimated infant's Total Sleep Time (TST) at 10 weeks and Longest Sleep Period (LSP) at 10, 12 and 18 weeks.

Conclusions: These results raise questions about the outcomes of previous infant sleep studies where accuracy of parentally-reported infant sleep data is assumed. That parental reports of infant sleep vary by feeding type is particularly important for reconsidering previous studies of infant sleep development and intervention studies designed to influence sleep outcomes, especially where feed-type was heterogeneous, but was not considered as an independent variable.

Key words: Objective sleep measures; subjective sleep measures; infant feeding; infant sleep location; sleep duration; sleep consolidation.

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1. Introduction

Anthropological and other qualitative studies examining public perceptions of infant sleep behaviour report a recurrent theme linking formula-use with longer infant sleep duration (Ball et al., 1999; Ball, 2003; Ball, 2002; Brown and Harries, 2015; Rudzik and Ball, 2016). In maternal folklore, 'giving the baby a bottle' is a commonly suggested solution for getting a 'good' night's sleep with a young baby. "Formula and sleep is the key, breastfeeding and sleep isn't happening," declared one study participant (Rudzik and Ball, 2016). However, feed-type is not a variable that has been typically considered in the majority of parent-infant sleep studies, with only a few recent exceptions (Montgomery-Downs et al., 2010), which have predominantly focussed on the impact of feed type on maternal sleep, as opposed to that of the infant. An anthropological perspective suggests that the interaction between feeding and sleeping is a key aspect of infant sleep that should be rigorously explored (Gettler and McKenna, 2011).

As has been identified elsewhere (Tham et al., 2017), many studies of infant sleep are based solely on parental reports (Field, 2017; Tham et al., 2017) captured via surveys or standardised questionnaires (Goh et al., 2017; Hughes et al., 2015; Sadeh et al., 2009; Symon and Crichton, 2017), sleep logs or diaries (Hiscock and Wake, 2002; Price et al., 2014), or recently, via smartphone apps (Mindell et al., 2016). The use of these methods assumes two things: a) that parents are able to accurately report on their infant's sleep, even though they may be asleep during much of what they are reporting on; and b) that even if parental reports are inaccurate, they will vary homogeneously and with consistency across families and thus discrepancies will have no systematic effect on outcomes. Some studies fail to acknowledge the limitations of parental report data while relying on these data to judge the efficacy of behavioural sleep interventions that target infants (Hiscock and Wake, 2002). Others, while listing parental report as a limitation of the research design, nevertheless draw conclusions about typical infant sleep from these data (e.g. Price et al., 2014; Goh et al., 2017).

Discrepancies between subjective and objective sleep data are well recognised in particular adult sleep research participants, however (Lauderdale et al., 2008; Malish et al., 2016); normal sleepers are known to inaccurately assess their own sleep parameters during pregnancy (Wilson et al., 2013) while those with sleep problems such as insomnia underestimate their sleep duration and overestimate sleep latency (Carskadon et al., 1976; Edinger and Krystal, 2003; Harvey and Tang, 2012). Consequently actigraphy is commonly used for in-home adult sleep studies (Kushida et al., 2001; Sadeh and Acebo, 2002; Sadeh et al., 2011), and the complementary use of subjective and objective sleep measures is generally recommended for accuracy (Sadeh, 1996).

Given the implications when findings are used as the basis of recommendations on optimal infant/child sleep it is essential that infant studies also employ the most objective measurement techniques (Tham et al., 2017). Validation studies of self-reports with actigraphy find that parents reliably report infant sleep schedules (e.g. sleep and wake onset), but poorly estimate infant total sleep time, night-wake frequency and duration (Acebo et al., 2005; Asaka and Takada, 2011; Sadeh, 1996; Simard et al., 2013). This has implications for the outcome validity and applicability of many studies that are based solely on parent-report data.

One source of potential discrepancy between objective and subjective (parentally-reported) measures of infant sleep concerns the strongly-held perception of differences in sleep outcomes between infants fed human milk versus cow's milk formula. The belief that formula-fed infants sleep 'better' than breastfed infants is widespread, and feeds into narratives of early breastfeeding cessation (Ball, 2002; Maehara et al., 2017); thus, it is claimed that formula-fed infants sleep longer, experience earlier sleep consolidation and wake less frequently during the night than breastfed infants (Brown and Harries, 2015; Brown and Lee, 2011; Rudzik and Ball, 2016). Although supported by parent-report studies (Karraker and Young, 2007; Ramamurthy et al., 2012; Sadeh et al., 2009), recent objective comparisons describe a picture of no differences in infant sleep duration by feed type, but confirm greater sleep fragmentation (frequency of night waking) for breastfed infants (Tikotzky et al., 2010). Video observation suggests that breastfed babies make up the same proportion of babies who do (65.6%) and do not (62.5%) sleep 5 or more hours and/or resettle themselves during the night (St James-Roberts et al., 2015). This picture of no difference in overall sleep duration, but reduced arousability among formula-fed infants, is supported by polysomnographic data (Horne et al., 2004), and led us to question how the parentally-reported sleep of infants fed human or formula-milk differed from objectively acquired infant sleep data.

As we could find no studies that have explored differences in subjective and objective measures of infant sleep duration by feed type these data were collected as part of the Durham 'Sleeping like a Baby Study' which examined the development of the infant circadian rhythm in human and formula-milk fed babies (2012-2014). Based on our qualitative work on maternal perceptions of infant feeding and sleeping (Rudzik and Ball, 2016) we hypothesised that breastfeeding mothers would under-report, and that formula-feeding mothers would over-report their infants' sleep duration in comparison to actigraphic recordings. Due to the well-known relationship between feed-type and sleep location (Ball et al., 2016; Galbally et al., 2013; McCoy et al., 2004; Quillin and Glenn, 2004) we also examined how night-time infant sleep measures varied by infant sleep location, and evaluated the effect of feed type on maternal reports of infant sleep parameters controlling for sleep location using general linear modelling.

2. Material and Methods

Mothers of healthy full-term normal birthweight singleton newborns born between September 2012 and December 2013 were approached by a member of the research team on the postnatal ward of James Cook University Hospital, a large teaching hospital in the North East of England. Ethics approval was obtained through the UK National Health Service Research Ethics Committee and Durham University. Primiparous and multiparous mothers between 18 and 45 years of age and intending to breastfeed or formula-feed exclusively for 18 weeks were invited to participate in the research. Those expressing interest in participating were given a study information leaflet and gave permission for a follow-up phone call at two weeks postpartum. Overall, 283 women agreed to be contacted, and 61 of those agreed to participate in the research, for a response rate of 22%. Mothers who agreed to participate scheduled their first data collection at four weeks postpartum, at which time they provided written informed consent, and completed a demographic questionnaire. Data were collected for one overnight period (6pm to 8am) every two weeks between four and 18 weeks postpartum, producing 8 cross-sectional samples. Data collection occurred in the participants' homes, to minimise disruption to sleep behaviours and for ecological validity.

At each data collection point, participants were provided with Micro Motionlogger actigraphic watches (Ambulatory Monitoring Inc., Ardsley, NY) to be worn by the mother and infant from 6pm to 8am. Mothers' watches were worn on the non-dominant wrist and infants' watches were worn on the left thigh; participants were shown how to properly position the watches. Watches were pre-programmed to begin recording at 6pm with a one-minute epoch interval for sleep-wake scoring, and continue recording until the watches were collected and the data uploaded by the researcher. The infant data reported here were analysed using Sadeh's scoring algorithm for infants (Sadeh et al., 1995). Data from the temperature channel, as well as clear activity level anomalies (abrupt zero-movement periods followed by resumption of usual movement) were used to identify off-body periods that might otherwise have been scored erroneously as sleep.

At each data collection point mothers also completed a sleep log that covered the same 6pm to 8am overnight period. The sleep log was divided into 15-minute increments, with space for recording both maternal and infant sleep.

At every data collection point, mothers provided data on infant feeding, using a standardized form provided by the researcher. From this data, each infant was classified as exclusively breastfeeding (EBF), exclusively formula-feeding (EFF) or mixed feeding for that point in time. Mixed feeding included those who were fed human and formula milk, formula and solids, or human milk and solids. Data from infants who were reported to be mixed feeding were excluded from analysis. A total of 36 observations were excluded from analysis due to mixed feeding. Principal sleep location, indicating the location in which the infant spent the majority of the night, was also recorded at each data collection point. Infants were coded as sleeping in the parental bedroom but not the parents' bed, sleeping in the parental bed (i.e. bedsharing) or sleeping in a different room.

Night-time total sleep time (TST) from actigraphy records was calculated by adding the total number of epochs scored as sleep or light sleep, as exported from the software. The software automatically calculated night-time longest sleep period (LSP), number of long wake episodes, and wake after sleep onset (WASO), and these parameters were exported. Night-time TST was calculated from sleep diaries by adding all 15-minute periods between 6pm and 8am during which the participant indicated that the infant was sleeping. Night-time LSP was calculated from sleep diaries by adding the longest continuous set of 15-minute blocks during which the participant indicated that the infant was sleeping, between 6pm and 8am. The number of night wakings was calculated by counting the periods of wakefulness occurring between the initial onset of sleep and the final 15-minute period of sleep. WASO was calculated by adding all 15-minute blocks of wake time that occurred after initial onset of night-time sleep and before the final 15-minute period of sleep.

3. Results

The number of individuals observed within the EBF and EFF groups varied between data collection points for three reasons. First, some participants were not available at all data collection time points, resulting in missing data (n=80 observations missing); second, some infants were classified as "mixed feeding" (n=36 observations excluded); and lastly three infants (n=11 observations) whose feeding method changed from breast-fed to formula-fed during the course of the study had some observations excluded, so that they contributed data only to the feeding group to which they belonged for the bulk of the study (Table 1).

Table 1: Cross-sectional sample size by feeding group at each data collection point

Week	Sleep Diary (n=)		Actigraphy (n=)	
	EBF	EFF	EBF	EFF
4	17	29	16	24
6	19	28	20	27
8	20	29	19	26
10	17	28	16	26
12	17	29	15	22
14	16	27	14	20
16	14	25	13	20
18	16	25	15	24

3.1 Participant Demographics

Sociodemographic data for the participant groups as they were constituted at the mid-point of the study, week 10 is provided in Table 2. The only significant differences between the EBF and EFF groups was with regard to maternal education.

Table 2: Participant demographics

Variable		EBF	EFF	*p*-value
Age		32.7 ±5.6	31.4 ±7.4	0.54
Marital Status	Married/Living Together	89%	93%	0.45
	Single, no partner	6%	0	
	With Partner, living apart	6%	7%	
Household Income	Up to £20,000	12%	29%	0.37
	£20,000-40,000	41%	39%	
	£40,000+	47%	32%	
Education	Up to age 16	0	11%	0.006
	16-18	6%	25%	
	Vocational Training	6%	32%	
	University	44%	18%	
	Post-graduate Study	44%	14%	

3.2 Actigraphy versus Maternal Report Infant Sleep Parameters

Actigraphic measures of night-time TST and LSP did not differ between EBF and EFF groups at 4, 6 and 8 weeks postpartum. There were also no differences in the reports of night-time LSP given by mothers of EBF and EFF infants at these time points (Figures 1 and 2).

Figure 1: Maternal diary vs actigraphy reported night-time TST for EBF and EFF infants

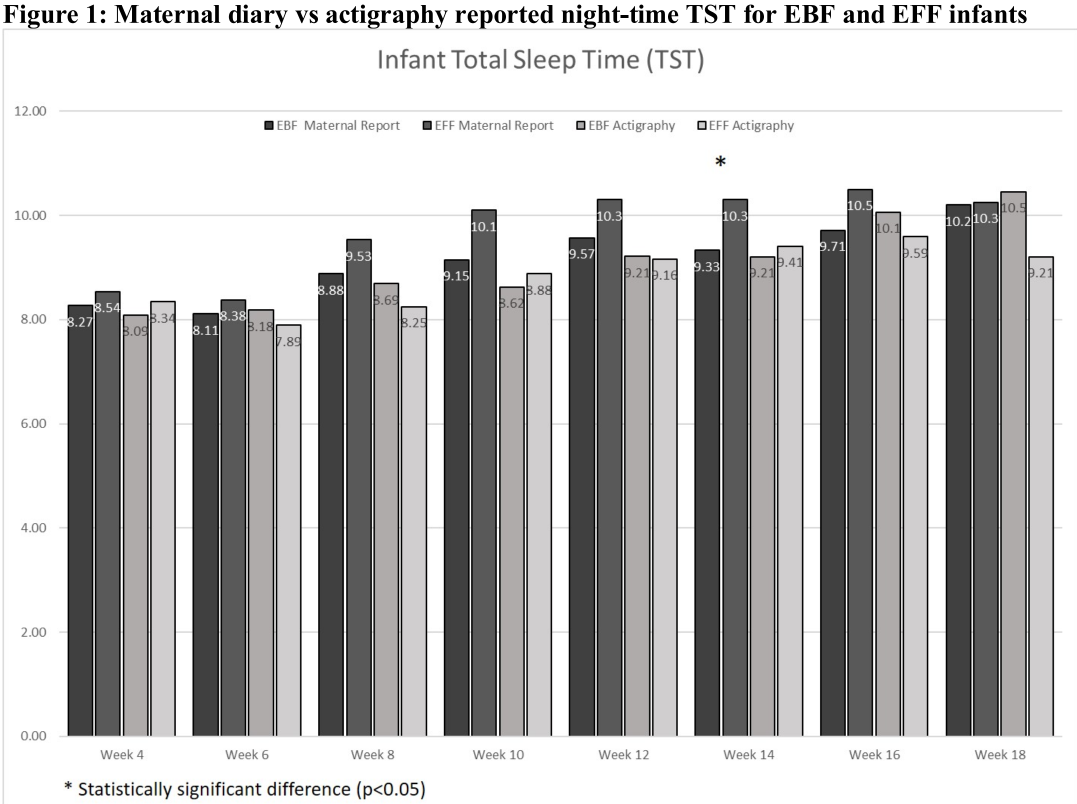
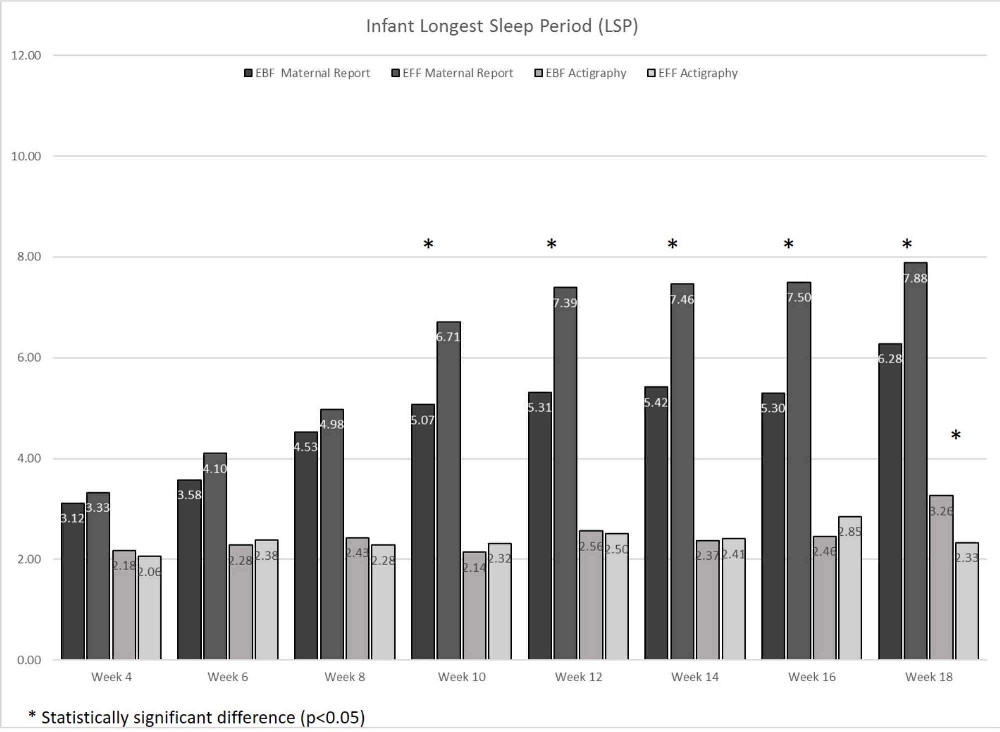


Figure 2: Maternal diary vs actigraphy reported night-time LSP for EBF and EFF infants



At 10, 12, 14 and 16 weeks postpartum actigraphy still did not show a group difference in sleep between EBF and EFF infants for night-time TST or LSP. However, at 10, 12, 14 and 16 weeks, mothers of EFF infants reported longer infant night-time TST than mothers of EBF infants, though this effect reached statistical significance only at 14 weeks (Table 3). Between 10 weeks and 16 weeks, EFF mothers estimated their infants' night-time TST to be between 41 and 58 minutes longer over the course of the night than EBF mothers estimated for their infants.

Table 3: t-test comparisons of EBF and EFF infants' TST (maternal report and actigraphy), by week

Week	Night-time TST Maternal Report (hours)					Night-time TST Actigraphy (hours)				
	EBF	EFF	*p*-value	95% Confidence Interval		EBF	EFF	*p*-value	95% Confidence Interval	
				Lower	Upper				Lower	Upper
4	8.27	8.54	0.65	-1.47	0.93	8.09	8.34	0.61	-1.28	0.76
6	8.11	8.38	0.66	-1.54	0.98	8.18	7.89	0.49	-0.55	1.12
8	8.88	9.53	0.21	-1.68	0.38	8.69	8.25	0.26	-0.34	1.22
10	9.15	10.05	0.06	-1.84	0.26	8.62	8.88	0.61	-1.27	0.76
12	9.57	10.25	0.09	-1.47	0.12	9.21	9.16	0.92	-1.01	1.11
14	9.33	10.29	0.03	-1.79	-0.12	9.21	9.41	0.64	-1.07	0.66
16	9.71	10.47	0.10	-1.67	0.16	10.06	9.59	0.35	-0.54	1.48
18	10.20	10.29	0.85	-1.04	0.86	10.45	9.21	0.06	-0.04	2.52

Similarly, despite there being no objective (actigraphically measured) difference in night-time LSP at 10, 12, 14 or 16 weeks, mothers of EFF infants reported significantly longer LSP than mothers of EBF infants at each of those four time points (Table 4). Between 10 weeks and 16 weeks, EFF mothers estimated their infants' night-time LSP to be between 1.64 and 2.29 hours longer over the course of the night than EBF mothers estimated for their infants.

Table 4: t-test comparisons of EBF and EFF infants' LSP via maternal report and actigraphy, by week

Week	LSP Maternal Report (hours)					LSP Actigraphy (hours)				
	EBF	EFF	*p*-value	95% Confidence Interval		EBF	EFF	*p*-value	95% Confidence Interval	
				Lower	Upper				Lower	Upper
4	3.12	3.33	0.53	-0.87	0.45	2.18	2.06	0.64	-0.40	0.64
6	3.58	4.10	0.26	-1.44	0.40	2.28	2.38	0.75	-0.75	0.55
8	4.53	4.98	0.32	-1.38	0.46	2.43	2.27	0.66	-0.55	0.87
10	5.07	6.71	0.03	-3.14	-0.14	2.14	2.32	0.61	-0.83	0.49
12	5.31	7.39	0.01	-3.56	-0.59	2.56	2.50	0.89	-0.79	0.91
14	5.42	7.46	0.02	-3.68	-0.40	2.37	2.41	0.93	-0.86	0.79
16	5.30	7.59	0.01	-3.40	-0.57	2.46	2.85	0.44	-1.41	0.63
18	6.28	7.88	0.05	-3.22	0.03	3.26	2.33	0.04	0.05	1.81

At 18 weeks, actigraphy data showed a longer night-time TST for EBF infants than for EFF infants, although this did not reach significance (p=0.06, 95%CI: -0.04, 2.52). Actigraphy also showed a significantly longer night-time LSP for EBF infants than for EFF infants (p=0.04, 95%CI: 0.05, 1.81). Actigraphy indicated that EBF infants' night-time TST was approximately 74 minutes longer and their LSP was approximately 55 minutes longer than EFF infants. However, for infant night-time TST at 18 weeks, maternal reports indicated no difference between EBF and EFF groups (p=0.85). For night-time LSP at 18 weeks, EFF mothers reported significantly longer duration (p=0.05, 95%CI: -3.22, 0.03), with a mean of 96 minutes extra sleep reported for EFF vs. EBF infants.

In addition to infant night-time TST and LSP, we examined two measures of infant night-time wakefulness, WASO and night waking frequency from maternal report and actigraphy (Table 5). Although maternal reports showed no differences in night-time WASO at any time point, according to actigraphy EFF infants experienced significantly longer WASO at 14 weeks (p=0.05, 95%CI -98.14, -0.45). EBF mothers reported significantly more infant night waking at 6 weeks (p=0.002, 95% CI 0.59, 2.32) and 14 weeks (p=0.01, 95% CI 0.30, 2.30); however, actigraphy showed a significant difference only at 16 weeks, when EFF infants experienced more night waking (Table 6).

Table 5: Cross-sectional t-test comparisons of EBF and EFF infants' WASO by maternal report and actigraphy

Week	WASO Maternal Report (min)					WASO Actigraphy (min)				
	EBF	EFF	*p*-value	95% Confidence Interval		EBF	EFF	*p*-value	95% Confidence Interval	
				Lower	Upper				Lower	Upper
4	264	248	0.61	-47.00	79.11	241	249	0.79	-73.62	56.01
6	242	205	0.34	-39.90	114.28	214	214	0.98	-61.83	60.62
8	200	160	0.16	-16.23	97.08	187	199	0.62	-60.99	36.86
10	192	141	0.14	-17.33	117.41	159	188	0.24	-77.71	20.00
12	138	137	0.98	-53.41	54.57	121	160	0.13	-91.27	11.90
14	149	116	0.24	-22.94	88.84	119	169	0.05	-98.14	-0.45
16	141	125	0.64	-51.75	83.80	130	127	0.95	-58.11	62.24
18	92	94	0.95	-54.39	50.94	92	142	0.07	-104.37	4.61

Table 6: Cross-sectional t-test comparisons of EBF and EFF night wake frequency by maternal report and actigraphy

Week	Number of Wakings Maternal Report					Number of Long Wakings Actigraphy				
	EBF	EFF	*p*-value	95% Confidence Interval		EBF	EFF	*p*-value	95% Confidence Interval	
				Lower	Upper				Lower	Upper
4	4.6	3.9	0.18	-0.31	1.62	9.9	9.5	0.73	-1.82	2.56
6	4.5	3.1	.002	0.59	2.32	10.7	9.1	0.08	-0.20	3.28
8	3.7	3.1	0.15	-0.20	1.30	9.7	9.8	0.93	-1.72	1.58
10	3.3	2.3	0.07	-0.07	2.02	8.6	9.3	0.43	-2.48	1.07
12	2.8	2.0	0.08	-0.10	1.6	9.0	8.2	0.44	-1.34	3.02
14	3.2	1.9	0.01	0.30	2.30	7.4	8.8	0.22	-3.47	0.83
16	2.6	1.8	0.09	-0.11	1.66	5.9	8.0	0.05	-4.01	-0.05
18	1.9	1.7	0.52	-0.54	1.05	6.6	7.6	0.28	-2.92	0.87

3.3 General Linear Models of Infant Sleep Parameters

Due to the potential for infant sleep location to confound results related to infant feeding and sleep, we constructed general linear models (GLM) to determine the impact of feeding type while controlling for sleep location (Tables 7-10). Compared with EBF infants, EFF was a significant independent predictor of longer maternally-reported night-time LSP at 10 weeks (7.3 hours vs. 5.8 hours; F=4.352, p=0.043), 12 weeks (7.3 vs. 5.5 hours; F=5.626, p=0.022) and 18 weeks (8.4 vs. 6.7 hours; F=4.556, p=0.039) and reached significance predicting night-time TST at 10 weeks (10.8 vs. 9.8 hours; F=4.449, p=0.041). Unlike maternal-reported parameters, feeding type did not predict night-time LSP as measured by actigraphy at 10 or 12 weeks or night-time TST at 10 weeks. At 18 weeks EFF was associated with significantly shorter night-time LSP as measured by actigraphy (2.3 vs. 3.3 hours; F=5.378, p=0.026).

In the GLM models, sleep location was also found to predict infant sleep parameters. In the early postpartum (4 weeks) infants who bed-shared with parents had significantly lower maternally-reported WASO (156 min vs. 269 min; F=5.921, p=0.019) and significantly fewer maternally-reported night wakings (2.7 vs 4.5; F=6.105, p=0.018) than infants who slept in the parental room separate from the parents. At this early stage, no infants slept in a separate room. Sleep location had its strongest effect on maternal reporting of sleep parameters at 14 weeks, at which time point sleep location was significantly predictive of maternally-reported night-time LSP (F=4.055, p=0.025), TST (F=3.502, 0.040) and night waking (F=4.716, p=0.014). In the case of maternally-reported night-time LSP and TST, the significant difference was between infants who slept in a different room and those who slept in the parental room but not the parental bed (reported LSP 8.2 vs. 6.3 hours; reported TST 10.8 vs. 9.6 hours). In the case of maternally-reported number of night wakings, the significant difference was between bed-sharing infants and those who slept in the parental room but not the parental bed (4.9 vs. 2.4 wakings reported). At none of these time points were the corresponding actigraphic measures (LSP, TST, WASO, night wakings) predicted by sleep location.

Table 7: General Linear Models for maternally-reported infant LSP (by week)

Week	Predictors	df	*F*	Significance
4	Intercept	1	189.660	0.000
	Feeding Type	1	0.739	0.395
	Sleep Location	1	1.814	0.185
6	Intercept	1	68.615	0.000
	Feeding Type	1	1.545	0.221
	Sleep Location	2	0.690	0.507
8	Intercept	1	109.576	0.000
	Feeding Type	1	0.842	0.364
	Sleep Location	2	1.303	0.282
10	Intercept	1	67.200	0.000
	Feeding Type	1	4.352	0.043
	Sleep Location	2	2.402	0.103
12	Intercept	1	156.755	0.000
	Feeding Type	1	5.626	0.022
	Sleep Location	2	2.218	0.121
14	Intercept	1	121.828	0.000
	Feeding Type	1	3.514	0.068
	Sleep Location	2	4.055	0.025
16	Intercept	1	125.217	0.000
	Feeding Type	1	2.620	0.114
	Sleep Location	2	3.016	0.062
18	Intercept	1	175.429	0.000
	Feeding Type	1	4.556	0.039
	Sleep Location	2	1.301	0.284

Table 8: General Linear Models for maternally-reported infant TST (by week)

Week	Predictors	df	*F*	Significance
4	Intercept	1	313.638	0.000
	Feeding Type	1	0.149	0.701
	Sleep Location	1	0.110	0.742
6	Intercept	1	173.507	0.000
	Feeding Type	1	0.445	0.508
	Sleep Location	2	1.672	0.200
8	Intercept	1	414.675	0.000
	Feeding Type	1	0.609	0.440
	Sleep Location	2	0.309	0.736
10	Intercept	1	421.066	0.000
	Feeding Type	1	4.449	0.041
	Sleep Location	2	1.798	0.178
12	Intercept	1	1375.612	0.000
	Feeding Type	1	2.326	0.135
	Sleep Location	2	2.458	0.098
14	Intercept	1	1175.839	0.000
	Feeding Type	1	3.637	0.064

	Sleep Location	2	3.502	0.040
16	Intercept	1	1062.978	0.000
	Feeding Type	1	0.290	0.593
	Sleep Location	2	2.970	0.064
18	Intercept	1	891.645	0.000
	Feeding Type	1	0.023	0.880
	Sleep Location	2	0.162	0.851

Table 9: General Linear Models for maternally-reported infant WASO (by week)

Week	Predictors	df	*F*	Significance
4	Intercept	1	85.556	0.000
	Feeding Type	1	0.883	0.353
	Sleep Location	1	5.921	0.019
6	Intercept	1	20.704	0.000
	Feeding Type	1	1.556	0.219
	Sleep Location	2	0.608	0.549
8	Intercept	1	76.415	0.000
	Feeding Type	1	1.002	0.323
	Sleep Location	2	1.025	0.368
10	Intercept	1	14.518	0.000
	Feeding Type	1	2.355	0.133
	Sleep Location	2	0.297	0.745
12	Intercept	1	37.656	0.000
	Feeding Type	1	0.147	0.703
	Sleep Location	2	1.119	0.336
14	Intercept	1	45.989	0.000
	Feeding Type	1	0.681	0.414
	Sleep Location	2	1.821	0.175
16	Intercept	1	34.873	0.000
	Feeding Type	1	0.134	0.716
	Sleep Location	2	2.744	0.078
18	Intercept	1	19.522	0.000
	Feeding Type	1	0.001	0.970
	Sleep Location	2	0.309	0.736

Table 10: General Linear Models for maternally-reported infant night waking (by week)

Week	Predictors	df	*F*	Significance
4	Intercept	1	104.647	0.000
	Feeding Type	1	3.395	0.072
	Sleep Location	1	6.105	0.018
6	Intercept	1	65.763	0.000
	Feeding Type	1	10.198	0.003
	Sleep Location	2	0.461	0.634
8	Intercept	1	82.586	0.000
	Feeding Type	1	0.866	0.357
	Sleep Location	2	2.425	0.100

10	Intercept	1	20.286	0.000
	Feeding Type	1	3.126	0.084
	Sleep Location	2	0.243	0.785
12	Intercept	1	57.369	0.000
	Feeding Type	1	2.650	0.111
	Sleep Location	2	1.479	0.240
14	Intercept	1	84.009	0.000
	Feeding Type	1	2.753	0.105
	Sleep Location	2	4.746	0.014
16	Intercept	1	51.610	0.000
	Feeding Type	1	0.871	0.357
	Sleep Location	2	2.919	0.067
18	Intercept	1	39.253	0.000
	Feeding Type	1	0.446	0.509
	Sleep Location	2	1.033	0.366

4. Discussion

Actigraphy data show that over the 8 cross-sectional data collection points mean total sleep time increased over time for both groups of infants, while longest sleep period remained consistent for both groups over time. The lack of a significant difference between breastfed and formula-fed infants in total sleep time and longest sleep period between 6pm and 8am from 4 to 16 weeks replicates previous findings (Tikotzky et al., 2015) . We did not find that exclusively breastfed infants experienced significantly more frequent night-waking than exclusively formula-fed infants on a consistent basis, but did so sporadically. In the present study breastfed infants showed a significantly greater night-time longest sleep period than did formula-fed infants at 18 weeks of age; as we did not collect data beyond this point we cannot ascertain whether this signified the onset of sleep consolidation among the breastfed infants or was a one-off event. We found no actigraphic measures of night-time infant sleep to be associated with sleep location.

Maternal reports aligned most closely with actigraphy at the outset of the study, diverging from the actigraphic data, and from each other by feed type, as the study progressed and infants aged. Discrepancies in maternally reported infant sleep variables by infant feed type appeared after infants attained eight weeks of age. In comparison with actigraphy, formula-feeding mothers over-reported their infant's total sleep time and longest sleep period during the night at data collection points 10, 12, 14, 16 and 18 weeks (TST being significant at 14 weeks, LSP being significant at all data points from week 10 to 18), and underestimated infant wake after sleep onset during the night at all data collection points from 8 weeks onwards. Breastfeeding mothers also overestimated night-time LSP compared with actigraphy, but not to the same degree as formula-feeding mothers. Breastfeeding mothers assessed their infant's total sleep time during the night much more accurately than formula-feeding mothers. This discrepancy in parental reports of infant sleep by feed type supported our initial hypothesis, and has not been previously documented; there are multiple explanations and implications.

Breastfeeding mothers have a tendency to co-sleep (Ball et al., 2016; McCoy et al., 2004; Quillin and Glenn, 2004) and breastfed infants often sleep in closer proximity to their mothers than formula-fed infants (Ball et al., 1999; Ball, 2003; Galbally et al., 2013). Closer sleep proximity may contribute to greater awareness by mothers of infant sleep and wake patterns, therefore breastfeeding mothers may be more accurate in their reports of infant sleep patterns. However, when we controlled for infant sleep location in the above analyses the relationship between feed-type and maternal discrepancy in reporting night-time infant sleep outcomes was maintained, with formula-feeding mothers reporting significantly longer night-time LSP at 10, 12 and 18 weeks, and night-time TST at 10 weeks in comparison to actigraphy.

Sleep location did have some effect on maternal reports. For the youngest infants (4 weeks old), sleeping in close proximity to the mother (bed-sharing) was associated with significantly fewer maternally-reported infant night-wakings and less night-time WASO than sleeping in the parental room but not bed. At 14 weeks of age maternally-reported night-time LSP and TST were significantly greater for those who slept in a separate room than those who slept in their parents' room but not bed. These results reinforce the importance of interpreting parentally-reported night-time infant sleep outcomes with caution.

Divergence of subjective reports from objective recordings could be attributed to diminishing participant vigilance in data collection over time, but this does not explain the persistent discrepancies in the cross sectional data provided by mothers on night-time LSP in each feeding group. Although some studies have questioned the ability of actigraphy to reliably detect early infant sleep patterns (Meltzer et al., 2012), it is unlikely that actigraphy would be differentially effective in capturing the sleep states of infants by feed type. The data reported here are therefore likely to reflect a perceived difference in infant sleep outcomes by mothers in these two groups.

There are several (non-mutually exclusive) potential explanations for this perception.

a) The physiological effect of breastfeeding on sleep.

   Two possible mechanisms are discussed in the literature. Exclusively breastfeeding mothers may be more sensitive to their infants' sleeping and waking patterns than are mothers who formula-feed due to the effects of lactation-related hormone changes on (i) maternal responsivity or (ii) maternal sleep architecture. Two small studies (n=12 in each) have found lactation to be associated with an increase in slow-wave sleep and a reduction in light sleep among breastfeeding women when compared to non-lactating controls, and to postpartum formula-feeding women, possibly related to increased levels of circulating prolactin (Blyton et al., 2002; Nishihara et al., 2004). These studies do not support the suggestion that lactation influences the sleep architecture of breastfeeding mothers in ways that will enhance awareness of infant sleep patterns, although attempts to replicate these findings were not successful in a larger sample (Rosen, 2009). However, studies investigating the associations between breastfeeding, maternal brain response to infant stimuli, and maternal sensitivity in the early postpartum have found that exclusively breastfeeding mothers show greater brain activation responses to their infant in comparison with exclusively formula-feeding mothers, along with greater maternal sensitivity in interactions with their infant at 3-4 months post-partum (Pilyoung et al., 2011). Lactation-related brain activations and responsivity may therefore promote greater maternal awareness of infant sleep among breastfeeding mothers.

b) The sharing of night-time care:

Sharing infant care, particularly night-time feeds is one reason that mothers give for choosing to feed their infants with formula (Brown and Harries, 2015; Rudzik and Ball, 2016). Paternal involvement in night-time care is associated with increased maternal sleep (Tikotzky et al., 2015). If formula-feeding mothers share night care with their partner they may have an incomplete picture of their infant's sleep and therefore overestimate sleep time and underestimate night-waking.

c) Expectations about infant sleep:

The belief of mothers that formula-use promotes infant sleep may have influenced their perceptions of actual infant sleep. There is an extensive psychological literature regarding parental dysfunctional perceptions of child sleep (Ng et al., 2013; Sadeh et al., 2007). However, parents generally attribute their child with less sleep than objective assessments indicate, rather than more, as is the case with the exclusively formula-feeding mothers here.

Several limitations of this study should be considered. A difference in educational level was found between breastfeeding and formula-feeding participant groups. However, as no significant difference was found for income level, this educational difference does not seem to have translated into a difference in life circumstances.

The response rate for the study was 22%, likely due to the relatively high demands placed on participants within the study protocol, including repeated data collection over a period of four months. While we attempted to minimise the burden on participants by conducting all data collection at the participant's home and having a researcher travel to the participant to drop off and pick up study equipment, there was likely some selection bias for women willing to engage in the study protocol during the early weeks and months of their child's life.

Due to the primary purpose for which these data were collected (to examine the development of the infant melatonin circadian rhythm) the study duration included only the first 18 postnatal weeks. Future studies that aim to assess subjective and objective differences in sleep duration by feed type should aim to capture at least a six month period.

As our purpose was to investigate the development of night-time sleep consolidation, the increase in the period of time for which an infant is able to sleep continuously and in line with circadian cues of darkness and light, we did not collect data on infant daytime sleep. We are therefore not able to control for differences that might arise from variations in daytime sleep between infants.

Although participants were recruited based on their intention to exclusively breast or formula-feed their infants for the first 18 weeks, several introduced new foods during the course of the study. To avoid contamination of the feeding groups, data from infants fed differently from the initial intention were dropped from the cross-sectional analysis, which reduced the overall sample size and caused inconsistencies in the number of participants in each feeding group at each time point.

Although the use of actigraphy to assess infant sleep is common, its accuracy in early infancy has been questioned due to lack of atonia (sleep-induced paralysis) prior to 4 months of age. If atonia were shown to develop differently in EBF and EFF infants this could explain the results found here, however we could find no previous reports assessing the variability in atonia development in infants.

Despite these limitations we provide preliminary evidence that the accuracy of maternal reports of infant sleep parameters varies depending on ecological factors; for example, when infants are formula-fed rather than when they are breastfed during a crucial period (10-18 weeks) for infant sleep development or when they are placed in a different room for night-time sleep. The implications of these findings are relevant to the interpretation of previous studies that draw conclusions about infant sleep outcomes based solely on maternal reports (Galland et al., 2017; Hiscock et al., 2014; Mindell et al., 2010; Paul et al., 2017; Price et al., 2014), particularly where participants' feeding strategies are undocumented or data are pooled across feed-type and sleep location (Hiscock and Wake, 2002). Some authors maintain that the accuracy of parental report may in fact be irrelevant because parents' perception of their infant's sleep is what is used to define an infant with a sleep problem (Sadeh, Mindell, Luedtke, & Wiegand, 2009). We disagree with this position as it inappropriately medicalises infants who are likely not to have any clinical pathology.

5. Conclusions

Although it is claimed by parents and others that formula-fed infants sleep longer, experience earlier sleep consolidation and have fewer night wakings than breastfed infants, and studies based on parentally reported infant sleep data appears to confirm this, analysis of actigraphy data found no significant differences in the total sleep time, longest sleep period, and duration or frequency of night waking between breastfed and formula-fed infants. However, subjective parental reports diverged from objectively collected data, with maternal reports of formula-fed infant sleep showing the biggest discrepancies. These results suggest we should more critically evaluate the outcomes of previous studies where data on parental perceptions of infant sleep were assumed to reflect actual infant sleep, particularly where studies provide no data on infant feed type or sleep location, including studies on infant sleep development, and those reporting the outcomes of behavioural interventions designed to influence sleep outcomes.

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