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Experimental manipulation of maternal proximity during short sequences of sleep and infant calming response

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Abstract

This study aimed to understand how different mother-infant sleeping arrangements impact infants' self-regulation, particularly their calming response. Thus this study investigated the effect of three prevalent mother-infant sleeping arrangements, co-sleeping (CS), sleeping beyond arm's length from their mother (BAL), and solitary sleeping (SS), on infants' physiological calming through self-regulation during a nap session in 24 infants (50% female, *M*=1.85 months *SD* = 0.93 months), who were identified as either regular co-sleepers with their mothers, infants who slept in the BAL sleeping arrangement from their mother, and infants who are solitary sleepers (SS). The effect of all three sleeping conditions amongst all the three types of infants with different habitual sleeping arrangements was assessed. All infants spent 10 min (2 × 5 min sessions) in each sleeping condition (CS, BAL, SS) during which electrocardiographic recordings were collected to obtain interbeat intervals (IBI) and rMSSD, a measure of heart rate variability (HRV) an index of physiological calming, maintained by the parasympathetic pathway involved in self-regulation. Infants who regularly co-slept with their mothers had the highest IBI, indicating greater physiological calming and self-regulation across all sleeping arrangement conditions (CS, BAL, SS), followed by infants who regularly slept in the BAL sleeping arrangement from their mothers. IBI was lowest amongst regular solitary sleepers, potentially indicating physiological stress due to mother-infant separation. However, HRV indices during the sleeping arrangements (especially across regular solitary sleepers) were inconclusive as to whether the lack of change in HRV across all sleeping conditions was due to physiological stress responses or greater physiological regulation. This study is the first to investigate the effect of manipulated and habitual mother-infant sleeping arrangements on infant physiological calming.

Keywords: Maternal proximity; Sleeping arrangement; Infant calming response; Co-sleep; Solitary sleep; Sleep within the vicinity of the mother

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Introduction

This study investigated the effect of mother-infant co-sleeping (CS), infant sleeping beyond arms length of the mother (BAL), and infant solitary sleeping (SS) on infant physiological calming, a self-regulatory process controlled by the parasympathetic pathway of the autonomic nervous system. The effects of all three prevalent sleeping conditions on infant physiological calming were assessed amongst infants who regularly co-slept, infants who regularly slept in the BAL sleeping arrangement, and in infants who slept solitarily. Mother and infant co-sleeping is a parenting custom that has endured through perhaps five million years of human history (Ball, 2003). This sleeping arrangement occurs when mother and infant share the same surface (i.e., bed-sharing) in close enough proximity for the two to respond to one another's cues (Huang, Wang, Zang, & Liu, 2010) and engage in bodily contact during the night (Lozoff, Askew, & Wolf, 1996). Only in the last two centuries has this traditional practice been questioned, and the idea of alternative sleeping arrangements surfaced. This paradigm shift was driven in part by changing cultural norms, foremost of which is the rise of the modern Western thought that places great emphasis on the development of personal independence (Keller & Goldberg, 2004a). Today, sleeping arrangements alternative to co-sleeping consist of solitary sleeping, where the infant sleeps separately from the mother (i.e., in another room), and room-sharing, in which the infant remains in the vicinity of the mother but is not within the mother's reach (i.e., beyond arm's length). As suggested, cultural norms greatly influence infant sleeping arrangements. Starkly different from Western nations (such as the United States) that typically adopt solitary sleeping arrangements thought to promote independence in infants (Keller & Goldberg, 2004a) are national norms (such as in Japan and China), where, respectively, mothers feel that solitary sleep is "merciless" (Morelli, Rogoff, Oppenheim, & Goldsmith, 1992) and mothers think that co-sleeping is critical to infant security (Huang et al., 2010). In a cross-cultural study that compared Western and Asian countries, the former reported higher rates of solitary sleeping, whereas the latter predominantly practiced co-sleeping (Mindell, Sadeh, Kwon, & Goh, 2013). Despite the spread of Western ideas among Asian societies that galvanized sociodemographic change (e.g., women's participation in the workforce, urbanization), Shimizu, Park, and Greenfield

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(2014) found equal prevalence of co-sleeping in Japan in 1980s as compared to the present, explained mostly by societal expectations of mothers, limited space, or greater emphasis on cultural values. Mahendran, Vaingankar, Mythily, and Cai (2006) also found that 33.1 % of children aged 2–19 years still slept with their parents in Singapore which is an economically advanced society, like Japan.

The ongoing debate about sleeping arrangements derives from contrasting opinions about the advantages and disadvantages of co-sleeping and has consequently spurred much research interest. Some studies support the benefits of co-sleeping, such as for comfort and warmth (Esposito, Setoh, & Bornstein, 2015; Esposito, Setoh, Yoshida, & Kuroda, 2015), better accessibility to cater to infant needs, such as breast-feeding and night-awakenings (Ball, 2003; Mao, Burnham, Goodlin-Jones, Gaylor, & Anders, 2004; McCoy et al., 2004; Mileva-Seitz, Bakermans-Kranenburg, Battaini, & Luijk, 2017; Mosko, Richard, & McKenna, 1997), and enhanced parent-child bonding (Chu, 2014; Esposito, Setoh, Bornstein et al., 2015; Esposito, Setoh, Yoshida et al., 2015; Trevathan & McKenna, 1994). Conversely, others espouse solitary sleeping and warn about the dangers of co-sleeping, such as increased risk of infectious diseases (McCallion et al., 1996; Mileva-Seitz et al., 2017) and Sudden Infant Death Syndrome (SIDS; McKenna & McDade, 2005; Moon, 2011; Shimizu et al., 2014). The belief in allegedly promoting infant autonomy also drives both types of parenting practices. Infant solitary sleep is thought to foster infant self-soothing behaviors, self-reliance, and later independence (Burnham, Goodlin□Jones, Gaylor, & Anders, 2002; Keller & Goldberg, 2004a; McKenna & Mosko, 1994; Mileva-Seitz et al., 2017). Co-sleeping is likewise believed to promote independence due to enhanced mother-child bonding at night that supports the child to become more autonomous during the day (Chu, 2014; McKenna & McDade, 2005).

Autonomy begins with the infant's physiological and psychological independence from the mother (Shimizu et al., 2014; Winberg, 2005). Distinct preferences of sleeping arrangements across cultures reflect differences in opinion as to when independence is presumed to develop. For instance, proponents of solitary sleep in the United States view birth as the point of physiological separation of the mother and child, after which infants are encouraged to further develop independent self-regulatory abilities (i.e., self-soothe to sleep at night; Burnham et al., 2002; Keller & Goldberg, 2004a; McKenna &

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Mosko, 1994; McKenna et al., 1994). However, infant physiology is immature and normally requires extensive external support from the mother for effective regulation (Winberg, 2005, McKenna and Mosko (1994) established that physical contact with the mother allows for the continuous exchange of dyadic sensory cues (i.e., motion, vocalization, touch, etc.) that provides external support to the child as the child gradually adapts and develops self-regulatory capacities (e.g., Baddock, Galland, Beckers, Taylor, & Bolton, 2004; Ball, 2006; Richard & Mosko, 2004). In the context of co-sleeping, the close proximity of mother and child promotes skin-to-skin contact that regulates the infant's core body temperature, enhances glucose metabolism and reduces cortisol levels (Lester et al., 2018; McKenna & Volpe, 2007; Moore et al., 2017; Winberg, 2005). These findings seem to contradict with the prevailing notion of infant physiological post-birth independence held by parents who advocate solitary sleep.

An indication of infant physiological independence is the ability to engage in effective physiological self-regulation, which is the maintenance of a constant internal homeostatic autonomic state of arousal (Pace-Schott et al., 2019; Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996; Ramsay & Woods, 2014). Because self-regulation processes involve cortical areas, such as the prefrontal and frontal areas, that communicate with and control the autonomic nervous system, the rMSSD (root of the Mean of the Square of Standard Deviation), which is a measure of heart rate variability (HRV) has been identified as an index of self-regulatory capacity (Porges, 2001; Reynard, Gevirtz, Berlow, Brown, & Boutelle, 2011; Segerstrom & Nes, 2007; Thayer & Lane, 2000). HRV is the fluctuation in the interval time between two adjacent heartbeats or interbeat intervals (IBI) and reflects the activity of the parasympathetic network of the auto- nomic nervous system (Shaffer & Ginsberg, 2017; Task Force, 1996). Longer IBI and greater HRV reflect a state of calming mediated by the parasympathetic pathway involved in self-regulation, whereas shorter and lower indices, respectively, denote physiological arousal due to increased activation of the sympathetic nervous system, often involved in the stress response (Esposito et al., 2013; Esposito, Setoh, Bornstein et al., 2015; Esposito, Setoh, Yoshida et al., 2015; Reynard et al., 2011; Stern, Ray, & Quigley, 2001; Webber et al., 2010). More mature and developed autonomic systems would exhibit longer IBI indices that suggest effective physiological self-regulation (Evans et al., 2013; Longin, Gerstner, Schaible, Lenz, & König, 2006; Schneider et al., 2018).

At present there is scarcity in the literature as to how mother-infant sleeping arrangements impact infants' self-regulation, particularly their calming response. Understanding the effect of different types of prevalent mother-infant sleeping arrangements (bed-sharing, room-sharing, and solitary sleeping) on physiological calming responses, measured by IBI and HRV, through systematic manipulation of sleeping arrangements would provide better insight into which sleeping arrangement could be beneficial to establish calming and promote greater self-regulation in infants. Taking into account the infants' habitual sleeping arrangement – infants who regularly co-sleep (CS) with their mothers, sleep beyond arm's length (BAL) from their mothers, and sleep solitarily (SS) – this study assessed infant physiological calming and self-regulation in each of these three sleeping arrangement condition during a 30 min nap. IBI and HRV were measured as physiological responses. Stress, as opposed to calming, shortens IBI and lowers HRV, whereas self- regulatory effort elevates IBI and HRV (Esposito, Setoh, Bornstein et al., 2015; Esposito, Setoh, Yoshida et al., 2015; Reynard et al., 2011; Segerstrom & Nes, 2007). Due to the stress induced by mother-infant separation, we hypothesized that infants would display greatest physiological calming during co-sleeping, less in the BAL sleeping condition, and show physiological stress in the solitary sleeping condition (Feldman, Singer, & Zagoory, 2010; Keller & Goldberg, 2004b; Morgan, Horn, & Bergman, 2011; Pryce, Aubert, Maier, Pearce, & Fuchs, 2011). Additionally, due to enhanced mutual regulation and intimacy when dyadic partners are in close physical contact (Ball, Hooker, & Kelly, 2000; Chu, 2014; Keller & Goldberg, 2004a, 2004b, McKenna & Mosko, 1994; McKenna & McDade, 2005), we expected infants who regularly co-sleep would have developed greater physiological self-regulation and adapt better to changes in sleeping conditions compared to their counterparts who regularly experience BAL and solitary sleeping arrangements. Alternatively, if regular solitary sleeping promotes self-regulation in infants (Burnham et al., 2002; Keller & Goldberg, 2004a; McKenna & Mosko, 1994; McKenna et al., 1994), physiological self-regulatory responses may also be found in infants who are regular solitary sleepers.

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Methods

Participants

Twenty-four mother-infant dyads from Singapore (Chinese Ethic group) took part in this study. The infants (50% female) were aged between 1–3 months (*M* = 1.85 months *SD* = 0.93 months). All the infants were born full-term with no health issues. The age of the mothers ranged from 23 to 42 years (*M* = 32.26 years, *SD* = 3.941). Most mothers were primiparous, except three who had one other older child. All mothers were currently married, had a form of tertiary education, and were healthy with no reports of any clinical depression. Recruitment was conducted through online advertisements on Facebook and mother-baby forums and through word-of-mouth in Singapore. Written consent was obtained from the mothers of the infants. Mothers were also asked through a questionnaire about the regular sleeping arrangement of their infant. Accordingly, infants were identified as regular co-sleepers (n = 9), BAL sleepers (n = 9), or solitary sleepers (n = 6). Nighttime co-sleeping and BAL sleeping occurred in the presence of the mother's partner as well. It should be noted that infant sleeping arrangements were intentional by the mothers and not reactive – the mothers of all infants were proactive about the sleeping arrangements of their infant.

All methods were performed in accordance with the relevant guidelines and regulations and the study was approved by the Institutional Review Board of Nanyang Technological University (IRB-2016-12-027).

Nap Session

The nap session (total of 30 min) was conducted at the infant's home. Mothers were instructed to have fed their infant before the start of the session to increase the likelihood of infants falling asleep quickly. For the study session, infants slept in the same room they usually do. Electrodes of the Bitalino Revolution device (https://bitalino.com/en/board-kit-bt) were attached to the infant to enable electrocardiography (ECG) data collection throughout the nap session. Infants slept in each of the three sleeping arrangement conditions – co-sleeping (CS) with mother, sleeping beyond arm's length (BAL) from mother, and solitary sleeping (SS) – during their nap session. The sequence of sleeping arrangement

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conditions was counterbalanced across infants. Each sequence was repeated twice. ECG recordings were collected for 5 min in each condition. A total of two 5-min ECG recordings of each infant in each of the three sleeping arrangement conditions were obtained. Mothers were instructed beforehand to quietly change their position according to the sequence of sleeping arrangement conditions when signalled by the experimenter. They lay down next to the infant during the CS condition. Mothers of regular solitary sleepers were asked to lay down on a make-shift bed placed adjacent to the infant's crib so as to enable them to lay down as close as possible to the infant by pulling down the rail of the crib adjacent to the bed. Mothers were instructed to naturally keep contact with the baby during the CS condition. During the BAL condition, mothers were instructed to move an arm's length away from the sleeping infant. During the SS condition, mothers were instructed to leave the sleeping infant alone in the room. ECG recording continued even if the infant woke up during any of the sleeping arrangement conditions. Only ECG recordings where the infants were asleep for more than 75 % throughout the sleeping arrangement condition were used for analysis; regular co-sleepers (n = 6), BAL sleepers (n = 6), or solitary sleepers (n = 5).

Inter-beat-interval and heart rate variability

ECG was collected at 1000 Hz for 5 min x 2 for each of the three sleeping arrangement conditions (CS, BAL, SS). ECG data underwent signal processing which consisted of high-pass and low-pass signal filtering, followed by detection of ReR peaks (see Esposito et al., 2013, for details). Visual inspection of the automatic ReR peak was also conducted to eliminate any technical computational errors. Mean interbeat interval (IBI) using ReR peaks and the root mean square of successive differences between normal heartbeats (rMSSD) was calculated using a moving window of 10 s with 5-sec steps for each infant for each condition. rMSSD is a time-domain index of heart rate variability (HRV) that reflects the function of the parasympathetic network of the autonomic nervous system responsible for calming through self-regulation (Shaffer & Ginsberg, 2017; Task Force, 1996) Longer IBI and higher HRV indices reflect a state of calming through self-regulation, and shorter and lower indices denote physiological arousal caused by stress (Esposito et al., 2013; Esposito, Setoh, Bornstein et al., 2015;

Esposito, Setoh, Yoshida et al., 2015; Reynard et al., 2011; Stern et al., 2001; Webber et al., 2010). Group averages of IBI and HRV (rMSSD) from both repetitions of sleeping arrangement conditions were calculated for each time window, based on the type of infants' regular sleeping arrangement. Thus, mean IBI and HRV measures were obtained for co-sleepers, BAL sleepers, and solitary sleepers, for all three sleeping arrangement conditions.

Analytical Approach

This study assessed the effect of mother-infant sleeping arrangement on infants' physiological calming through self-regulation during a nap session among regular co-sleepers, BAL sleepers, and solitary sleepers. The 3 × 3 repeated-measures design had a between-subject independent variable (type of infants' regular sleeping arrangement) of three levels (co-sleepers, BAL sleepers, solitary sleepers) and a within-subject independent variable (sleeping arrangement conditions) of three levels (CS, BAL, SS). The dependent variables were infant physiological calming during a nap session as measured by IBI and HRV (rMSSD). The distributions of IBI and HRV (rMSSD) by type of infants' regular sleeping arrangement were evaluated for normality and outliers. Repeated- measures analysis of variance (RM-ANOVA) is fairly robust to any violations of normality and presence of outliers (Laerd Statistics, 2018; Quinn & Keough, 1991), so the data were left intact.

Results

Effect of sleeping arrangements on infant IBI

A 3 × 3 RM-ANOVA was conducted to assess the effect of mother-infant sleeping arrangement on the mean interbeat interval in infants who regularly co-sleep, sleep beyond arms length from their mother, or sleep solitarily. There was a significant interaction between sleeping arrangement condition and the type of infant regular sleeping arrangement, $F(2.30, 196.82) = 41.62$, $p < 0.001$, partial η2 = 0.327. Post-hoc analyses revealed statistically significant2differences in mean IBI during the co-sleeping condition across the three types of sleepers, $F(2, 173) = 523.75$, $p < 0.001$, partial η = 0.858; Infants who regularly co-slept had the highest mean IBI (M = 0.494s, SD = 0.016) followed by infants who regularly slept beyond arm's length from their mothers (M = 0.481s, SD = 0.006), and last infants who regularly

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slept alone (M = 0.426s, SD = 0.123) had the shortest mean IBI when they were made to sleep in the co-sleeping condition. Mean IBI during the BAL sleeping condition was also statistically different among all the three types of sleepers, $F(2, 173) = 544.78$, $p < 0.001$, partial η2 = 0.863. Again, co-sleepers had the longest mean IBI (M = 0.489, SD = 0.013), followed by BAL sleepers (M = 0.469, SD = 0.011), and last solitary sleepers (M = 0.415, SD = 0.140) when they were made to sleep in the BAL sleeping condition. Similarly, the mean IBI during the solitary sleeping condition was statistically different among all three types of sleepers, $F(2, 175) = 179.12$, $p< 0.001$,partial η2 = 0.672. Again, co sleepers had the longest mean IBI (M = 0.504, SD = 0.011), followed by BAL sleepers (M = 0.473, SD = 0.009), and last solitary sleepers (M = 0.351, SD = 0.079).

Post-hoc analyses also showed that there was a significant main effect of sleeping arrangement condition on mean IBI amongst co- sleepers, $F(1.81, 103.28) = 37.80$, $p < 0.001$, partial η2 = 0.399. Mean IBI in infants during the solitary sleeping condition (M = 0.504, SD = 0.011) was significantly longer than the mean IBI during the co-sleeping condition (M = 0.493, SD = 0.015) and the BAL sleeping condition (M = 0.489, SD = 0.013). Similarly, amongst BAL sleepers there was a significant main effect of sleeping arrangement condition on mean IBI, $F(1.77, 100.79) = 99.33$, $p < 0.001$, partial η2 = 0.635. Mean IBI in infants was the longest during the co-sleeping condition (M = 0.482, SD = 0.005), followed by mean IBI during the solitary sleeping condition (M = 0.473, SD = 0.009), and last the BAL sleeping condition (M = 0.468, SD = 0.005). There also was a significant main effect of sleeping arrangement condition of mean IBI amongst solitary sleepers, $F(1.07, 61.43) = 35.84$, $p < 0.001$, partial η2 = 0.386. Mean IBI was longest in the co-sleeping condition (M = 0.426, SD = 0.012) followed by mean IBI in the BAL sleeping condition (M = 0.415, SD = 0.014), and showed the shortest mean IBI in the solitary sleeping condition (M = 0.361, SD = 0.071). Refer to Fig. 1 for the graphical representation of the mean IBI for all sleeping arrangement conditions based on the type of infants' regular sleeping arrangement.

Effect of sleeping arrangement on infant HRV (rMSSD)

A 3 × 3 RM-ANOVA was conducted to assess the effect of mother-infant sleeping arrangement on HRV (rMSSD) in infants who regularly co-sleep, sleep beyond arm's length from their mother, or

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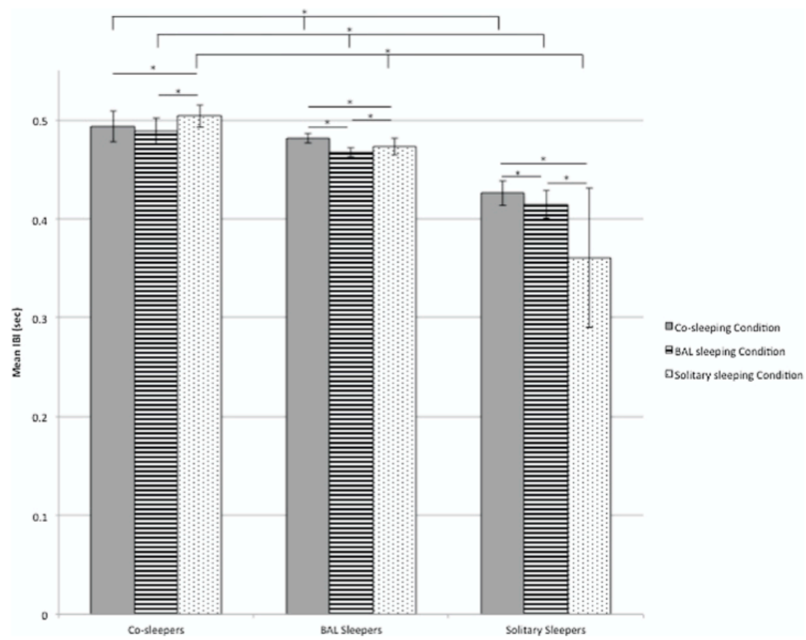

Fig. 1. Mean IBI for three sleeping arrangement conditions based on three types of infants' regular sleeping arrangement. The error bars represent the standard deviation.

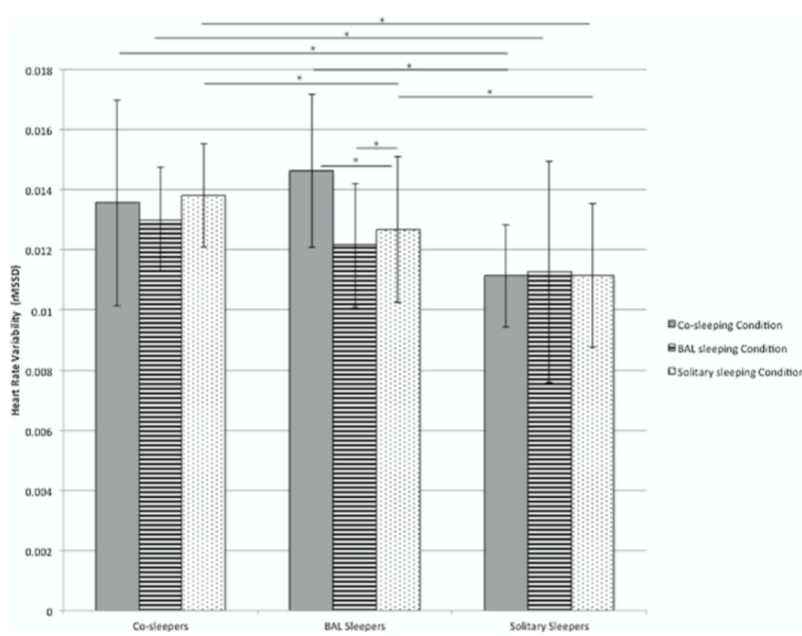

Fig. 2. Heart rate variability (rMSSD) for three sleeping arrangement conditions based on three types of infants' regular sleeping arrangements. The error bars represent the standard deviation.

sleep solitarily (see Fig. 2). There was a significant interaction between sleeping arrangement condition and the type of infants' regular sleeping arrangement, $F(3.93, 336.38) = 5.20$, $p = 0.001$, partial $\eta2 = 0.057$. Post-hoc analyses revealed a statistically significant difference in HRV during the co-sleeping condition, $F2{,}174 = 24.85$, $p < 0.001$, partial $\eta2 = 0.222$, where infants who were solitary sleepers had

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lower HRV (rMSSD) ($M = 0.011$, $SD = 0.003$) compared to infants who regularly slept in the co-sleeping arrangement ($M = 0.014$, $SD = 0.003$) and infants who regularly slept beyond arm's length of their mothers ($M = 0.014$, $SD = 0.003$). In the BAL sleeping condition, HRV (rMSSD) was significantly higher only amongst regular co-sleepers ($M = 0.013$, $SD = 0.003$) compared to regular solitary sleepers ($M = 0.011$, $SD = 0.004$), $F(2,173) = 5.74$, $p = 0.004$, partial η2 = 0.062. There was also a significant difference amongst infants during the solitary sleeping condition, $F2,175 = 25.97$, $p < 0.001$, partial η2 = 0.229. HRV (rMSSD) was the highest amongst infants who regularly co-slept ($M = 0.013$, $SD = 0.003$), followed by infants who regularly slept in beyond arm's length of their mothers ($M = 0.012$, $SD = 0.003$), and was the lowest amongst infants who were solitary sleepers ($M = 0.011$, $SD = 0.003$) (Fig. 2).

Post-hoc analyses also showed that heart rate variability did not significantly differ in any of the sleeping arrangement conditions in infants who were regular co-sleepers, $F(1.46, 83.04) = 1.74$, $p = 0.189$, partial η2 = 0.030. Infants who regularly slept beyond arm's length from their mothers had HRV that differed during the different sleeping arrangement conditions, $F(2, 114) = 18.23$, $p < 0.001$, partial η2 = 0.242. HRV (rMSSD) was significantly higher in these infants during the co-sleeping condition ($M = 0.15$, SD=0.003) compared to the BAL sleeping condition (M=0.012, SD=0.002) and the solitary sleeping condition (M=0.013, SD=0.002). There were no significant differences in the HRV (rMSSD) amongst infants who were solitary sleepers, $F(1.61, 91.48) = 0.033$, $p = 0.943$, partial η2 = 0.001, across the co-sleeping condition ($M = 0.011$, $SD = 0.002$), BAL sleeping condition ($M = 0.011$, $SD = 0.004$), and solitary sleeping condition ($M = 0.011$, $SD = 0.002$).

Discussion

This study investigated the effects of three mother-infant sleeping arrangement (co-sleeping, sleeping beyond arm's length, and solitary sleeping) conditions on infant physiological calming and self-regulation as reflected by infants' mean heart rate interbeat interval and heart rate variability in infants who are regular co-sleepers, beyond arm's length sleepers, and solitary sleepers. Specifically, each infant of each sleeping type was observed in all three sleeping arrangements conditions in a counterbalanced sequence repeated twice and averages of mean IBI and HRV (rMSSD) were obtained from all three types of sleepers in all three sleeping arrangement conditions. It was hypothesized that infants display greater physiological calming while co-sleeping, followed by sleeping beyond arm's length and show physiological stress while solitary sleeping owing to stress caused by mother-infant separation (Feldman et al., 2010; Keller & Goldberg, 2004b; Morgan et al., 2011; Pryce et al., 2011). Along the same line of thought, infants who regularly co-sleep were expected to have developed greater physiological self-regulation and adapt better to changes in sleeping condition compared to their counterparts who regularly sleep beyond arm's length and sleep solitarily owing to enhanced mutual regulation when dyadic partners are in close physical contact (Ball et al., 2000; Chu, 2014; Keller & Goldberg, 2004, 2004b, McKenna & Mosko, 1994; McKenna & McDade, 2005). Alternatively, it was also hypothesized that physiological self-regulatory responses of calming may be evident in infants who are regular solitary sleepers as predicted by an opposing notion that regular solitary sleeping promotes self-regulation in infants (Burnham et al., 2002; Keller & Goldberg, 2004; McKenna & Mosko, 1994; McKenna et al., 1994).

Our results indicated that infants who regularly co-slept with their mothers had the longest IBIs across all three sleeping arrangement conditions, followed by infants who regularly slept beyond arm's length from their mothers. There was significant de- crease in IBI across all three sleeping arrangements in infants who regularly slept solitarily. These results accord with our first and second hypotheses. Longer IBI reflects a state of physiological calmness maintained by the parasympathetic pathway involved in self- regulation (Esposito et al., 2013; Esposito, Setoh, Bornstein et al., 2015; Esposito, Setoh, Yoshida et al., 2015; Reynard et al., 2011; Stern et al., 2001; Webber et al., 2010). Mother-infant separation is said to be stressful for infants due to disruption of covert mother- infant regulatory interactions (Beijers, Riksen-Walraven, & de Weerth, 2013; Loman & Gunnar, 2010; Morgan et al., 2011). Covert mother-infant interactions consist of sensorimotor, thermal, and nutrient based events which have long-term regulatory effects on infant behavior and physiology. Research has shown that disruptions in mother-infant covert interactions or loss of skin-to-skin contact lead to increases in cortisol levels triggered by the sympathoadrenal system (Loman & Gunnar, 2010; McKenna & Volpe, 2007; Moore et al., 2017; Sapolsky, Romero, & Munck, 2000; Winberg, 2005). The shorter IBIs seen in infants who are regular

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solitary sleepers may be attributable to a similar physiological stress response triggered by activation of the sympathetic pathway, reducing parasympathetic activity (Loman & Gunnar, 2010; Sapolsky et al., 2000). Moreover, infants who were regular co-sleepers displayed longer IBIs when made to sleep in a solitary sleeping arrangement. This finding concurs with Hofer's (1994) concept that promoting covert interactions between mother and infant, which is assumed to be depicted here in regular co-sleepers, enhances infant self- regulation during stress. Interpretations of the IBI findings in this study should be taken with caution as we did not collect a direct behavioral measure of mother-child interaction during the co-sleeping arrangement. We only assume, based on the co-sleeping literature, that there may be enhanced mother-infant interactions. This deduction needs to be empirically tested along with IBI to provide empirical confirmation.

Heart rate variability (rMSSD) was the lowest in the solitary sleeping condition and the highest in the co-sleeping condition amongst all infants. These findings contradict what Morgan et al. (2011) and Richard and Mosko (2004) reported in their studies. Both reported high HRV during sleep when infants were separated from their mothers, compared to HRV (rMSSD) during sleep when infants were sleeping with skin-to-skin contact with their mothers. Morgan et al. (2011) attributed the increase in HRV to activation of central corticotrophin releasing hormone based stress response circuitry, which in turns activated the autonomic nervous system (Francis & Meaney, 1999; Herman & Cullinan, 1997). It is this activation that was responsible for the rise in infant HRV (rMSSD) during stressful sleep when the infant was separated from the mother. By contrast, as the results suggest from this study, high HRV (rMSSD) can indicate greater calming due to self-regulation, and low HRV (rMSSD) can signify a stress response (Esposito et al., 2013; Esposito, Setoh, Bornstein et al., 2015; Esposito, Setoh, Yoshida et al., 2015; Evans et al., 2013; Longin et al., 2006; Reynard et al., 2011; Schneider et al., 2018; Stern et al., 2001; Webber et al., 2010). In addition, HRV (rMSSD) amongst regular co-sleepers and regular solitary sleepers did not differ significantly amongst all the three sleeping conditions. Co-sleepers had a significantly higher HRV than solitary sleepers across all sleeping conditions. The lack of change in HRV across the three sleeping conditions could suggest that co-sleepers are so well regulated that they did not

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respond to a change in sleeping conditions with a stress response. Whereas the lack of change in HRV (rMSSD), in addition to relatively low HRV (rMSSD), across the different sleeping conditions amongst regular solitary sleepers may indicate a lack in physiological regulation to different sleeping conditions. Alternatively, the lack of change in HRV (rMSSD) across the different sleeping conditions could indicate that solitary sleepers are also well regulated and did not respond to a change in sleeping condition with a stress response, with the overall low HRV (rMSSD).

Limitations and Future Directions

The question of whether the low HRV (rMSSD) and the lack of change in HRV (rMSSD) across sleeping conditions amongst solitary sleepers was due to a physiological stress response and lack of physiological regulation, or a physiological calming response merits further investigation. HRV (rMSSD) measures collected to investigate the effect of sleeping arrangement on physiological calming might be coupled with measures of cortisol production during each sleeping arrangement to distinguish increases in HRV (rMSSD) due to stress or calming based on the common presence of cortisol during stress.

As previously mentioned, we did not record behavioral measures of mother-child interacting during the co-sleeping or beyond arm's length sleeping arrangements. Differences in behavioral responsiveness to infants may be conditioned by dyads' typical sleeping arrangements. For instance, compared to beyond arm's length or solitary sleepers, mothers who regularly co-sleep with their infants may more effectively respond to their infants' needs when co-sleeping (2006, Ball, 2003; Bornstein, Cote, Haynes, Suwalsky, & Bakeman, 2012; Chu, 2014; Keller & Goldberg, 2004a, 2004b, McKenna & Mosko, 1994; McKenna & McDade, 2005). Another index that might be fruitfully incorporated in future studies investigating mother-infant sleeping arrangements could be mother-infant physiological synchrony. Mutual arousal offers an excellent opportunity for bidirectional exchanges of signals that scaffold tempo- rally coordinated reciprocal interactions (Bornstein et al., 2013; Azhari, Leck, & Gabrieli et al., 2019; Feldman, Magori-Cohen, Galili, Singer, & Louzoun, 2011). Among mammals, synchrony is fundamental to regulating infant heart rate, stress responsiveness, and self- regulation (Champagne et al., 2008; Mileva-Seitz et al., 2017; Pratt, Singer, Kanat-Maymon, & Feldman, 2015). Mother-infant

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behavioral and physiological synchrony correlates of infants' physiological responses could provide an in-depth explanation of the mechanisms underlying infant physiological responses.

Other limitations to this study include the fact that the study took place in a span of only 30 min and during the day to minimize intrusion to participants' night time sleep. Mothers are usually awake in the day and may respond to their infants in a different manner as compared to when they are aroused to attend to their infants at night. This methodological choice needs to be tested empirically in future research. Furthermore, we had no baseline IBI and HRV (rMSSD) recordings of infants during normal wake- fulness. Co-sleepers may enjoy naturally longer IBIs and higher HRV (rMSSD), a fact that would support the hypothesis that co- sleepers command better self-regulatory capacities, but without a baseline IBI and HRV (rMSSD) it is difficult to compare effects of different sleeping arrangements across infants with various habitual sleeping arrangement styles. Thus its is recommended that incorporating baseline measures during wake will allow for more accurate comparisons across infants with habitual sleeping arrangement styles. Finally, this study only investigated sleeping arrangements between mother and infant, but in reality fathers and other caregivers (e.g., domestic helpers) may be present during sleep or be equally or more attentive to the child during sleep (Ball et al., 2000; Mahendran et al., 2006; Mileva-Seitz et al., 2017). For this reason, investigating co-sleeping with other caregivers in future research will broaden the applicability of any findings about sleeping arrangements and physiological calming responses in infants.

All the mothers from the sample in this study were proactive in their decision about their infants' sleeping arrangements. Proactive here meant that the mothers were practicing the type of sleeping arrangement they prefer with their infants. None of these mothers were reactive in following their current sleeping arrangement with their infants. Reactive sleeping arrangements occurs when parents do not prefer a particular sleeping arrangement but need to use this arrangement in reaction to their infant's sleep problems. Mother's availability (mainly emotionally) may differ based on the whether they are proactively or reactively practicing a particular sleeping arrangement (Keller & Goldberg, 2004a; Ramos, Youngclarke, & Anderson, 2007; Shimizu & Teti, 2018). This in turn may affect the child's physiological calming and self-regulatory responses particularly in the reactive co-sleeping condition that enhances mother-infant interaction and physiological synchrony. That is, physiological synchrony with a distressed mother will not promote self-regulation in the co-sleeping infant (Laurent, Ablow, & Measelle, 2012; Papp, Pendry, & Adam, 2009; Suveg, Shaffer, & Davis, 2016). Investigating physiological calmness in infants from a sample consisting of reactive sleeping arrangement may increase the applicability of findings as to which sleeping arrangement promotes better physiological calmness. Additionally, this study was conducted on a sample with a relatively high sociodemographic background (all the mothers were married with no health issues and had received tertiary education). Whether similar findings occur across various sociodemographic backgrounds needs to be investigated to broaden the applicability of the findings.

Despite these several limitations, the current study is the first to our knowledge to investigate physiological calming responses through self-regulation in three prevalent types of mother-infant sleeping arrangements; co-sleepers, beyond arm's length sleepers, and solitary sleepers. The findings in this study along with its limitations open opportunities in future for more in-depth research.

Conclusion

Infants who regularly co-slept with their mothers had the longest IBIs, indicating greater physiological calming and self-regulation across three sleeping arrangement conditions (CS, BAL, SS), followed by infants who regularly slept beyond arm's length from their mothers. IBIs were shortest in regular solitary sleepers, potentially indicating physiological stress due to mother-infant separation. However, HRV (rMSSD) during sleeping arrangements especially across regular solitary sleepers were inconclusive as to whether the lack of change in HRV (rMSSD) across all the sleeping conditions was a response to physiological stress or greater physiological regulation. Overall, this study investigated effects of manipulated and habitual mother-infant sleeping arrangements on infant physiological calming.

Authors statement

Conceptualization, G.E. and P.S.; data collection, B.L.R. and A.A.; data analysis, BLR.; writing—original draft preparation, B.L.R.; writing—review and editing, A.A., M.H.B. and G.E.. All authors have read and agreed to the final version of the manuscript.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.infbeh.2020. 101426.

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