Tampere University

TIINA E. MÄKELÄ

Signaled Night Awakening in Infancy

Associations with psychomotor development, executive functioning, social information processing, and socio-emotional behavior

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Tiina Mäkelä

ABSTRACT

Sleep is important for the maturation of the brain. A common feature of sleep in infancy is night awakening that differentiates it from sleep later in childhood. These night awakenings are normative and usually known to diminish with age. Some children, however, continue to have night awakenings, even though it would be physiologically possible to sleep through the night. These night awakenings are usually so called signaled night awakenings. Signaled night awakening refers to a night awakening that is signaled to parents, for example, with crying, and the parent's assistance is needed for a child to fall asleep again. Signaled night awakenings can influence the well-being of the whole family. However, it is unknown whether signaled night awakening is associated with the child's overall development. This dissertation aimed to determine whether signaled night awakening is associated with children's development or particularly to certain aspects of development during the first two years of life.

Within the CHILD-SLEEP birth cohort two groups were formed based on parent-reported signaled night awakening. Thus far, children with three or more signaled night awakenings formed the waking group, and children with no more than one signaled night awakening formed the non-waking group. Child development was investigated longitudinally using versatile traditional and eye-tracking methods at eight and 24 months old covering aspects of cognitive, social, and emotional development. Dissertation includes three original publications. The main objective was to investigate whether children with signaled night awakenings differ from children without signaled night awakenings in cognitive, language, or motor functioning or in tasks measuring more specifically executive functioning, social information processing, and socio-emotional behavior. Additionally, the stability of signaled night awakening was investigated and whether children with signaled night awakenings differ in parent-rated sleep quality and duration from children without signaled night awakenings. Further, child sleep was also measured with motion sensors.

Based on the results, signaled night awakening is persistent continuing through infancy. Children with signaled night awakenings at eight months old had more parent-reported signaled night awakenings at 18 and 24 months old than children

without signaled night awakenings. Moreover, sleep duration and quality differed between the two groups in data averaged across eight, 18, and 24 months old. Children with signaled night awakenings had shorter sleep duration and they spent more time awake during the night than children without signaled night awakenings. Motion sensor measures supported parent-reports as informants of signaled night awakenings. There were no differences in cognitive, language, or motor functioning between children with and without signaled night awakenings at eight or 24 months old. However, the children with signaled night awakenings had lower performance in a computerized executive functioning task than children without signaled night awakenings. The difference between groups was evident at 24 months old whereas at eight months old the two groups did not differ in their performance. With parent-ratings of executive functioning and more traditional executive functioning tasks at 24 months old, however, the two groups did not differ. Additionally, the children with signaled night awakenings showed a different pattern of attention to emotional faces across time than children without signaled night awakenings. More precisely, the children with signaled night awakenings had a more pronounced attentional bias to fearful faces relative to other face types than children without signaled night awakenings. Further, the children with signaled night awakenings had more parent-reported dysregulation problems and lower social competence than children without signaled night awakenings at 24 months old.

Taken together, signaled night awakening is often prolonged and possibly predisposes children to other changes in sleep quality and duration. Signaled night awakening seems to be predominantly associated with higher-order cognitive functioning, such as executive functioning and social or emotional information processing, and socio-emotional behavior. However, at least during the first two years of life, no differences were observed in the child's overall development. According to the results, it seems that signaled night awakening is associated with a larger problem of self-regulation that possibly predisposes children to altered developmental trajectory. Additionally, the differences between groups were already visible within the first two years of life in a normative population without any major sleep difficulties. Signaled night awakening should be systematically assessed as part of well-child visits. If the child has frequent signaled night awakenings, special attention and follow-up should be paid to sleeping characteristics and the development of the child. Additionally, parents should be advised on how to support their child's sleep and self-regulation skills in infancy.

TIIVISTELMÄ

Uni on tärkeää lasten aivojen kehitykselle. Varhaislapsuuden unen erityispiirre, joka erottaa varhaisen unen myöhemmästä unesta, on yöaikainen heräily. Nämä yöheräämiset ovat normaaleja ja usein ne vähenevät iän myötä. Osalla lapsista yöheräämiset kuitenkin jatkuvat pidemmälle varhaislapsuuteen, vaikka fysiologisesti olisi jo mahdollista nukkua läpi yön. Tällöin on usein kyse niin kutsutuista signaloiduista heräämisistä, jotka lapsi signaloi vanhemmilleen esimerkiksi itkemällä ja vanhemman apua tarvitaan, jotta voidaan nukahtaa uudelleen. Nämä signaloidut heräämiset voivat rasittaa koko perhettä ja vaikuttaa perheen hyvinvointiin. Ei kuitenkaan tiedetä ovatko signaloidut yöheräämiset yhteydessä lapsen kehitykseen. Tämän väitöskirjatutkimuksen tavoitteena oli selvittää, onko signaloitu yöheräily yhteydessä lapsen kehitykseen tai erityisesti johonkin tiettyyn kehityksen osa-alueeseen ensimmäisen kahden elinvuoden aikana.

CHILD-SLEEP-tutkimuskohortissa muodostettiin kaksi ryhmää vanhempien raportoiman lapsen signaloidun yöheräilyn perusteella. Lapset, jotka heräilivät kahdeksan kuukauden iässä vähintään kolme kertaa yössä, muodostivat heräilevien lasten ryhmän ja lapset, jotka heräilivät maksimissaan kerran yössä, muodostivat ei-heräilevien lasten ryhmän. Lasten kehitystä tutkittiin pitkittäisesti kahdeksan kuukauden ja 24 kuukauden ikäisinä monipuolisesti sekä perinteisillä että silmänliikkeitä hyödyntävillä tutkimusmenetelmillä kattaen kognitiivisen, sosiaalisen ja emotionaalisen kehityksen osa-alueita. Väitöskirja koostuu kolmesta osajulkaisusta. Päätavoitteena oli tutkia eroavatko heräilevät lapset ei-heräilevistä lapsista kognitiivisessa, kielellisessä tai motorisessa kehityksessä tai tarkemmissa toiminnanohjausta, sosiaalisen informaation prosessointia ja sosio-emotionaalista käyttäytymistä arvioivissa tehtävissä. Lisäksi tutkittiin signaloidun yöheräilyn pysyvyyttä ja sitä eroavatko heräilevät lapset vanhempien raportoimana unen laadussa ja määrässä lapsista, jotka eivät heräilleet yön aikana. Lisäksi lapsen unta mitattiin myös liikerekisteröinnin avulla.

Tulokset osoittivat, että yöheräily on usein pitkittyvä, jatkuen pidemmälle varhaislapsuuteen. Lapset, jotka heräilivät vanhempien raportoimana kahdeksan kuukauden ikäisinä, heräilivät enemmän myös 18 kuukauden ja 24 kuukauden ikäisinä verrattuna lapsiin, jotka eivät heräilleet yöllä kahdeksan kuukauden ikäisinä.

Lisäksi unen määrässä ja laadussa oli eroja ryhmien välillä, kun unen määrää ja laatua arviointiin pitkittäisesti yhdistäen kahdeksan, 18 ja 24 kuukauden aikapisteet. Lapset, jotka heräilivät, nukkuivat vähemmän ja olivat pidempiä aikoja hereillä yöaikaan kuin lapset, jotka eivät heräilleet. Liikerekisteröintimittaukset tukivat vanhempien havaintoja lasten signaloidun yöheräilyn määrästä. Kognitiivisessa, kielellisessä tai motorisessa kehityksessä ei kuitenkaan havaittu eroja kahdeksan eikä 24 kuukauden ikäisinä. Sen sijaan lapset, jotka heräilivät, suoriutuivat heikommin tietokonepohjaisesta toiminnanohjauksen tehtävästä kuin lapset, jotka eivät heräilleet. Tämä ero suoriutumisessa näkyi lasten ollessa 24 kuukauden ikäisiä, kun kahdeksan kuukauden ikäisinä ryhmien välisessä suoriutumisessa ei ollut eroa. Vanhempien arvioimana, tai perinteisillä toiminnanohjauksen tehtävillä arvioituna eroja ryhmien välillä ei löydetty 24 kuukauden ikäisenä. Lisäksi lapsilla, jotka heräilivät, tarkkaavuus emotionaalisiin kasvoihin oli erilaista, kuin lapsilla, jotka eivät heräilleet. Erityisesti, signaloidusti heräilevillä lapsilla oli suurempi tarkkaavaisuuden vinouma pelokkaita kasvoja kohtaan suhteessa muihin kasvoihin kuin lapsilla, jotka eivät heräilleet. Vanhempien arvioimana lapsilla, jotka heräilivät yöaikaan, oli enemmän säätelyn oireita ja heikompi sosiaalinen pystyvyys 24 kuukauden ikäisenä kuin lapsilla, jotka eivät heräilleet.

Johtopäätöksenä tuloksista voidaan todeta, että lapsen signaloitu yöheräily on usein pitkittyvä ja voi mahdollisesti altistaa myös muille unen laadun ja määrän muutoksille. Signaloitu yöheräily on yhteydessä erityisesti korkeamman tason kognitiivisiin toimintoihin, kuten toiminnanohjaukseen sekä sosiaalisen tai emotionaalisen informaation prosessointiin ja sosio-emotionaaliseen käyttäytymiseen. Lapsen kokonaiskehityksessä ei kuitenkaan havaittu eroja lapsen ensimmäisen kahden elinvuoden aikana. Tulosten perusteella näyttäisi siltä, että signaloitu yöheräily on yhteydessä laajempaan itsesäätelyn vaikeuteen, joka saattaa altistaa lapset mahdollisille myöhemmille kehityksen haasteille. Ryhmien väliset erot olivat näkyvissä jo ensimmäisten kahden elinvuoden aikana lapsilla, jotka edustivat normatiivista otosta eikä heillä esiintynyt erityisiä univaikeuksia. Signaloitu yöheräily tulisi systemaattisesti arvioida neuvolakäyntien aikana. Mikäli lapsella on useita signaloituja yöheräämisiä tulisi neuvolakäyntien aikana erityistä huomiota kiinnittää lapsen unen piirteisiin ja kehitykseen. Lapsen unta ja kehitystä tulisi seurata sekä lisäksi vanhempia tulisi ohjata lapsen unen ja itsesäätelyn taitojen tukemiseen.

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ORIGINAL PUBLICATIONS

This dissertation consists of the following three publications, which will be referred to in the text by their Roman numerals I – IV.

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Publication II Mäkelä, T. E., Peltola, M. J., Saarenpää-Heikkilä, O., Himanen, S., Paunio, T., Paavonen, E. J., & Kylliäinen, A. (2020). Night Awakening and Its Association With Executive Functioning Across the First Two Years of Life. Child Development, 91(4), e937–e951. https://doi.org/10.1111/cdev.13326

Publication III Mäkelä, T. E., Kylliäinen, A., Saarenpää-Heikkilä, O., Paavonen, E. J., Paunio, T., Leppänen, J. M., & Peltola, M. J. (2021). Signaled night awakening and its association with social information processing and socio-emotional development across the first two years. Sleep, 44(12), zsab179. https://doi.org/10.1093/sleep/zsab179

1 INTRODUCTION

Sleep is crucial for the developing brain and during the early years, a great amount of time is spent asleep. Even though the amount of sleep gradually declines, it has been estimated that by two years of age, over half of the child's life is spent sleeping (Dahl, 1996a). During infancy, major ongoing processes are seen in sleep and brain development and the development is understood as interdependent. Due to these ongoing, interdependent, and parallel processes, it has been hypothesized that the influence of sleep is even more significant for brain maturation during the first years of life than later in life (Dahl, 1996b). Therefore, disruptions in sleep may be especially harmful during the early years of development.

In infancy, a common disruption of sleep is night awakening. Night awakening in infancy is a normative phenomenon; in many children, it decreases with age. Nevertheless, some infants continue to have many night awakenings when it would be physiologically possible to sleep through the night. These night awakenings interrupt parents' sleep by requiring parental soothing, often referred to as signaled night awakenings, and are known to influence the whole family's well-being (Sadeh et al., 2007). Further, they are most often reported when parents evaluate their infants' sleep (Palmstierna et al., 2008), but whether these night awakenings are associated with the child's development is largely unknown.

The dissertation investigates whether children with and without signaled night awakenings differ in their development during the first two years of life within the CHILD-SLEEP birth cohort. CHILD-SLEEP is a large consortium that studies the role of early sleep and circadian rhythm evolution in typical neurological and psychological development. The dissertation includes three original studies that longitudinally investigated whether signaled night awakening appears as a persistent problem and whether children with and without signaled night awakenings differ in sleep quality and duration parameters during the first two years of life. As the main objective, it was determined whether children with and without signaled night awakenings differ in cognitive, language, or motor development and whether there are differences, especially in executive functioning, social information processing, or socio-emotional behavior. This dissertation contributes to the existing literature by investigating different aspects of development with multifaceted methods in the same sample of children as early as eight and 24 months old. Before presenting the original studies in more detail, an overview of the relevant research for the present dissertation will be provided. First, the unique characteristics of sleep in infancy will be described. Second, prior studies investigating the associations of sleep and night awakening on children's development will be reviewed. After this, the scope and aims for the present dissertation will be presented.

1.1 Sleep and its unique characteristics in infancy

Sleep in infancy has unique characteristics that differentiate it from the sleep characteristics later in childhood and adulthood. These particular features include the time spent in a sleeping state and different architecture of sleep, referring to the stages of sleep and the length of the sleep cycle. These unique features are also related to the greater number of night awakenings experienced in infancy. Newborn infants sleep almost through the day and sleep is equally distributed across day and night. However, with age, the duration of sleep gradually declines. By the age of six to eight months, approximately 13 to 14 hours in a day are spent asleep (Iglowstein et al., 2003; Paavonen et al., 2020), and at 18 and 24 months of age, approximately 13 hours are spent asleep (Iglowstein et al., 2003). The decrease in total sleep time is mainly affected by the decreasing trend in daytime naps, both in the number of naps and the total duration spent asleep during the day (Louis et al., 1997). Thus, with age, sleep duration is more concentrated in the nighttime. This lengthening of continuous sleep during the night and decreasing sleep during the day is an important developmental task in infancy called consolidation of sleep. This consolidated and self-regulated sleep at night can be achieved already during the first year of life (El Shakankiry, 2011; Henderson et al., 2011; Iglowstein et al., 2003).

1.1.1 Sleep architecture in infancy

Sleep can be divided into different stages based on the brain's electrical activity (EEG) (Davis et al., 2004). There are two different types of sleep based on electrical activity: REM sleep (rapid eye movement) and non-REM sleep (NREM sleep) (Graven & Browne, 2008). Furthermore, NREM sleep is further divided into four stages based on EEG activity and the depth of sleep. These NREM sleep stages are called Stage N1, Stage N2, Stage N3, and Stage N4 (Grigg-Damberger, 2016). However, in newborns, the stages of sleep consist of REM sleep, NREM sleep, and transitional sleep, which refers to the transition from NREM sleep to REM sleep or vice versa (El Shakankiry, 2011; Grigg-Damberger, 2016). Newborns experience REM sleep almost immediately after falling asleep. Contrastingly, in adults, the four sleep stages are experienced in order, and REM sleep appears at the end of the sleep cycle (Louis et al., 1997). By six months of age, the infant's sleep architecture more closely resembles that of an adult as it already contains similar stages of sleep. Nonetheless, the length and amount of each stage differ. With age, REM sleep declines; by six months, NREM sleep is found to dominate in total sleep duration. Notwithstanding, at nighttime, the amount of REM sleep is still greater than in adults (Gillioen et al., 2017; Louis et al., 1997). Another difference between infants and adults is the length of the sleep cycle. At first, the mean duration of the sleep cycle is approximately 50 minutes (Anders, 1978; Stern et al., 1969), and with age, it gradually lengthens to 75 minutes in early childhood, and by middle childhood, it settles to 90 minutes, as in adults (Kahn et al., 1996).

The differences in sleep architecture also predispose infants to fragmented short periods of sleep with several night awakenings (Anders, 1978; Hysing et al., 2014). Brief night awakenings are normative between the sleep cycles in infants and adults (Anders, 1978) and do not create a problem if sleep is continued almost immediately. The ability to settle to sleep alone has been thought to be important in the phenomenon of night awakening. In particular, it seems that night awakening is not problematic and long-lasting for those infants who can soothe themselves to sleep on their own without signaling to their parents (Sadeh et al., 2007). The number of night awakenings is known to decrease with age in many children (Galland et al., 2012; Hysing et al., 2014; Palmstierna et al., 2008). However, night awakening appears to be the aspect of sleep with the greatest variation between individuals (Galland et al., 2012). It has been estimated that approximately 20%–30% of one-year-old infants (Adair et al., 1992; Mindell et al., 2006) and yet 15%–50% of two- to five-year-old children continue to have night awakenings even though consolidated and self-regulated sleep could have been already established (Hysing et al., 2016; Petit et al., 2007).

1.1.2 Signaled night awakening in infancy

Night awakenings where parental assistance is needed for the child to fall asleep again are called signaled night awakenings where an awakening is signaled to parents, for example, with crying or excessive movements. Signaled night awakenings concern parents and are one of the most often parent-reported features of their child's sleep quality (Palmstierna et al., 2008). Signaled night awakenings require parental assistance and therefore can also interrupt parents' sleep. It has been shown that parents' and children's sleep patterns are highly related (Boergers et al., 2007; Gay et al., 2004; Meltzer & Mindell, 2007), and therefore frequent signaled night awakenings can result in parents' prolonged sleep deprivation (Karraker, 2008).

Even though the general trend in night awakenings is decreasing, it seems that children with frequent night awakenings follow a different developmental trajectory. Studies have shown that children with more than three-night awakenings at six months of age were at greater risk of having frequent night awakenings at 18 months old (Hysing et al., 2014). In another study, children with frequent night awakenings at 12 months old were at risk of having more night awakenings even at four to six years old (Palmstierna et al., 2008; Tikotzky & Shaashua, 2012). Previous studies have also supported the notion that sleep difficulties generally are relatively stable over time (Gregory & O'Connor, 2002; Williams et al., 2017). One possibility is that the signaling nature of night awakenings may cause them to persist into older ages in infants who cannot soothe themselves to sleep on their own.

Importantly, it has also been suggested that night awakening may be a precursor for later sleep difficulties and not just for the continuation of night awakening (Goodlin-Jones et al., 2001). Persistent and prolonged signaled night awakenings in infancy could lead to shorter sleep duration and a poor diurnal rhythm and possibly be related to pathologically fragmented sleep. Signaled night awakening is predominantly studied with parental reports or actigraphs. Actigraphs measure movement through an acceleration sensor, making it possible to classify the day to periods of sleep and wake with a clockwise devise. According to cross-sectional actigraphy-based studies on sleep quality, infants with frequent night awakenings have been found to have reduced sleep efficiency, referring to the percentage of time spent asleep in relation to the time spent in bed. Further, they spent more time awake during the night than children without night awakenings (Sadeh et al., 2007). Longitudinal and cross-sectional studies concerning sleep duration have shown contradictory findings. Touchette et al. (2005) found that children with night awakenings slept less and did not compensate for their sleep during the day.

Contrastingly, Acebo et al. (2005) found that infants with night awakenings compensate for shorter nighttime sleep with increased napping during the daytime. In turn, a cross-sectional study by Sadeh et al. (1991) found no differences in sleep duration between infants with and without night awakenings. Based on these prior studies, the findings concerning sleep duration between children with and without night awakenings are contradictory, and it is unknown how stable the possible differences are.

Several child- and parent-related behaviors have been associated with persistent night awakening. The child-related factors have mainly focused on the child's temperament, particularly known as difficult temperament, which refers to negative emotionality, low regularity, intense reactions, and withdrawal (Bates, 1980). In some studies, children high on negative emotionality have been found to have more frequent night awakenings (Scher et al., 2005; Weinraub et al., 2012), but the association has not been evident in all studies (Scher et al., 1998). Additionally, Scher et al. (2005) showed that the associations between night awakening and difficult temperament were not sustained. This could reflect the interrelatedness of night awakening and temperament in early childhood and the methodological concerns referring to the use of parent ratings in assessing temperament and night awakening. It has been proposed that the mechanism linking difficult temperament and night awakening could be due to a lower threshold for arousal. Therefore, children with difficult temperament could be more easily aroused from sleep (Carey, 1974). However, the temperamental dimensions were not related to the ability to self-soothe, which is thought to be highly associated with night awakening (Burnham et al., 2002).

The parent-related behaviors most often associated with frequent night awakening are co-sleeping with the infant, a high level of parental involvement when falling asleep, and breastfeeding (Dias & Figueiredo, 2020; Hysing et al., 2014; Touchette et al., 2005). Additionally, parental behaviors when falling asleep and responding to a night awakening are highly connected with children's sleep consolidation (Touchette et al., 2005). Even though these factors are well-known, the direction of causality between these factors and night awakening is still unclear. Another important issue in the phenomenon of signaled night awakening is attachment security. In the few longitudinal studies, insecure attachment has been connected to the greater number of parent-reported night awakenings (Morrell & Steele, 2003). Contrastingly, cross-sectional studies using objective measures of sleep have not found differences in night awakening as a function of attachment security (Scher, 2001; Scher & Asher, 2004). It has been speculated that the association between attachment and night awakening would become more predictive after the first year of life when the attachment relationship is more fully established, and sleep patterns are consolidated, as shown by Zentall et al. (2012). The child- and parent-related factors associated with signaled night awakening demonstrate that signaled night awakening is a complex phenomenon involving biological and environmental factors.

1.2 Sleep and its association with children's development

Infancy is when rapid development is evident in sleep and brain development. For example, brain volume increases significantly in the gray matter and white matter across the first two years (Knickmeyer et al., 2008). Additionally, the magnitude of the cerebellum, lateral ventricles, caudate, and hippocampus increases. Maturation of the brain has been related to the functions of sleep, and several milestones in sleep development correspond with the critical periods of brain maturation (Heraghty et al., 2008; Mirmiran et al., 2003), and sleep is recognized as a period with cerebral activity also in higher cortical functions.

The interdependent relationship between neurocognitive development and sleep can be manifested in infants with developmental disorders. Specifically, sleep disruptions are common in addition to developmental challenges (Ahmareen et al., 2014; Bonuck & Grant, 2012; Krakowiak et al., 2008). Additionally, studies conducted with children with neuropsychiatric disorders where problems in attention or reciprocal social interaction are common usually have sleep difficulties as well (Cortese et al., 2009; Cortesi et al., 2010; Krakowiak et al., 2008; van der Heijden et al., 2018). Moreover, the severity of sleep problems is positively associated with symptom severity in these neuropsychiatric disorders (Corkum et al., 2001; Schreck et al., 2004; Tudor et al., 2012). Thus, sleep is vital for development, but whether signaled night awakening, particularly, is associated with certain aspects of development is unknown.

In recent years, different sleep parameters and their associations with development in normative populations have been investigated (Astill et al., 2012; Kocevska et al., 2017; Paavonen et al., 2010; Short et al., 2018; van der Heijden et al., 2018). However, most of this knowledge has been cross-sectional and focused on sleep duration in school-aged children. Contrastingly, there is a lack of longitudinal studies which would aid the understanding of developmental trajectories of different sleep characteristics and their associations with children's psychological development. Only with longitudinal studies can it be seen whether the development follows a particular trend or pathway and whether the association with signaled night awakening and development varies in different aged children.

1.2.1 Psychomotor development

During infancy, different aspects of development are highly interrelated and not easily distinguished from each other. In this dissertation, psychomotor development refers to a broad view of development (Cioni & Sgandurra, 2013), consisting of the child's cognitive, language, and motor development. In the first two years, infants acquire knowledge through their senses and motor skills and by imitating others (Bayley, 2009). Acquisition of new skills requires interplay between the different aspects of development. Due to the extensive brain maturation in infancy, rapid development is seen, and several milestones are reached in psychomotor development already in infancy during the first two years of life. Cognitive development refers to mental processes through which we acquire and use knowledge (Gauvain, 2022). With the use of these mental processes, we can effectively act in everyday life. The mental processes, for example, refer to mental processes used in perceiving, thinking, learning, remembering, reasoning, and communicating. During the first year, infants observe similarities and combine things or objects based on these similarities (Gelman, 2006). During the second year of life, pretend or symbolic play evolves (Fein, 1981). The development of language consists of receptive and expressive language, which develop partly independent of each other (Bayley, 2009). Receptive language refers to the understanding of language. Understanding language proceeds spoken language and usually appears at approximately six to nine months old (Bergelson & Swingley, 2012). Expressive language consists of the ability to use language. Babbling starts around three months of age, and with age, it starts to resemble more spoken language through the combination of vowels (Hoff, 2006). First words usually appear during the first year of life, and during the second year, children typically start to combine words into sentences (Hoff, 2006). Motor development can be divided into the gross motor and fine motor development. In gross motor development, infants learn first to control the movements of the head and then movements of the rest of the body (Bayley, 2009). At approximately six to eight months old, children learn to sit, and typically during the second year of life, children learn to walk (Petersen et al., 2011). Fine motor functioning refers to eye-hand coordination, the planning of motor sequences, and the processing speed of motor actions (Bayley, 2009). In infancy, there is a lot of normative variation in the ages at which the specific milestones are reached. An interplay between these different aspects of development is evident, and the importance of sleep for developing new skills has been recognized, but whether the role of sleep is more important to some areas of development needs further studies.

Sleep difficulties and shorter sleep duration have been associated with lower cognitive functioning in longitudinal and cross-sectional studies in pre-school and school-aged children (Astill et al., 2012; Paavonen et al., 2010; Short et al., 2018; Touchette et al., 2007). Further, the associations seem more robust for younger children, as shown by Dewald et al. (2010). Recent studies have also focused on the possible non-linear association between sleep duration on cognitive functioning. These studies have shown that the optimal or recommended amount of sleep is related to favorable cognitive development or academic achievement compared to shorter or longer sleep duration (Eide & Showalter, 2012; Kocevska et al., 2017). In infancy, however, the results are less consistent.

In infancy, there is no common understanding of whether specific sleep parameters and overall psychomotor development are associated in healthy, typically sleeping individuals. In preterm infants and toddlers, more matured sleep, referring to the amount of night-centered sleep, has been related to better cognitive functioning (Gertner et al., 2002; Holditch-Davis et al., 2005; Schwichtenberg et al., 2016), and snoring being related to lower cognitive functioning (Piteo, Kennedy, et al., 2011; Piteo, Lushington, et al., 2011). A few longitudinal studies with typically sleeping infants have found that more matured sleep in infancy favors cognitive functioning later in childhood (Dearing et al., 2001). Contrastingly, other longitudinal studies have not found associations between the maturity of sleep and cognitive functioning (Bernier et al., 2010; Spruyt et al., 2008). In addition, cross-sectional studies have also had inconsistent findings. For example, a questionnaire-based study did not observe associations between different aspects of sleep and overall cognitive functioning in three- to 13-month-old infants (Mindell & Lee, 2015). In contrast, Gibson et al. (2012) found that 12-month-old infants with greater night-centered sleep measured with actigraphy showed better parent-rated cognitive functioning. Another cross-sectional actigraphy-based study found that infants with more frequent night awakenings and higher motor activity during sleep had lower cognitive functioning. In contrast, infants with higher sleep efficiency showed better cognitive functioning at 10 months old (Scher, 2005). However, the longitudinal study by Bernier et al. (2010) did not find associations between parent-rated night awakening and cognitive functioning during the first two years. Besides cognitive functioning, longitudinal studies focusing on language or motor functioning are more limited in number. According to the few studies that exist, more matured sleep has been associated with better language functioning later in childhood (Dearing et al., 2001; Dionne et al., 2011). For motor development, the results of previous studies have been mixed. According to a longitudinal study there were no associations between the maturity of sleep and motor development (Spruyt et al., 2008) whereas Gibson et al. (2012) found that 12-month-old infants with greater night-centered sleep measured with actigraphy showed better parent-rated motor development. Therefore, based on previous studies on infancy, it is not entirely clear whether different sleep parameters and psychomotor development are associated and whether night awakening, particularly, is connected to psychomotor development. Additionally, prior studies have differed in their methodology to measure sleep and children's development, which could partly explain the contradictory findings.

1.2.2 Executive functioning

It has long been suggested that the network of cortical and subcortical structures (e.g., prefrontal and limbic regions, the thalamo-basal ganglia circuit, and cerebellum), which are essential for the development of higher-order cognitive functioning, could be predominantly susceptible to the effects of sleep (Dahl, 1996b; Thomas et al., 2003; Wu et al., 1991). Studies with adults have supported this notion by showing that sleep disruptions or lack of sleep interfere with higher-order cognitive functioning (Lim & Dinges, 2010). Recent research on children has also proposed that besides overall psychomotor development, executive functioning (EF) could be particularly vulnerable to the effects of sleep. Specifically, due to its long course of maturation from infancy to early adulthood and strong associations with the development of the frontal lobes (Bernier et al., 2013). EF refers to higher-order and complex cognitive processes comprising interrelated functions of impulse control, set-shifting, and working memory (Lehto et al., 2003; Miyake et al., 2000). In addition, EF is regarded as a part of a broader concept of self-regulation, which refers to the flexible control of cognition, emotion, and behavior (Bridgett et al., 2015; Nigg, 2017).

The development of EF begins in infancy, and the first six years are thought to be especially important for the development even though development continues into early adulthood (Garon et al., 2008; Zelano et al., 1997). During the first year, the development of EF relies on parents' external regulation and inhibition of their infant's behavior, and after that, the infant's internal regulation is gradually growing. The different functions of EF are thought to develop sequentially depending on each other. For example, working memory and inhibition abilities are thought to develop first, whereas set-shifting develops later since it requires and builds upon the other two components (Garon et al., 2008). However, in infancy and toddlerhood, these three core functions of EF are not yet easily distinguished, and EF can be seen as a more unitary construct (Espy et al., 2011; Shing et al., 2010; Wiebe et al., 2008). EF abilities have shown modest stability in infancy, with the size of connection depending on the EF component being measured (Bernier et al., 2010; Wolfe et al., 2014). During childhood, the stability of EF is found to increase (Best & Miller, 2010). EF abilities have been associated with later success in school (Borella et al., 2010; Duncan et al., 2007) and life quality (Brown & Landgraf, 2010; Davis et al., 2010).

In school-aged children, shorter nighttime sleep duration (Astill et al., 2012; Steenari et al., 2003) and sleep fragmentation (Sadeh et al., 2002) have been associated with lower EF functioning. Additionally, Sadeh et al. (2003) have shown that 30 minutes of extended nighttime sleep improved children's performance in a task measuring sustained attention and inhibition. Contrastingly, no improvement in performance was observed in a task with a lower cognitive load. In younger children, previous studies are more limited in number. Nonetheless, according to these studies, shorter nocturnal sleep duration is associated with lower attentional control in pre-school-aged children (Lam et al., 2011) and parent-reported EF abilities (Taveras et al., 2017). However, EF is less studied in younger children, and it is unclear whether the associations with different sleep duration and quality parameters are similar in younger children.

According to the limited number of longitudinal studies on infancy, the greater amount of night-centered sleep at 12 and 18 months was associated with better performance in an EF task that required impulse control at 26 months old (Bernier et al., 2010). In addition, sleep maturity at 18 months was also associated with better working memory performance at the same age. In addition, in their follow-up study, Bernier et al. (2013) showed that maturity of sleep at 12 months was still associated with better EF functioning when the children were four years of age. Therefore, according to these studies, more matured sleep favors later performance in EF-related tasks. However, we do not know whether the associations are the same for signaled night awakening and EF and whether the possible associations are already visible in children under one year of age. Sadeh et al. (2015) have shown that greater amount of night awakenings at 12 months old predicted lower performance in a computerized task measuring attention regulation in children three to four years of age. However, the study of Bernier et al. (2010) did not find associations between night awakenings at 12 months old and EF performance at 24 months old. These two longitudinal studies varied in their methodology to measure sleep and EF and are not entirely comparable, which could partly explain the contradictory findings. Moreover, the studies measured different domains of EF. For example, Bernier et al. (2010) assessed working memory, inhibitory control, and set-shifting with behavioral measures, whereas Sadeh et al. (2015) examined attention regulation with a computerized method. In addition, Sadeh et al. (2015) measured night awakenings with actigraphs, whereas Bernier et al. (2010) measured night awakening with mother-filled sleep diaries. Furthermore, EF was measured at two different developmental periods. In the past few years, new methods have emerged that enable the study of EF already in the second half of the first year (Best & Miller, 2010; Kovacs & Mehler, 2009), but the methods have not been utilized in the field of sleep research.

1.2.3 Social information processing and socio-emotional behavior

In addition to psychomotor development and EF, markable development is also evident in socio-emotional development during the first year of life. The areas participating in socio-emotional processing (e.g., medial prefrontal cortex, superior temporal sulcus, temporoparietal junction, temporal poles, amygdala, and insula (Kennedy & Adolphs, 2012) contains the same areas that are thought to be susceptible to sleep disruptions (Dahl, 1996b). Socio-emotional development refers to the ability to interact and communicate with others within the social context. Social development can be seen as a temporal sequence where early social skills are required to acquire additional social skills (Happé & Frith, 2014). Visual abilities and biological movement discrimination are crucial in developing social skills as infants learn by observing others and mimicking their behavior (Soto-Icaza et al., 2015). Successful interaction and communication also require emotional regulation, and overall socio-emotional development can be seen as skillful coordination of different cognitive abilities (Happé & Frith, 2014). Socio-emotional development can be examined, for instance, through the expression of observable socio-emotional behavior, which refers to the children's ability to interact with others by the socio-emotional skills they possess or through cognitive mechanism underlying the processing of social information (Soto-Icaza et al., 2015; Kennedy & Adolphs, 2012).

The expression of socio-emotional behavior and its associations with challenges in sleep have been studied in a wealth of longitudinal and cross-sectional research in different aged children. In adolescents, prior sleep difficulties have been associated with greater behavioral and emotional problems (Gregory & O'Connor, 2002; Touchette et al., 2012). In school-aged children, children with shorter sleep duration have exhibited greater internalizing symptoms (e.g., anxiety, depression, and withdrawal) and externalizing symptoms (e.g., aggression, impulsivity, and rule-breaking behavior) (Astill et al., 2012). Additionally, toddlers with shorter sleep duration have shown to manifest increased emotional and behavioral problems at five years old (Sivertsen et al., 2015). Furthermore, toddlers with sleep difficulties at 24 months old exhibited greater internalizing behavior at 36 months old (Troxel et al., 2013).

Even though the research has been accumulating lately, the associations between signaled night awakening and socio-emotional behavior are less clear, especially in infancy and early childhood. A few studies have shown that in 24-month-old children, parent-reported night awakening was associated with greater socio-emotional problems also reported by parents (Hysing et al., 2016). Additionally, a recent cohort study showed that children with frequent parent-reported night awakenings at three, eight, 18, and 24 months of age had more internalizing and dysregulation symptoms (e.g., difficulties in eating, sleeping, and emotional regulation) at 24 months old (Morales-Muñoz et al., 2020). Contrastingly, greater number of night awakenings only at the age of three and 24 months old were associated with more externalizing problems at 24 months old (Morales-Muñoz et al., 2020). Similar associations between greater number of night awakenings and more socio-emotional problems have also been found in other studies conducted in early childhood during the first five years of age (Jansen et al., 2011; Sivertsen et al., 2015; Zaidman-Zait & Hall, 2015). However, some studies have also failed to find these associations between parent-reported night awakening and socio-emotional development in infancy (Mindell et al., 2017). Moreover, most of these studies on socio-emotional behavior have focused on problems such as internalizing and externalizing behavior. Contrastingly, the positive aspects of socio-emotional development, such as social competence, have not been investigated.

Social competence refers to the ability to engage in peer or adult social interaction (Fabes et al., 2006), and it consists of skills such as perspective taking, social problem solving, and emotional regulation, which are considered necessary for the effective social interaction (Junge et al., 2020). Earlier time to go to bed, sleeping more than 10 hours a night, and having a total sleep duration of more than 12 hours in a day has been associated with better social competence at the concurrent age of 18 months (Tomisaki et al., 2018). In another study, children with longer sleep duration had better peer acceptance, social skills, and social engagement in children three to five years old (Vaughn et al., 2015). However, in Mindell et al. (2015) study, total sleep duration, bedtime, or sleep onset latency were not associated with social competence concurrently at 12 months old. Importantly, Mindell et al. (2015) found that the frequency of night awakening and the longest stretch of sleep were associated with social competence. In addition to Mindell et al. (2015), there are hardly any studies focusing on night awakening and social competence, even though early childhood is a crucial period for development of social competence (Fabes et al., 2006).

Whereas the expression of socio-emotional behavior and their association with different sleep characteristics have received much attention in previous studies, the cognitive mechanism underlying the processing of social information and their associations with sleep have been studied in only a limited number of studies. Social cognition refers to the cognitive processes involved in perceiving, processing, interpreting, and storing information from other people and social situations in general (Soto-Icaza et al., 2015; Kennedy & Adolphs, 2012). These conscious and unconscious processes underlie socio-emotional behavior (Kennedy & Adolphs, 2012) The cognitive processes allow us to process social information, understand, and interpret other people's emotions, intentions, and behaviors. It could be that the way we behave in social situations is influenced by the individual differences in social information processing through, for instance, attentional or interpretative biases in processing emotional cues. One component of social cognition is the ability to recognize facial identity and emotions (Herba & Phillips, 2004). Already newborns show a preference for faces and sensitivity to eye contact (Farroni et al., 2006) and infant-directed speech (Cooper & Aslin, 1990). Detection and coordination of eye contact is the basis for joint engagement, and this ability for joint engagement emerges in infancy during the first year (Striano & Reid, 2006; Tomasello et al., 2005). Moreover, sensitivity to emotional expressions increases (Leppanen & Nelson, 2009). During the first year, infants can use emotional cues to guide their behavior (Baldwin & Moses, 1996; Campos et al., 2000; Mumme et al., 1996). In preverbal children, the gaze can be used as a useful experimental tool in assessing the ability to predict the behavior of others (Soto-Icaza et al., 2015).

Accurate discrimination of facial expressions is a crucial component of social cognition and has shown to be associated with social adjustment (Phillips et al., 2003). According to experimental social information processing studies conducted in adults, lack of sleep interferes with the processing of visual and emotional information (Alfarra et al., 2015; Tempesta et al., 2010), and the ability to recognize facial expressions is impeded (van der Helm et al., 2010). Additionally, greater number of night awakenings and reduced sleep quality in adolescence are associated with poorer recognition of facial emotions (Soffer-Dudek et al., 2011). In children, there is a lack of understanding of how sleep and social information processing are related. One study showed that nap-deprived four-year-old children exhibited greater attentional bias toward emotional stimuli, whereas a similar attentional bias was not evident in children without nap deprivation (Cremone et al., 2017). In 12-month-old children, fewer night awakenings after sleep onset and lower sleep-wake pattern variability were related to differences in concurrent face and emotional information processing (Sun et al., 2018). Children with more night awakenings fixated less on the eye region than children with fewer night awakenings after sleep onset. In addition, when viewing emotionally negative faces, children with shorter sleep duration showed lower autonomic arousal than children with longer sleep duration. According to these few studies, certain sleep parameters and social information processing may be related in childhood. However, during infancy, the period of extensive development in social cognition, there are hardly any studies investigating the association between signaled night awakening and social information processing.

Thus, previous studies support the notion that different aspects of development and sleep are associated in childhood. Based on these prior studies, it is possible that higher-order cognitive functioning and socio-emotional development are particularly associated with different sleep parameters. However, these studies have primarily investigated school-aged children, and it is unknown whether the same associations are found in infancy or whether various aspects of sleep are susceptible. Additionally, as previously mentioned, signaled night awakening has only been investigated in limited studies, even though it concerns parents and is a unique feature of sleep in infancy. Therefore, it would be especially important to shift the focus to infancy to promote sleeping habits and the ongoing rapid developmental processes in neurobehavioral functioning (Dahl, 1996b).

2 AIMS OF THE STUDY

Building on our current understanding on the associations between different sleep characteristics and aspects of development, the studies reported in this dissertation were designed to investigate whether signaled night awakening, a unique characteristic of infancy and a typical worry for parents, is associated with the development of the child during the first two years of life. A comprehensive view of the development was chosen, and, in particular, it was focused on areas suggested to be associated with sleep. This dissertation comprises three quantitative studies examining the stability of signaled night awakening and whether children with and without signaled night awakenings differ in sleep quality and duration parameters, psychomotor development, EF, social information processing, and socio-emotional development. A longitudinal design (eight and 24 months old) and multidimensional methods in data gathering were utilized by combining questionnaire data and eye-tracking data with standard psychological methods. With these methods, it was possible to investigate the associations between signaled night awakening and children's development in children under one-year-old. Two groups of children were formed within the CHILD-SLEEP birth cohort (Paavonen et al., 2017). These two groups of infants were comprised according to the number of signaled night awakenings reported by parents when the infants were eight months old. Infants with three or more-signaled night awakenings formed the waking group, and infants with no more than one-signaled night awakening formed the non-waking group. The groups were comprised at the age of eight months because, at that age, sleep usually transitions to more night-centered sleep, and the role of nurturing behavior during the night is no longer emphasized.

2.1 Signaled night awakening, sleep quality, and duration

As described in the introduction, signaled night awakening is suggested to be a persistent problem in infancy (Hysing et al., 2016; Palmstierna et al., 2008; Tikotzky & Shaashua, 2012) and potentially a precursor for later appearing sleep difficulties as well (Goodlin-Jones et al., 2001). Study I aimed to replicate the previous findings concerning the persistence of signaled night awakening in early childhood. Additionally, we sought to clarify the differences in sleep quality and duration parameters between children with and without signaled night awakenings measured with parent reports at eight, 18, and 24 months old. Sleep quality included the proportion of night-centered sleep, sleep onset latency, and time spent awake during the night. Sleep duration parameters included daytime, nighttime, and total duration of sleep. Group formation was based on parent reports of signaled night awakening at eight months old. In additional analyses, the validity of group formation was assessed with parent-reported questionnaires in Study I and with actigraphy-based sleep data in Study II. Consistent with previous studies (Gregory & O'Connor, 2002; Hysing et al., 2014; Palmstierna et al., 2008; Tikotzky & Shaashua, 2012), it was expected that signaled night awakening would manifest as a persistent problem. Thus, continuing to distinguish the two groups of children in both follow-up ages at 18 and 24 months old. Additionally, it was hypothesized that children with signaled night awakenings would differ both in sleep quality and duration parameters, paralleling prior studies (Acebo et al., 2005; Sadeh et al., 1991, 2007; Touchette et al., 2005) at eight, 18, and 24 months of age as compared to children without signaled night awakenings.

2.2 Psychomotor development

Study I investigated the associations between signaled night awakening and psychomotor development in infancy by studying whether children with and without signaled night awakenings differ in psychomotor development (cognitive, language, and motor functioning). This was conducted at eight and 24 months old and measured with a comprehensive assessment battery, the Bayley Scales of Infant and Toddler Development (third edition, Bayley, 2009). At eight months old, it was expected that there would not be differences in cognitive, language, or motor functioning between children with and without signaled night awakenings. However, at 24 months old, it was hypothesized that longitudinally children with signaled night awakenings would exhibit lower psychomotor development than children without signaled night awakenings, paralleling previous studies conducted in early childhood (Dearing et al., 2001; Dionne et al., 2011, Gibson et al., 2012; Scher, 2005).

2.3 Executive functioning

Specifically, Study II focused on EF performance, investigating associations between sleep and higher-order cognitive functioning, known to be sensitive to the effects of sleep in childhood and adults (Lim & Dinges, 2010). This was performed by examining whether children with and without signaled night awakenings differ in EF performance at eight or 24 months old. More specifically, the aim was to study whether the possible differences in EF performance are already observable within the first year of life. The goal was to measure EF longitudinally with versatile methods, and therefore, EF was studied at eight and 24 months of age with an eye-movement-based method called the Switch task (Kovács & Mehler, 2009). Additionally, at 24 months of age, parental evaluation and three different behavioral measures of EF were also used. The three behavioral measures of EF were chosen on the basis that different domains of EF could be investigated in a playful, age-appropriate manner (Carlson, 2005).

The Switch task is a method that allows to study EF already in children under one-year-old (Kovács & Mehler, 2009). Thus, we were able to measure EF longitudinally with the Switch task since the same task could be presented to eight- and 24-month-old children. In the first phase of the Switch task, children are required to learn a predictable stimulus sequence and, in the second phase, to inhibit their previously learned response to learning a new conflicting response. Hence, it appears that Switch task requires all three domains of EF (inhibitory control, working memory, and set-shifting) even though in infancy and toddlerhood, those three core domains of EF are not easily distinguished. Further, EF may be manifested as a more unitary construct than later in life (Espy et al., 2011; Shing et al., 2010; Wiebe et al., 2008). Previous studies with the Switch task have shown that when compared to monolingual infants, bilingual infants are better at inhibiting their responses and learning a new conflicting response (Kovács & Mehler, 2009). Additionally, the Switch task has been used as an indicator of EF in a study where attentional control training was measured on 11-month-old infants (Wass et al., 2011). The Switch task is also suitable for different cultures and socioeconomically challenging settings in infants under one-year-old (Forssman et al., 2017).

For Study II, regarding the eight-month-data, an exploratory approach was adopted without any definite hypothesis as signaled night awakening and EF have not been studied previously in children under one-year-old. However, at 24 months old, it was anticipated that children with signaled night awakenings would exhibit lower performance in various EF tasks and parent-rated EF compared to children without signaled night awakenings based on studies conducted with older children (Sadeh et al., 2002, 2015).

2.4 Social information processing and socio-emotional behavior

To further broaden the view of development to aspects sensitive to sleep in older children and adults (Alfarra et al., 2015; Tempesta et al., 2010; van der Helm et al., 2010), Study III focused on social information processing and socio-emotional behavior. First, it was examined whether children with and without signaled night awakenings differ in social information processing and, more precisely, in attention to emotional and neutral faces longitudinally measured with the Overlap task (Peltola et al., 2008, 2018) at eight and 24 months old. Moreover, it was investigated whether children with and without signaled night awakenings differ in parental evaluations of socio-emotional behavior at 24 months old. Socio-emotional behavior included internalizing, externalizing, dysregulation, and social competence domains. Finally, it was determined whether attention to emotional and neutral faces at eight and 24 months old would be associated with the parent evaluations of socio-emotional behavior at 24 months old.

The Overlap task is widely used in studying face perception and facial emotions in early childhood (Forssman et al., 2014, 2017; Peltola et al., 2008). According to these previous studies, the disengagement of attention is slower from faces compared to non-faces. Further, the disengagement of attention from fearful faces is slower than disengagement from happy, angry, or neutral faces (Leppänen et al., 2018; Peltola et al., 2008; Yrttiaho et al., 2014). This attentional bias, that is slower disengagement of attention, is typically observed in infants from five to seven months old (Leppänen et al., 2018; Peltola et al., 2008, 2009; Yrttiaho et al., 2014), or even earlier as established by Heck et al. (2016). However, a limited number of longitudinal studies have suggested that the attentional bias toward fear seems to attenuate after the first year of life (Leppänen et al., 2018; Peltola et al., 2018). More importantly, generally, the interindividual variation in attention to faces and fearful faces, have been suggested to be associated with different aspects of children's social development, with greater attention to faces being related to more prosocial behavior (Peltola et al., 2018). Further, a relatively larger bias for fear relates to secure than insecure attachment (Peltola et al., 2015) and greater altruistic behavior (Rajhans et al., 2016).

The approach was exploratory in study III concerning attention to faces and signaled night awakening. No definite hypothesis was drawn as signaled night awakening and attention to faces have not been studied previously. The second aim was based on paralleling previous studies (Hysing et al., 2014; Jansen et al., 2011; Morales-Muñoz et al., 2020; Sivertsen et al., 2015; Zaidman-Zait et al., 2015). It was hypothesized that at 24 months old, children with signaled night awakenings would evince more parent-rated socio-emotional problems than children without signaled night awakenings. However, studies focusing on social competence and its relations with night awakening are limited in number. Therefore, no definite hypothesis was made on social competence and its association with signaled night awakening. Regarding the connections between attention to faces and parent-rated socio-emotional behavior, previous studies have shown that robust attentional biases to faces and negative emotions are normative during early childhood. Further, the strength of these biases seems to be related to positive developmental outcomes (Peltola et al., 2015; Rajhans et al., 2016). Furthermore, associations between attention to negative emotions and internalizing and anxiety problems in older children and adults are well known (Bar-Haim et al., 2007). Thus, for the third aim, it was hypothesized that greater attention to faces would be related to better social competence. Nonetheless, no definite hypothesis was made on the emotional valence of faces or whether attention to faces would be related to negative aspects of socio-emotional behavior.

3 METHODS

3.1 Participants and study design

Participants of the current dissertation are derived from the CHILD-SLEEP birth cohort (1,667 families), where various aspects of sleep are investigated in infancy and toddlerhood (Paavonen et al., 2017). Approximately on 32nd gestational week, the participating families were recruited through maternity clinics by their maternity nurse. All families participating in the cohort study received questionnaires before birth and when their child was three, eight, 18, and 24 months old. Additionally, three questionnaires were sent to families (child, mother, father). The study design of Sleep for Cognitive, Social, and Emotional Development (CHILD-SLEEP) was reviewed and approved by Pirkanmaa Hospital District Ethical Committee (ETL-code: R11032) and Tampere University Hospital Pediatric Unit.

For the present dissertation, children were randomly recruited at eight months old. The sample of studies included in this dissertation was recruited from a sub-study of the main cohort gathered between 4/2011 to 2/2013. The families were contacted by a research assistant with a phone interview and asked how often their child had typically woken up during the night (between midnight and six o'clock in the morning) and needed soothing during the past two weeks. All eligible children were invited to participate. The inclusion criteria for the current group of studies were that the infant woke up three or more times during the night or the infants woke up no more than one time during the night. Children with three or more signaled night awakenings formed the waking group (81 children), and children with no more than one-night awakening formed the non-waking group (70 children). The exclusion criteria for the current sub-sample were prematurity or native language other than Finnish. Moreover, children with two signaled night awakenings were excluded from the study to form two distinguishable groups in the tendency to wake up during the night. The current sample was recruited from the main cohort's prevention sub-study aimed at preventing sleep problems in early childhood. The sample was based on the randomization of healthcare centers in Tampere, Finland into prevention and control healthcare centers. Altogether, 207 children participated in the prevention group and 199 children in the control group. In the prevention group, families received procedures with preventive psychoeducation regarding infant sleep development and strategies to support sleep quality. The control group received standard information during the well-child visits.

The study protocol comprised clinical and laboratory assessments at eight and 24 months of age (Figure 1). At both ages, the clinical research visit was conducted first and after that, the children participated to a laboratory research visit. Further, during the clinical research visit, psychomotor development was evaluated. After that, the child participated in a medical examination. Additionally, the pediatrician interviewed parents on sleep- and health-related questions and, if necessary, provided basic sleep psychoeducation for the infant's sleeping habits. The laboratory research visit was conducted in a laboratory setting. At eight months old, the laboratory research visit consisted of tasks measuring EF and social information processing. Parent-child interaction and heart-rate variability were also measured during the laboratory research visit but results regarding those are out of scope for this dissertation. At 24 months of age, the same tasks measuring psychomotor development, EF, social information processing, parent-child interaction, and heart-rate variability were repeated. Moreover, at 24 months, three different age-appropriate behavioral EF tasks were conducted during the laboratory research visit. After the research visits, the children wore actigraphs for three consecutive days, and the parents were asked to complete a detailed sleep log. The actigraphs were received and returned by postal mail. In addition to clinical and laboratory assessments at eight and 24 months old, questionnaire data sent to the whole cohort were utilized at eight, 18, and 24 months old on sleep related questions and at 24 months old on socio-emotional behavior.

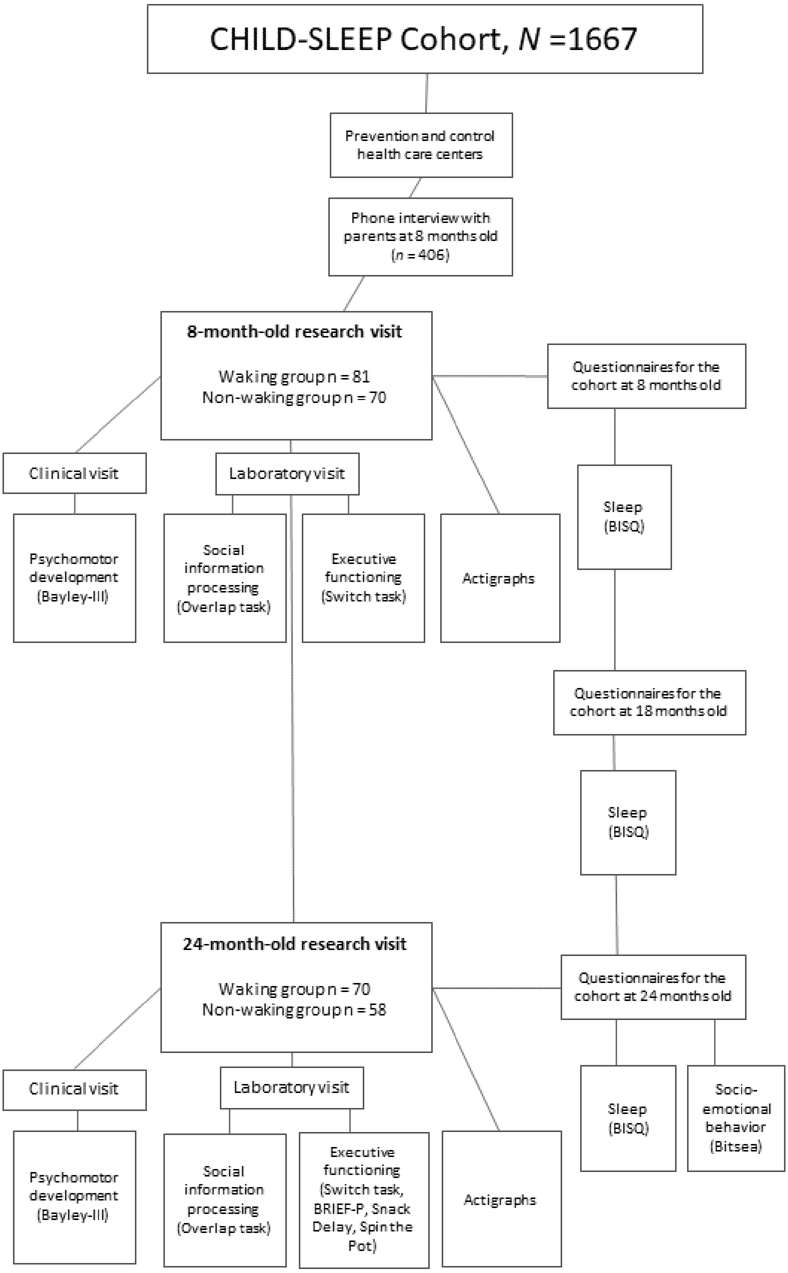

Figure 1. Flow chart of data collection and study protocol for the waking and non-waking groups.

Study I investigated signaled night awakening, sleep quality, duration, and psychomotor development, utilizing sleep-related questionnaire data at eight, 18, and 24 months old and psychomotor data from the clinical research visit at eight and 24 months old. EF and social information processing were measured in Study II and III, utilizing the data from the laboratory research visit at eight and 24 month old, thus posing slight variation to sample size. Additionally, Study III utilized questionnaire data on socio-emotional behavior gathered at 24 months old. The sample consisted of 151 Finnish children participating in the eight-month clinical assessment at 7.5–11.5 months old (psychomotor development). Of these children, 81 came from the waking group and 70 from the non-waking group. For the follow-up visit at 24 months old, 70 children from the waking group and 58 from the non-waking group returned for the assessment at 22.5–27.5 months old. An additional three participants were examined but excluded from further analyses due to a developmental disorder apparent at birth, prematurity, and native language other than Finnish. For the EF tasks and social information processing, 146 children participated in the second research visit at eight months old, 77 from the waking group and 69 from the non-waking group (Study II and Study III). At 24 months old, 65 children from the waking group and 56 from the non-waking group returned for the second research visit. At eight months old, the waking and non-waking groups differed in the amount of breastfeeding, co-sleeping, and the ability to fall asleep alone. Nonetheless, there were no differences in other child-, mother-, or father-related features (child gender, age, number of children in the family, maternal or paternal education, or income). The children in the waking group were more likely to be breastfed, co-sleeping with their parents, and less likely to be able to fall asleep alone than the children in the non-waking group. The healthcare center status did not differ between groups, thus confirming that children in the waking and non-waking groups came from the prevention and control healthcare centers. The analysis included breastfeeding, co-sleeping, and the ability to fall asleep alone as categorical covariates to control for the potential confounding effects. Additionally, the healthcare center status was included as a covariate in the analysis to control for its possible effects on the results. The demographic statistics of the sample are shown in Table 1. The exact number of participants providing data is presented in the measurement section under each measurement.

Table 1. Descriptive statistics for the waking and non-waking groups.

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	Waking group		**Non-waking group**		
	n	%	*n*	%	*p*
Gender					.889
girls	33	43.4	34	49.3	
boys	43	56.6	35	50.7	
Siblings					.354
yes	27	36.5	33	34.2	
no	47	63.5	34	50.7	
Mother's education					.210
> 15 years	36	47.4	31	45.2	
< 15 years	40	52.6	37	54.8	
Father's education					.671
> 15 years	55	70.5	45	70.3	
< 15 years	23	29.5	16	25.0	
Mother's monthly net income					.377
> 2000€	23	29.5	23	35.9	
1000 – 2000 €	39	50.0	24	37.5	
< 1000€	14	17.9	14	21.9	
Father's monthly net income					.492
> 2000€	49	62.8	42	65.6	
1000 – 2000 €	20	25.6	16	25.0	
< 1000€	8	10.3	3	4.7	
Health care center					.065
prevention	43	55.8	28	40.6	
control	34	44.2	41	59.4	
Co-sleeping					<. 001
> once in a week	29	44.6	4	7.4	
< 2 times a month	36	55.4	50	92.6	
Breastfeeding					.002
breastfed only	43	58.9	20	33.3	
breastfed and formula-fed	16	21.9	11	55.0	
formula-fed only	14	19.2	29	48.3	
Falling asleep alone					<. 001
once in a week	49	68.1	20	32.8	
once in a day	23	31.9	41	67.2	

3.2 Measurements

3.2.1 Signaled night awakening, sleep quality, and duration

Signaled night awakening, sleep quality, and duration were measured using the Brief Infant Sleep Questionnaire (BISQ; Sadeh, 2004), which was utilized as a part of the child questionnaires sent for the main cohort when the child was eight, 18, and 24 months old (Study I). Questionnaires at eight and 18 months were paper-pencil questionnaires sent via postal mail, and the questionnaire at 24 months old was web-based and sent to families through email. Parent-reported sleep quality included the time spent awake during the night and time to fall asleep. The proportion of night-centered sleep was calculated from the parent-reported nighttime and daytime sleep duration, and it was considered to represent the maturity of sleep. Parent-reported sleep duration included night, daytime, and total sleep duration. Different sleep quality and duration parameters and the number of participants providing data are presented in Table 2.

Actigraphy-based sleep measures were collected with Actiwatch AW7 activity monitors in Study II (Cambridge Neurotechnology Ltd, Cambridge, UK). The actigraphs were placed on the infant's ankle for three consecutive days, and the parents were instructed to keep a detailed sleep log. From the parent-rated sleep log, time to fall asleep and wake up time in the morning were used in the analysis. Activity counts were summed over one-minute-intervals (for a detailed description of the algorithm, see Oakley, 1997 and Kushida et al., 2001). Actigraphs and sleep logs were initiated at midnight; thus, the number of successive nights varied from two to four depending on the number of nights the parents had filled the sleep log. Over 80% of the participants in the waking (n = 68) and non-waking group (n = 61) participated in the actigraphy assessment at eight months old (Study II). At 24 months old, the retention rate was lower; only approximately 50% of the participants in the waking (n = 36) and non-waking groups (n = 28) participated. The actigraphy data is only reported and analyzed for the eight-month assessment point where most children participated. Parameters analyzed from the actigraphy data were actual sleep time, sleep latency, sleep efficiency, the proportion of nighttime sleep, and activity score during active periods. When considering signaled night awakening, actigraphy-based and parent-reported measures are not directly comparable. Thus far, the mean activity score during active periods at night was thought to most closely represent the phenomenon of signaled night awakening. The mean score during active periods is the total activity score divided by the number of epochs with greater than zero activity. Additionally, the actigraphy data considering night awakenings were also analyzed with a smoothing algorithm to reduce the number of actigraphy-based night awakenings, many of which may represent movements unrelated to signaled night awakenings (Sitnick et al., 2008). With this smoothing algorithm, the start of the awakening required two or more consecutive minutes with activity counts greater than 100. If an epoch preceded these epochs with activity count greater than zero, that epoch was considered to represent the start of the awakening. The awakening was thought to end at the first of three consecutive minutes with an activity count equal to zero. The mean value of night awakenings was calculated for two consecutive nights to ensure consistent data between participants.

3.2.2 Psychomotor development

Psychomotor development was measured at eight and 24 months old using the third version of Bayley Scales of Infant and Toddler Development (Bayley-III; Bayley, 2009). Bayley-III is a widely used and robust measure of children's development during infancy and toddlerhood (Study I). The five subscales measured cognitive, receptive, and expressive language and fine and gross motor functioning. All five different subscales were performed by a trained examiner unaware of the child's group status. During the assessment, the child sat on the parents' lap except for the gross motor scale conducted on the floor. Raw scores from these subscales were transformed into standardized scores with the original norms, and the standardized scores were used in the analyses. Additionally, combined indexes for cognitive, language and motor functioning were calculated, which showed similar results as the five different subscales. Only the results concerning the five subscales are provided for brevity and to diminish the number of statistical tests.

3.2.3 Executive functioning

Executive functioning was measured longitudinally at eight and 24 months old with the Switch task (Kovács & Mehler, 2009), which assesses the ability to learn new stimulus sequences and to inhibit a previously learned response to learning a new conflicting response (Study II). The presentation of the Switch task was performed in laboratory settings where the child sat in the parent's lap at approximately a 60-cm distance from the computer screen. Parents were informed not to interact with their children during stimulus presentations unless necessary. The child observation and stimulus presentation control were executed with a hidden video camera placed at the top of the computer screen. Additionally, these videos were saved for offline analyses of eye movements. At 24 months old, a child's saccades were measured using an eye-tracking paradigm.

A trial in the Switch task started with a red fixation circle which expanded from 0.4° to 4.3° in a continuous fashion. After the fixation circle, together with an auditory beep sound, two rectangles (11.6° x 11.2°) with black borders appeared on the screen either to the left or right side (11.5° from the midpoint of the screen). After 1,855ms–1,900ms, a monkey performing somersaults (4.6°–93.8°) appeared on either of the rectangles with a bell sound for 4,000ms. For the first nine trials, the monkey always emerged on the same side (pre-switch block), after which the monkey emerged on the other side for the remaining nine trials (post-switch block). An example of a trial is shown in Figure 2. At 24 months old, the number of trials was reduced to include six trials for both blocks, and the stimuli were presented from a 21-inch screen. Additionally, before starting the experiment at 24 months old, the eye-tracker camera was calibrated with a five-point calibration procedure where a cat and beep sound appeared for each corner and at the center of the screen. In case of insufficient calibration data that is one or more calibrations were missing or not properly calibrated, the calibration was repeated no more than two times. The last attempt was accepted if the calibration was still missing in one or more locations, and the task presentation was initiated. Since the analysis of gaze disengagement and shift between two objects were not reliant on precise spatial tracking accuracy, the children were not excluded from the analysis based on a lack of calibration points. Further, the analysis of gaze disengagement has been found to be robust against variations in calibration quality (Leppänen et al., 2015). The order of the target location was balanced across participants. The proportion of anticipatory looks toward the correct stimulus location was coded offline by a trained observer who was unaware of the child's group status and calculated separately for the pre-switch and post-switch blocks. Eye movements were considered anticipatory if the first saccade was to the correct stimulus location within a time window of 160ms before the monkey appeared and 160ms after the monkey appeared. A trial was rejected if the child did not focus attention on the screen at the beginning. Excessive movement during a trial also resulted in rejection due to undetectable saccades. Children with more than three rejected trials within the pre-switch or post-switch blocks were excluded from further analyses. At 24 months old, eye-tracking data were analyzed with a library of MATLAB routines for offline analysis of raw gaze data (Leppänen et al., 2015). The correlations of children's saccadic responses with eye-tracking and manually coded from videos are very high (>97%) (Leppänen et al., 2015). The areas of interest were manually defined. These areas covered the central area of the screen, the rectangle where the monkey would appear, and the area between the center and the rectangle. Eye movements were coded as anticipatory if the first saccade was to the correct location (a rectangle where the monkey would appear). The proportion of anticipatory looks toward the correct stimulus location was calculated separately for the pre-switch and post-switch blocks as in the eight-month data analyses. At eight months old, the average numbers of scorable trials in the pre-switch and post-switch blocks were 8.6 and 8.5, and at 24 months old, the average numbers of scorable trials in the pre-switch and post-switch blocks were 4.3 and 3.9, respectively. There were no differences between the pre-switch and post-switch blocks at both ages. The coding reliability at eight months was ensured with two independent observers coding 25% of all cases (n = 37). Agreement between the main coder and the reliability coder (intraclass correlation) on the proportion of anticipatory looks in both the pre-switch and post-switch blocks was .97. At eight months old, 62 children in the waking group and 48 children in the non-waking group provided data and were included in the analysis. At 24 months old, 65 children in the waking group and 54 children in the non-waking group provided successful data and were included in the analysis.

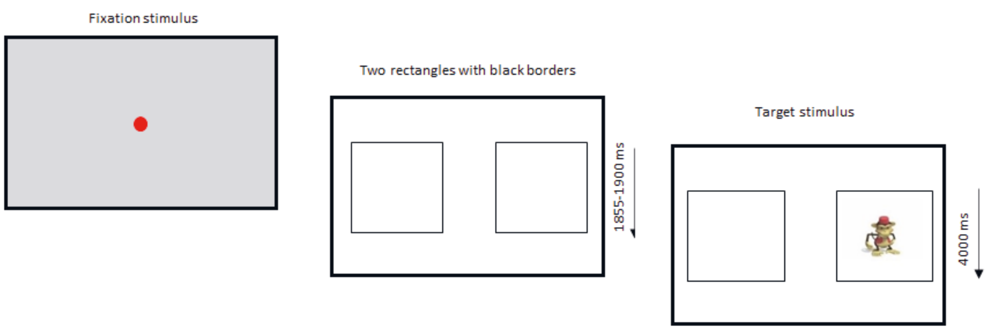

Figure 2. Example of a trial presented in the Switch task.

[Adapted from Study II republished with the permission of John Wiley and Sons. From Mäkelä et al., 2019. Night Awakening and Its Association With Executive Functioning Across the First Two Years of Life. Child Development, 91(4), e937–e951.]

Parent-rated EF was assessed with the Behavior Rating Inventory of Executive Function –Preschool Version (BRIEF-P) questionnaire in Study II, which consists of 63 items where parents answer on a three-point scale (never/sometimes/often) (Gioia et al., 2003). The questionnaire can assess EF in children from two to five years and 11 months old (Gioia et al., 2003). The questionnaire yields five different scales (inhibit, shift, emotional control, working memory, and plan/organize) from which three different indexes are combined. The Inhibition Self-control Index ISCI represents an ability to modulate actions, emotions, responses, and behavior through appropriate inhibitory control. Flexibility Index FI reflects an ability to flexibly move among actions, emotions, responses, and behavior. The Emergent Metacognition Index EMC represents an ability to sustain ideas and activities in working memory and to plan and organize problem-solving approaches. Additionally, a Global Executive Composite Index can be calculated by combining the scores of all five scales. The original norms were used to convert the raw scores to gender-specific standardized t-scores, with higher scores indicating a lower EF ability. The questionnaire was given to parents at the end of the first research visit at 24 months and asked to return during the second research visit. For the BRIEF-P questionnaire, 49 participants from the waking group and 38 from the non-waking group provided data at 24 months old.

In addition to a computer-based task and parent-rating of EF, three different behavioral tasks were used in Study II with the Spin the Pots task (Hughes & Ensor, 2005) representing a measure of working memory, Snack Delay task (Kochanska et al., 2000) representing a measure of inhibitory control, and Trucks task (Hughes & Ensor, 2005) as a measure of set-shifting. In the Spin the Pots task, six different treats were hidden under eight opaque, visually different-looking pots in front of the child, after which the child was asked to find the treats. After finding a treat, the child was allowed to eat the treats. After each attempt, the tray was covered and rotated 180°. The task was coded offline from video recordings, and the score was calculated as the number of maximum trials of 12 minus the errors the child made. The errors included perseverative looking or looking under the pots with no treats. The score for the task varied between zero to 12, with a higher score representing better performance. A total of 64 children from the waking group and 54 from the non-waking group provided successful data for the Spin the Pots task. In the Snack delay task, a small candy was placed on top of a candy box in front of the child. The child had to wait for a bell to ring and was allowed to have the candy after waiting. Three trials with increasing waiting times of 10, 20, or 30s were performed. The child was reminded of the waiting rule before each trial. On the 30s trial, the experimenter placed her hand on the bell when 20s had elapsed but rang the bell only after 30s. Video recordings were used to code children's behavior. The score for the Snack

Delay was calculated as the number of seconds the child waited before touching the candy or candy box. The score varied between zero to 60, with higher scores representing better performance. For the Snack Delay task, 64 children from the waking group and 53 from the non-waking group provided successful data. Due to the inconsistencies between experimenters in the presentation of the Trucks task, it was consequently excluded from data analysis.

3.2.4 Social information processing and socio-emotional behavior

Attention to emotional and neutral faces was measured at eight and 24 months old with the Overlap task (Peltola et al., 2008, 2018), where four different color images of a female model were used (Study III). The model depicted fearful, happy, neutral with eyes open, and neutral with eyes closed expressions. Additionally, two different black and white distractor stimuli were used (a black-and-white checkerboard and a circle pattern). Figure 3 represents an example of the Overlap task and the different facial expressions used. Emotional expressions and neutral stimuli with eyes open were chosen based on previous studies (Peltola et al., 2008, 2018). Based on these studies, it is known that the eyes draw attention. Therefore, a neutral face with eyes closed was also included to have two different neutral stimuli differing in the eye region.

The Overlap task was presented in the same laboratory setting as the Switch task. Further, the child sat in the parent's lap at an approximately 60-cm distance from the computer screen, and parents were informed not to interact with their child during the task unless necessary. A hidden video camera was placed on top of the computer screen to observe and control the stimulus presentation. After the same fixation stimulus as in the Switch task, a trial in the Overlap task started with the appearance of a facial stimulus (15.8° x 11.4°), which emerged at the center of the screen for 1000ms. Then, the facial stimulus was flanked by a lateral distractor stimulus (15.8° x 4.0°) which emerged either to the left or right side of the screen. The distractor and the facial stimulus appeared visible together for 3000ms. The distance between the face and the distractor stimulus was 13.6°. In total, 24 trials were used, with six trials for each of the four different face conditions. The stimulus presentation was randomized so that the same face stimulus could be presented no more than four times in a row, and the location of the lateral distractor stimulus was the same no more than three times in a row. At 24 months, the distractor stimulus was altered to have colors (blue–red and green–yellow), and these color schemes shifted rapidly, giving the impression that the distractor stimulus was animated. In addition, at 24 months, children's saccades were measured with eye-tracking, and the task was presented on a 21-inch screen. The same calibration procedure with the Switch task was used. The child's saccades during a trial at eight months old were coded to calculate dwell times for the four different face conditions following the methodology of previous studies (Peltola et al., 2008, 2013). Coding was done offline by a trained examiner unaware of the child's group status. The duration of attention dwell times to the four stimuli (happy, fearful, neutral with eyes open, and neutral with eyes closed) were determined for the period starting 160ms from the onset of the lateral distractor stimulus and ending 1000ms after distractor stimulus onset. Next, following previous studies (Leppänen et al., 2015), the duration was converted to a normalized dwell time index score. With the dwell time index formula, the shortest acceptable saccadic eye movement latency (160ms) results in a score of zero, and the longest possible latency (or a lack of saccade, which is equal to the last measured time point of the first stimulus at 1000ms) with a score of one. Dwell time indexes were calculated separately for the four different face stimuli. A trial was rejected if the child, at the beginning of a trial, did not focus on the screen. In addition, trials with anticipatory saccades (<160ms), excessive movements, or saccades not directed toward lateral distractor stimulus resulted in the rejection of the current trial. At 24 months old, eye-tracking data were analyzed with a library of MATLAB routines for offline analysis of raw gaze data which was also utilized in Switch task 24-month-old analyses (Leppänen et al., 2015). It included the timestamps corresponding to face and distractor stimuli onset time. Saccadic eye movements from the face stimulus to the distractor stimulus were implemented by automatic coding of the x and y coordinates of the eye-tracking data. Further, the following trials were eligible for analysis: trials with a sufficient length of fixation on the facial stimulus (>70% of the time) during the time preceding gaze disengagement or the 1000ms timeout, a sufficient number of valid samples in the gaze data (no gaps > 200ms), and valid information about eye movement from the face stimulus to the lateral distractor stimulus (the eye movement did not occur during a period of missing gaze data). After that, the dwell times were calculated the same way as in the eight-month analysis except for the difference in the threshold of anticipatory eye movements, which was set to 150ms in the 24-month data. At both ages, at least two successful trials for each face stimuli were required to be included in the analyses. At eight months old, the average number of scorable trials for each face stimuli were: happy: 5.4 (waking group) and 5.3 (non-waking group); fear: 5.5 (waking group) and 5.3 (non-waking group); neutral with eyes open: 5.4 (waking group) and 5.2 (non-waking group); and neutral with eyes closed: 5.4 (waking group) and 5.2 (non-waking group). The average number of scorable trials at 24 months of age were: happy: 4.5 (waking group) and 4.6 (non-waking group); fear: 4.8 (waking group) and 4.5 (non-waking group); neutral with eyes open: 4.5 (waking group) and 4.5 (non-waking group); and neutral with eyes closed: 4.4 (waking group) and 4.3 (non-waking group). In summary, at eight months old, 74 children in the waking group and 62 in the non-waking group provided data and were included in the analysis. At 24 months of age, 64 children in the waking group and 55 children in the non-waking group provided successful data and were included in the analysis.

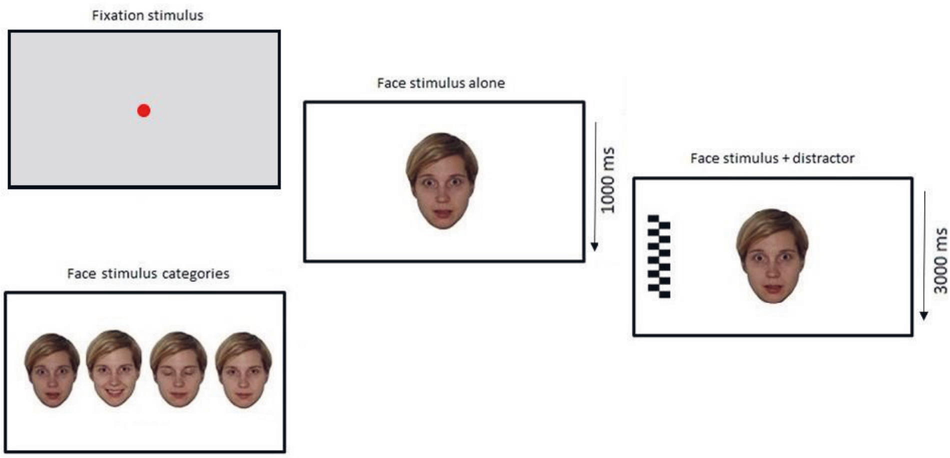

Figure 3. Example of a trial presented in the Overlap task and the different face stimulus categories used in Study III.

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Socio-emotional development was measured as part of the questionnaire packet for the cohort at 24 months old with the Brief Infant-Toddler Social and Emotional Assessment (BITSEA; Briggs-Gowan & Carter, 2006). The BITSEA consists of 42 statements, and parents answer with a three-point scale (not true/rarely, somewhat true/sometimes, and very true/always). Of these 42 items, 31 measure socio-emotional problems, and 11 measure social competence. From the questionnaire, externalizing, internalizing, dysregulation, and social competence domains were derived and used in the analyses with the original norms in Study III. Items in the externalizing domain measure areas such as overactivity, aggression, and defiance.

Covered areas for the internalizing domain are, for example, anxiety and depression. The dysregulation domain measures, for example, negative emotionality, eating, and sleeping difficulties. Finally, social competence domain items cover social-emotional abilities such as sustained attention, compliance, mastery motivation, prosocial peer relations, empathy, imitation/play skills, and social relatedness. For the BITSEA questionnaire, 53 participants from the waking group and 47 from the non-waking group provided data.

4 RESULTS

4.1 Signaled night awakening, sleep quality, and duration

The results of Study I confirmed that the waking group had more parent-reported signaled night awakenings than the non-waking group, even at the ages of 18 and 24 months. Figure 4 illustrates the number of signaled night awakenings measured with actigraphs at eight months and parent-reported questionnaires at eight, 18, and 24 months old. With age, the normative reduction of signaled night awakening from 18 to 24 months was evidenced in both groups. The covariates that differentiated between groups at eight months old (co-sleeping, breastfeeding, and the ability to fall asleep alone) did not significantly affect the number of signaled night awakenings at 18 or 24 months old when averaged over both groups. The inclusion criteria for the study consisted of a phone interview with parents asking the number of signaled night awakenings at eight months old. Additionally, questionnaires sent to the cohort were also utilized and the number of signaled night awakenings was analyzed at eight months old to validate this group formation. The questionnaire data was in line with the phone interview data indicating that the waking group had more signaled night awakenings than the non-waking group at eight months old. Actigraphy-based night awakening data analyzed with the smoothing algorithm further validated the group formation based on parent reports (Study II). The waking group showed more night awakenings than the non-waking group at eight months old. Additionally, parent-reported signaled night awakenings and night awakenings based on the smoothing algorithm correlated positively. As seen in Figure 4, the number of signaled night awakenings was not entirely constant between the phone interview, questionnaire, and actigraphy data. However, it should be noted that the definition of nighttime was not identical, and the number of night awakenings was not measured at the same time. The phone interview consisted of the strict definition of nighttime (24.00–06.00). Therefore, it was considered to represent the severity of signaled night awakening at that particular time more precisely than the data gathered with the questionnaire or actigraphs.

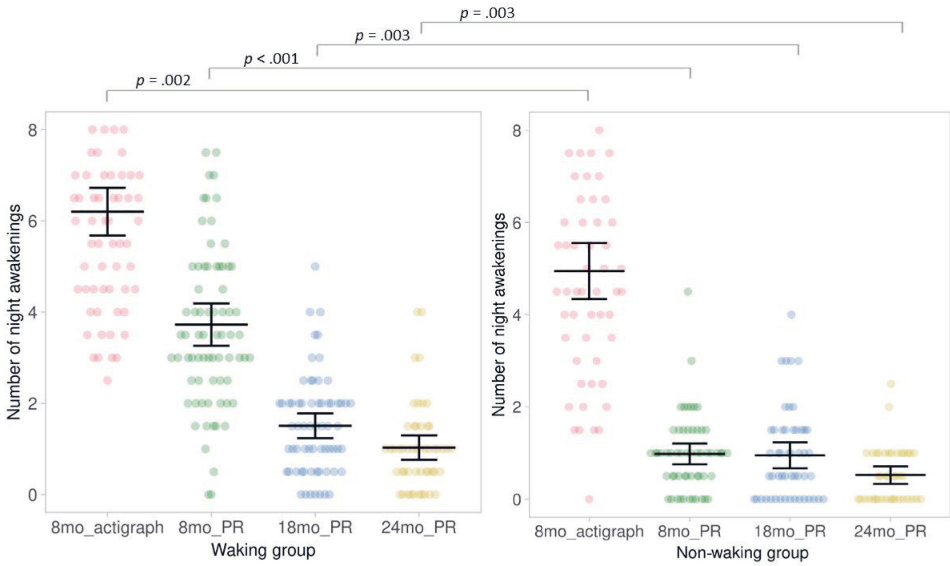

Figure 4. Group differences in the number of night awakenings measured with actigraphs at eight months old (smoothing algorithm) and parent-reported questionnaires at eight, 18, and 24 months old (and 95% CI) (The data were visualized by an R Shiny app by Postma and Goedhart, 2019). PR = parent-report.

Table 2 comprehensively describes the different sleep quality and duration parameters separately for the waking and non-waking groups. According to the longitudinal analysis of parent-reported sleep quality and duration parameters (Study I), the waking and non-waking groups differed in total sleep duration and time spent awake during the night in data averaged across eight, 18, and 24 months old. Across time, the children in the waking group slept less and spent more time awake during the night compared to the non-waking group. The normative reduction of daytime and total sleep duration from eight months to 18 and 24 months old was evident in data averaged over both groups. Actigraphy-based sleep data at eight months of age revealed that the waking group had higher mean activity scores than the non-waking group demonstrating that the waking group showed more significant activity during nighttime activity periods than the non-waking group (Study II). No other differences were observed in actual sleep time, sleep latency, sleep efficiency, or proportion of nighttime sleep between the two groups.

Table 2. Descriptive statistics in parent-reported and actigraphy-based sleep quality and duration parameters at eight and 24 months old separately for the waking and non-waking groups.

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	Waking group			Non-waking group		
	n	M	SD	n	M	SD
8 months old						
Parent-reported						
Duration of nighttime sleep [min]	75	589.9	58.4	60	597.8	55.7
Duration of daytime sleep [min]	76	188.4	53.6	60	204.8	63.1
Duration of total sleep [min]	75	778.8	70.9	60	802.6	60.5
Sleep latency [min]	74	24.8	16.9	57	18.2	15.5
Time spent awake at night [min]	69	30.6	25.7	48	15.8	20.6
Night awakenings [count]	73	3.8	1.9	54	0.9	0.6
Proportion of nighttime sleep [%]	75	75.9	5.8	60	74.7	6.6
Actigraphy-based						
Actual sleep time [min]	67	511.1	55	61	518.5	56.6
Sleep latency [min]	66	19.3	19.3	58	17.8	22.1
Sleep efficiency [%]	66	78.7	6.2	58	79.1	6.8
Proportion of nighttime sleep [%]	37	85.7	5.7	31	85.1	6.6
Activity score in active periods [count]	68	127	48.7	60	102.6	46.6
24 months old						
Duration of nighttime sleep [min]	53	589.4	46.4	41	605.5	37.9
Duration of daytime sleep [min]	53	105.4	38.8	41	114.6	46.1
Duration of total sleep [min]	53	694.8	45.3	41	720.6	55.5
Sleep latency [min]	48	23.9	18.1	38	17.9	12.5
Time spent awake at night [min]	46	11.8	12.3	38	4	9
Night awakenings [count]	50	1	0.9	40	0.6	0.6
Proportion of nighttime sleep [%]	53	84.9	5.1	41	84.3	5.1
Actigraphy-based						
Actual sleep time [min]	35	539.7	43	28	542.8	46.6
Sleep latency [min]	36	26.6	18.7	28	22.3	15
Sleep efficiency [%]	36	81.7	5.6	28	83.8	4.2
Proportion of nighttime sleep [%]	31	87.4	7.4	17	89.4	5.9
Activity score in active periods [count]	36	82.8	31.8	28	76.4	31

4.2 Psychomotor development

The waking and the non-waking groups did not differ in psychomotor development at eight or 24 months old (Study I). Thus, no differences were found in cognitive, receptive, or expressive language or fine or gross motor functioning. Table 3 presents the means, standard deviations, and range of the different Bayley-III subscales at eight and 24 months old separately for both the waking and non-waking group.

Table 3. Means, standard deviations, and range of Bayley- III standard scores for the waking and non-waking groups.

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	Waking group		**Non-waking group**	
	M (SD)	Range	M (SD)	Range
8 months old				
Cognitive	12.2 (1.8)	8 – 16	12.1 (1.7)	8 – 16
Receptive language	7.8 (1.5)	4 – 11	7.8 (1.5)	4 – 11
Expressive language	10.3 (1.7)	6 – 14	10.1 (1.9)	6 – 14
Fine motor	10.9 (2.1)	6 – 17	10.9 (2.4)	5 – 17
Gross motor	8.7 (2.4)	4 – 14	8.2 (2.8)	3 – 15
24 months old				
Cognitive	11.2 (2.3)	7 – 19	11.1 (2.3)	5 – 17
Receptive language	12.4 (2.5)	6 – 19	11.7 (2.5)	1 – 17
Expressive language	10.0 (2.8)	4 – 15	9.9 (2.7)	2 – 15
Fine motor	11.6 (2.1)	7 – 18	11.1 (1.8)	7 – 15
Gross motor	9.4 (2.3)	5 – 18	9.3 (1.6)	5 – 15

4.3 Executive functioning

The results of the Switch task in Study II indicated that overall, children had greater number of anticipatory looks in the pre-switch block than in the post-switch block. Additionally, the waking group had a lower percentage of correct anticipations in data averaged across eight and 24 months old than the non-waking group. However, the interactions were nonsignificant, indicating that the differences were not specific to either eight or 24 months old or pre-switch or post-switch block. To better respond to our research question concerning how early the possible differences could be detected, we nevertheless decided to conduct age-specific analyses even though the interactions concerning age were non-significant. The age-specific analyses were conducted to conclude whether the differences would be observable already at eight months or whether the differences would be more pronounced at 24 months old as suggested by the visual inspection of Figure 5. The age-specific analyses at eight and 24 months old replicated the finding of a higher proportion of correct anticipations in pre-switch than the post-switch block. Additionally, the age-specific analyses showed that the groups did not differ in their proportion of anticipatory looks at eight months old. Contrastingly, at 24 months old, the waking group had a lower percentage of anticipations than the non-waking group. Notably, the interactions with block were nonsignificant. Therefore, the differences between groups were not specific to either pre-switch or post-switch blocks. Sleep duration was controlled in the 24-month-old Switch task analysis, and it did not influence the observed differences.

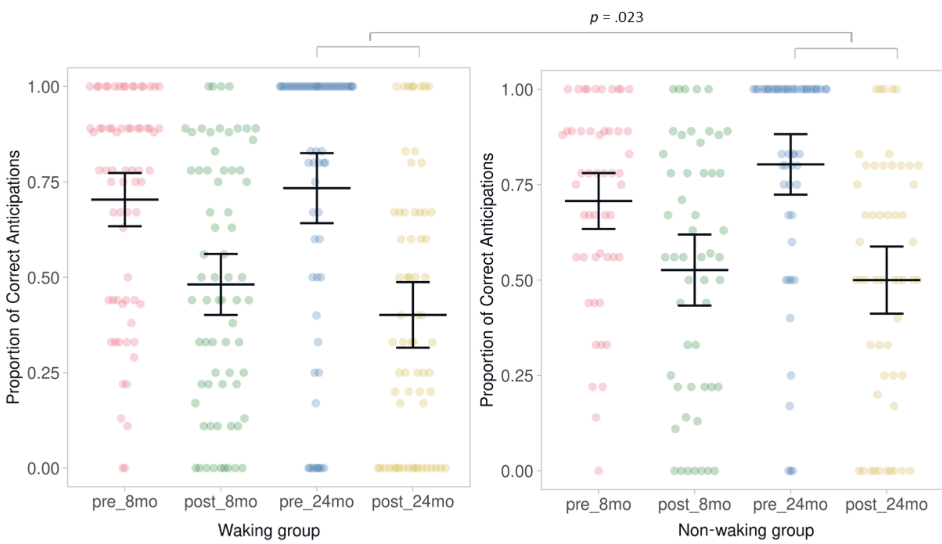

Figure 5. Switch task performance at eight and 24 months old (and 95% CI) separately for the waking and non-waking groups (The data were visualized by an R Shiny app by Postma and Goedhart, 2019). Pre_8mo = pre-switch block at eight months old, post_8mo = post-switch block at eight months old, pre_24mo = pre-switch block at 24 months old, post_24mo = post-switch block at 24 months old.

In the parental ratings of EF at 24 months, there were no clearly significant differences in any of the BRIEF-P indexes' t-scores between the waking and non-waking groups. Only a marginal difference in the Flexibility scale was found with the children in the waking group having higher scores than the children in the non-waking group. Contrastingly, no differences were found in the Inhibition Self-control Index, Emergent Metacognition Index, or Global Executive Composite Index (Study II). In addition to parental ratings, the waking and non-waking groups did not differ in behavioral measures of EF, that is, the Spin the Pots and Snack Delay tasks, at 24 months old.

4.4 Social information processing and socio-emotional behavior

Longitudinal analysis of the Overlap task replicated the robust finding of longer attentional dwell times averaged over both groups to fearful faces compared to happy, neutral with eyes open, or neutral with eyes closed (Study III). Moreover, dwell times were longer in the happy face condition than in neutral face conditions. Additionally, the interaction between group and face conditions revealed that the pattern of dwell times to the four different face conditions varied within the groups in data averaged across eight and 24 months old. The differences between groups were observed, particularly in attention to emotional faces (see Figure 6). In the waking group, dwell times to fearful faces were longer than the other face conditions of happy, neutral with eyes open, and neutral with eyes closed. In contrast, in the non-waking group, dwell times to fearful faces were longer than neutral face conditions, but dwell times between fearful and happy face conditions did not differ. Additionally, in the non-waking group, dwell times to happy faces were longer than dwell times to neutral with eyes open.

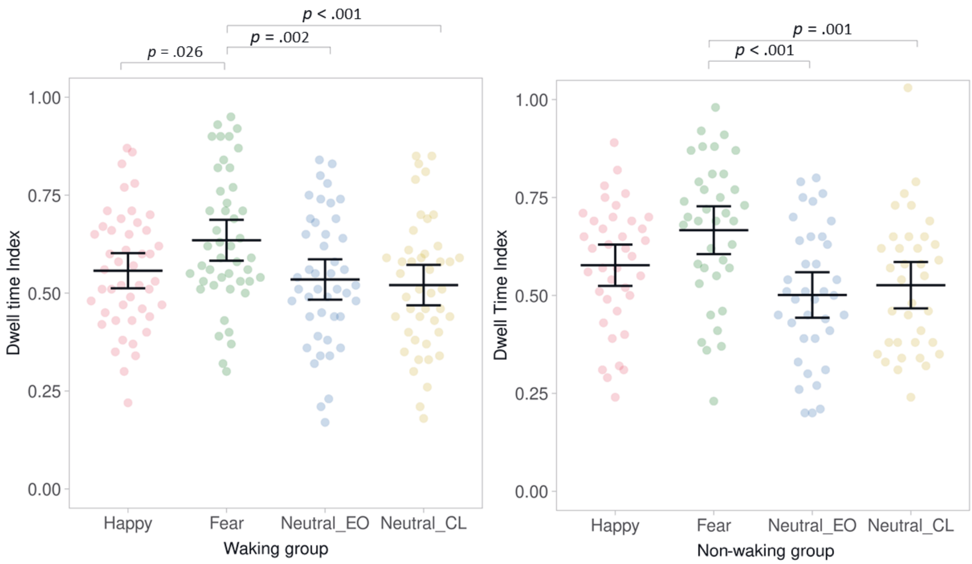

Figure 6. Individual dwell times and their means (and 95% CI) to different face conditions separately for the waking and non-waking groups (The data were visualized by an R Shiny app by Postma and Goedhart, 2019). Neutral_OE, neutral with open eyes; Neutral_CL, neutral with closed eyes.

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Parental ratings of socio-emotional behavior at 24 months of age indicated that the children in the waking group differed from the children in the non-waking group in their socio-emotional behavior (Study III). Table 4 presents means and standard deviations for the different BITSEA domains separately for the waking and non-waking groups. The waking group had higher scores in the dysregulation domain and lower scores in the social competence domain than the non-waking group. In the externalizing domain, the waking and non-waking groups did not differ. Likewise, the difference between the groups was non-significant in the internalizing domain, even though a marginal difference, with the waking group exhibiting slightly more problems than the non-waking group was found. The dysregulation subdomain includes two items concerning sleep ("Wakes up at night and needs help to fall asleep again" and "Has trouble falling asleep or staying asleep"). Since the waking and non-waking groups differed in the number of signaled night awakenings, the analysis for the dysregulation domain was performed again with the two items concerning sleep removed to ensure that the differences in the dysregulation domain were not produced by night awakening. The differences between the two groups remained, even though the differences between groups became smaller.

Table 4. Means and standard deviations of BITSEA questionnaire domains for the waking and non-waking groups.

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BITSEA domain	Waking group		Non-waking group		
	M	*SD*	*M*	*SD*	*p*
Dysregulation	4.23	2.74	2.47	2.14	0.002
Social competence	18.11	2.42	19.13	2.6	0.049
Externalizing	3.41	2.27	3	2.1	0.355
Internalizing	1.59	1.75	1.05	0.99	0.065
Dysregulation (no sleep)	2.42	1.81	1.79	1.53	0.049

The results of study III also revealed that attention to happy faces and parent-rated socio-emotional behavior correlated. At eight months old, dwell times in the happy face condition were associated positively with the social competence and externalizing domain measured at the age of 24 months old. Additionally, at 24 months old, dwell times in the happy face condition correlated negatively with the dysregulation scores (with the two sleep items removed).

Table 5. Correlations between attention dwell times to faces at eight and 24 months old and BITSEA domains at 24 months old.

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	Internalizing	Externalizing	Dysregulation (no sleep)	Social competence
8 months old				
Happy face	.203	**.260***	−.031	**.337****
Fearful face	.242	.157	−.096	.047
Neutral with eyes open	.150	.174	.019	.072
Neutral with closed eyes	.146	.155	.050	.228
24 months old				
Happy face	−.135	.204	**−.214***	.132
Fearful face	−.096	.042	−.096	.130
Neutral with eyes open	−.088	.131	−.092	.069
Neutral with closed eyes	−.070	−.037	−.087	.047

* Correlation is significant at the .05 level. * * Correlation is significant at the .01 level. The correlations are unadjusted for multiple comparisons.

5 DISCUSSION

The present series of studies investigated whether signaled night awakening, a common feature of sleep in infancy, is associated with the child's development during the first two years of life. Signaled night awakening and different aspects of development were investigated longitudinally in children with and without signaled night awakenings with versatile methods covering various aspects of cognitive, social, and emotional development in early childhood. These two groups of children were formed based on parent-reported signaled night awakening within the CHILD-SLEEP birth cohort at eight months old. The children in the waking group had three or more signaled night awakenings. Contrastingly, the children in the non-waking group had no more than one signaled night awakening requiring parental intervention. First, our results confirmed the persistence of signaled night awakening by showing that children in the waking group had more parent-reported signaled night awakenings even at 18 and 24 months old. Furthermore, across time children with signaled night awakenings had shorter parent-reported sleep duration and spent more time awake during the night than children without signaled night awakenings. Second, there were no differences in cognitive, language, or motor functioning at eight or 24 months of age between children with and without signaled night awakenings. Third, our results showed that children with signaled night awakenings performed worse on a computerized EF task than children without signaled night awakenings. Nonetheless, no differences between the two groups were observed in the parental ratings of EF or traditional behavioral EF measures at 24 months old. Fourth, the children with signaled night awakenings showed different patterns of attention to emotional faces and had greater parent-reported dysregulation problems and lower social competence than the children without signaled night awakenings at 24 months old. In the following, the present results are first observed and evaluated in light of the hypotheses stated. Finally, these findings are put into a larger context, and the implications of the present results on practical recommendations are discussed.

5.1 Signaled night awakening, sleep quality, and duration

The children with signaled night awakenings continued to have more parent-reported signaled night awakenings even at 18 and 24 months old compared to children without signaled night awakenings (Study I). This persistence of night awakening in early childhood was expected and seems to manifest as a consistent phenomenon between studies (Gregory & O'Connor, 2002; Hysing et al., 2014; Palmstierna et al., 2008; Tikotzky & Shaashua, 2012). However, both groups evidenced the normative trend of decreasing signaled night awakenings with age. Therefore, the differences in the number of signaled night awakenings between groups became smaller. In addition to the number of signaled night awakenings, the children with signaled night awakenings were more likely to be breastfed, co-sleeping with their parents, and less able to fall asleep alone than the children without signaled night awakenings at eight months old. Even though these factors were concurrently associated with the frequency of night awakening, they did not predict the number of night awakenings longitudinally at 18 or 24 months old, whereas longitudinal associations have been found in other studies (Hysing et al., 2014; Sadeh et al., 2009; Touchette et al., 2005).

In addition to the greater number of signaled night awakenings, as expected, the children with signaled night awakenings also differed in parent-reported sleep quality and duration from the children without signaled night awakenings. Across time, the children with signaled night awakenings slept less in total and spent more time awake during the night than children without signaled night awakenings. Previous studies have shown contradictory findings on whether children with night awakenings compensate for their nighttime sleep loss during daytime (Acebo et al. (2005) or whether the sleep duration is similar in both groups (Sadeh et al., 1991). Similar to Touchette et al.'s (2005) study, our results showed that the children with signaled night awakenings did not compensate for their sleep during the daytime. Notably, even though in this study there were differences in sleep duration between children with and without signaled night awakenings in data averaged across eight, 18, and 24 months old, both groups slept the preferred duration of more than 12 hours in a day at eight months old and more than 11 hours at two years old (Paruthi et al., 2016). Therefore, the children with signaled night awakenings cannot be considered as representing children of the so-called short sleepers. Furthermore, actigraphy-based sleep duration measures at eight months old did not reveal differences between children with and without signaled night awakenings in total, nighttime, or daytime sleep duration. Nevertheless, the children with signaled night awakenings exhibited more nighttime activity during activity periods than the children without signaled night awakenings but showed no differences in other sleep quality parameters. The analyses of parent-reported sleep duration and quality parameters were longitudinal. Contrastingly, the actigraphy data were analyzed only at eight months of age due to missing data and loss of power at 24 months old. Possibly, with adequate actigraphy data at 24 months old, the small differences in total sleep duration would have shown similar results in longitudinal analysis. In the future, it is essential to follow these same children through childhood and adolescence to determine whether the differences in sleep duration became more prominent with age. Additionally, persistent signaled night awakening could predispose children to the accumulation of other sleep problems (Goodlin-Jones et al., 2001; Troxel et al., 2013). Within the CHILD-SLEEP birth cohort, the children participating in the present studies are being followed, and sleep quality and duration will be investigated together with developmental outcomes.

In the present studies, the two groups were clearly distinguished in the number of signaled night awakenings. Moreover, the parent-reported group formation was verified with questionnaire and actigraphy data at eight months old. Based on all these measured, children with signaled night awakenings had more signaled night awakenings than the children without signaled night awakenings at eight months old. The consistency between parent-reported signaled night awakening and actigraphy-based data also supports the use of parents as informants of signaled night awakening. The actigraphy-based night awakening data at eight months was analyzed with a smoothing algorithm. In particular, this was performed for the number of actigraphy-based night awakenings to be more consistent with signaled night awakenings, as many actigraphy-based night awakenings may represent movements unrelated to signaled night awakenings (Sitnick et al., 2008). These unrelated movements during sleep may represent, for example, motor activity during REM sleep falsely recognized as night awakenings. Additionally, night awakenings without movements may be falsely labeled as sleep (Sitnick et al., 2008). We used the algorithm initially developed for preschoolers since no algorithm was designed for children as young as eight months old. With that algorithm, we could reduce the number of night awakenings to resemble signaled night awakenings more closely. However, with the algorithm, the number of night awakenings was still greater than the number of night awakenings gathered with questionnaire data. This was consistent with previous research showing that the main difference between parental ratings and actigraphy-based studies is that parent evaluations show fewer night awakenings compared to actigraphy-based measures (Sadeh, 2004). This finding seems rational since different measures of night awakening do not represent identical measures (Acebo et al., 2005; Sadeh, 2004). Even though parental questionnaires, parent-reported sleep diaries, and actigraphy-based measures have shown to be moderately or strongly associated (Sadeh, 2004), as also found in Study II. A significant difference, for example, is that the actigraphy-based sleep measures describe sleep on a limited number of nights. In contrast, parent reports are based on sleep across more extended periods. Another difference, as previously mentioned, concerns the signaling behavior such that actigraphs identify night awakenings based on movements and not on the signaling behavior per se, and therefore it may be possible that some awakenings identified by actigraphs are not signaled to parents or signaled night awakenings without movements may not be identified as awakenings by the actigraphs.

5.2 Psychomotor development

Concerning the results on psychomotor development in Study I, the two groups did not differ in cognitive, language, or motor functioning at eight or 24 months old. The results at eight months old were expected. At 24 months old, however, the two groups were hypothesized to differ in psychomotor development longitudinally based on previous studies showing associations with the maturity of sleep and better later cognitive (Dearing et al., 2001) and language functioning (Dionne et al., 2011). Even though contrary to our expectations, the results are in line with the study of Mindell & Lee (2015), showing that concurrently night awakening and developmental outcomes were unrelated within the first year of life and with a study by Bernier et al. (2010) showing that night awakenings at 12 months old were unrelated to later overall cognitive development during the first two years of life. Our study measured psychomotor development with a valid and robust measure of early development, including cognitive, language, and motor functioning in two groups. Previous studies have estimated the developmental level based on a parent-reported questionnaire (Mindell & Lee, 2015) or a less comprehensive measure of early psychomotor development (Dearing et al., 2001; Dionne et al., 2011). Our results align with previous, such as Bernier et al. (2010, 2013) and Mindell & Lee (2015), by showing that the child's overall cognitive development is not related concurrently or longitudinally to signaled night awakening. Additionally, our results add to previous studies by showing that signaled night awakening is unrelated to the child's language or fine or gross motor functioning, at least when the development is followed until the children are two years old. The current results, together with the previous studies, could be seen as suggesting that the maturity of sleep (Dearing et al., 2001; Dionne et al., 2011; Gibson et al., 2012; Sadeh et al., 1991) is perhaps associated with later psychomotor development, rather than signaled night awakening alone.

It has been suggested that fragmented sleep would result in restricted sleep duration (Acebo et al., 2005) and that disturbing length of nighttime sleep would have longitudinal effects on the development of the child. In these studies, children with shorter sleep duration showed lower cognitive performance than children with longer sleep duration (Paavonen et al., 2010; Short et al., 2018; Touchette et al., 2007). In recent studies, the optimal or recommended amount of sleep has been associated with better cognitive functioning compared to more prolonged and shorter sleep durations (Eide & Showalter, 2012; Kocevska et al., 2017). In our study, the children with signaled night awakenings did not differ in nighttime sleep duration from children without signaled night awakenings. Both groups slept the preferred amount of total sleep. However, signaled night awakening could be associated with psychomotor development when the children get older or with children who continue to have severe sleep fragmentation caused by signaled night awakenings. Even though, in our study, psychomotor development was measured with a valid and robust measure, previous studies have shown that within the first two years of life, the ability of Bayley-III to predict later development or IQ is only moderate (Anderson & Burnett, 2017; Burakevych et al., 2016; Flynn et al., 2020; Spittle et al., 2012). Longitudinal studies from early childhood to adolescence are needed to determine the long-term associations of signaled night awakening and psychomotor development, considering the low predictive value in psychomotor development during early childhood.

5.3 Executive functioning

The findings of Study II revealed that the children with signaled night awakenings had lower performance in a computerized EF task across time. The age-specific analyses revealed that the differences in the Switch task between groups were not yet evident at eight months old. As anticipated, at 24 months old, children with signaled night awakenings had lower performance than children without signaled night awakenings. The results align with previous research showing that fragmented sleep is related to diminished EF when measured with a sensitive computerized method in preschool- and school-aged children (Sadeh et al., 2002, 2015). The age-specific analyses were conducted despite the nonsignificant interaction to answer our central research question concerning signaled night awakening and Switch task performance in different aged children. It is acknowledged, however, that probing subgroup differences may not be advisable in a situation where the higher-order interaction is statistically nonsignificant (Nieuwenhuis et al., 2011); therefore, some cautions exist in the interpretation. The differences between groups at 24 months of age were not specific to either the learning or the task's inhibition part. Thus, it cannot be concluded that the differences between groups were more pronounced by the children with signaled night awakenings being less able to anticipate the correct stimulus location or being less able to inhibit the previous response and learn a new conflicting response when compared to children without signaled night awakenings. It was anticipated that the inhibition part of the task would more closely reflect the emerging EF abilities. One possibility, however, is that the result could reflect the maturing of EF in infancy and toddlerhood and that the different domains of EF are not yet easily separated at that age (Espy et al., 2011; Shing et al., 2010; Wiebe et al., 2008). It could also be due to insufficient statistical power to detect effects of age and block, especially in the three-way interaction analysis. In previous studies, shorter sleep duration has been associated with worse performance on EF tasks (Astill et al., 2012; Steenari et al., 2003; Taveras et al., 2017). In our study, sleep duration did not affect the found differences. Therefore, the shorter sleep duration across time in children with signaled night awakenings did not produce our result. Notably, these differences in the Switch task performance were not a mere reflection of differences in overall development. Study I showed that the children with and without signaled night awakenings did not differ in their overall psychomotor development.

Contrary to our expectations, the parental ratings of EF did not differ at 24 months old. Therefore, it does not lend strong support to the differences between groups observed with parent-reported questionnaires at two years old. Only a marginal difference in the Flexibility scale was found, suggesting that the children with signaled night awakenings are perhaps less able to move among actions emotions, and behavior flexibly, than children without signaled night awakenings. More substantial differences between groups were expected since previous studies with the BRIEF-P questionnaire have shown it to distinguish performance in preschoolers and to be related to laboratory assessments of EF (Ferrier et al., 2014; Garon et al., 2016). Possibly, the results might reflect parents' difficulty in distinguishing the relatively small differences in currently emerging EF skills in children as young as 24 months of age. It could also be the case that the lower response rate of the questionnaire compared to other EF measures used in the study could have resulted that the difference between groups was smaller than expected. The lower response rate was possibly influenced by the protocol used, which could have resulted in some families forgetting to return the questionnaire.

In the traditional EF tasks, Spin the Pot and Snack Delay, the children with and without signaled night awakenings did not differ in their EF performance at 24 months old. Even though this finding was contrary to our expectations, it is not surprising considering the differences between these traditional EF tasks and the Switch task. With the Switch task looking behavior is measured on a millisecond scale which perhaps makes it more sensitive than behavioral methods for assessing EF in infancy and toddlerhood and therefore being able to detect the subtle differences in the normal range of performance. In addition, our finding is consistent with Bernier et al. (2010), who did not find an association between night awakening and later EF when measured with traditional behavioral methods. Another possibility regarding the discrepant results of the behavioral tasks, parental ratings, and the Switch task is that the tasks measured different aspects of EF. However, this is unlikely since the selected tasks were chosen to cover the various domains of EF. Additionally, in early childhood, the development of EF is rapid, and the different subdomains are found to be highly inter-related and parallel, making it even more challenging to distinguish the various aspects of EF (Espy et al., 2011; Shing et al., 2010; Wiebe et al., 2008). Moreover, tasks that tap only into one aspect of EF are difficult or almost impossible to design in infancy (Diamond, 2013). Unfortunately, a task planned to measure set shifting was restricted from analyses due to the inconsistencies in task presentation between experimenters (Trucks task). However, the mentioned sensitivity problems also concern the behavioral set-shifting task, and probably the same patterns of results would have been found.

Our results on EF development propose that children with signaled night awakenings have some challenges in their EF development compared to children without signaled night awakenings. It could be that children with signaled night awakenings are on a different developmental trajectory and during the first two years the small differences on EF functioning are perceived with sensitive methods. However, the differences in EF functioning seem more evident at 24 months of age and not yet visible at eight months old. At eight months old, EF skills are still poorly developed, thus making it difficult to distinguish the subtle differences between groups (Espy et al., 2011; Shing et al., 2010). It could also be the case that, consistent with prior studies, the associations with signaled night awakening would be evident longitudinally and, therefore, more clearly perceived at 24 months old (Bernier et al., 2010, 2013; Dearing et al., 2001; Dionne et al., 2011; Gertner et al., 2002; Sadeh et al., 2015). Moreover, Touchette et al. (2007) showed that shorter sleep duration before the age of three years was associated with a risk of lower higher-order cognitive functioning at six years old in a group where sleep duration had normalized at approximately three years old. Our results add to previous knowledge by showing that longitudinal associations are also observed between signaled night awakening and higher-order cognitive functioning. Interestingly the differences between groups were already visible at 24 months old, even in a normative sample where the differences in signaled night awakening became smaller with age. Our results suggest that sleep is especially important to higher-order cognitive functioning in infancy. With further follow-up, it remains to be determined whether the children with signaled night awakenings at eight months continue with the different developmental trajectory into older ages and whether the small differences in EF functioning became greater and, therefore, observable with more traditional methods.

5.4 Social information processing and socio-emotional behavior

Regarding the links between signaled night awakening and social information processing in Study III, the children with signaled night awakenings had across time different attention dwell times to emotional faces compared to children without signaled night awakenings. Dwell times to fearful faces compared to dwell times to happy or both types of neutral faces were longer in children with signaled night awakenings, whereas in children without signaled night awakenings, the dwell times between fearful and happy faces did not differ. However, the children without signaled night awakenings exhibited the same pattern of longer attention dwell times to fearful faces than to both types of neutral faces as the children with signaled night awakenings. Hence, the children with signaled night awakenings showed a more pronounced attentional bias to fearful faces relative to other face types compared to children without signaled night awakenings. In four-year-old-children, naps reduce attentional bias to emotional stimuli (Cremone et al., 2017). Our results extend prior knowledge by showing that signaled night awakening is already associated with attention to emotional stimuli in very young children, with children without signaled night awakenings showing a less pronounced attentional bias to fearful faces. Additionally, as expected, our results replicated, when averaged over both groups, the robust finding of previous studies showing longer attention dwell times to fearful faces than to happy or neutral faces (Peltola et al., 2013, 2015, 2018; Yrttiaho et al., 2014). This attentional bias toward fearful faces is thought to reflect a normative phenomenon of early social information processing during the second half of the first year (Peltola et al., 2008, 2018; Yrttiaho et al., 2014). Further, it is possibly related to positive developmental aspects such as prosociality and attachment security (Peltola et al., 2015, 2018; Rajhans et al., 2016).

This pattern of attentional bias toward fearful faces was evident in children with signaled night awakenings. In contrast, the dwell times for fearful and happy faces did not differ in children without signaled night awakenings. Previous longitudinal studies have proposed that the attentional bias toward fearful faces observed in early infancy may attenuate and become less selective to fearful faces with age (Leppänen et al., 2018; Peltola et al., 2018; Xie et al., 2021). Thus, considering these results, it would be intriguing to speculate whether the different attention patterns to emotional faces reflect differential age-related patterns. This speculation remains, however, to be determined in future studies since our analysis of the Overlap task was longitudinal, with the attention patterns perceived in data averaged across eight and 24 months of age since no interactions with age were detected. Hence, the longitudinal associations of signaled night awakening and social information processing remain an important topic for future studies. Additionally, the role of infant temperament and more precisely negative affectivity or behavioral inhibition as a possible factor affecting signaled night awakening, EF, and attentional biases in early development is important to recognize. In future studies, it would be necessary to characterize the relations between temperament and attentional biases covering representative variation in relevant temperament dimensions with sufficiently large samples in determining whether findings linking temperament and attentional biases in older children (White et al., 2017) are replicated in younger children.

In addition to differences in social information processing, the two groups differed in parent-reported socio-emotional behavior, as expected at 24 months old. Children with signaled night awakenings had greater parent-reported dysregulation symptoms compared to children without signaled night awakenings. This finding is supported by a previous study from the current cohort showing that night awakenings in infancy were related to greater dysregulation symptoms at 24 months old (Morales-Muñoz et al., 2020) and conflicting with another study in which night awakening in infancy was unrelated to dysregulation symptoms concurrently at 12 months or longitudinally at 18 months old (Mindell et al., 2017). Generally, a mutual association between sleep problems and problems in dysregulation of emotion and cognition has been suggested (Wang et al., 2019). Further, research on behavioral dysregulation, including difficulties in sleeping and eating, has shown that these regulation problems in infancy are connected to later behavioral problems (Winsper & Wolke, 2014), lower social developmental scores (Sidor et al., 2013), and internalization and externalization problems later in childhood and adolescence (Hyde et al., 2012). The dysregulation scale in the BITSEA questionnaire consists of questions referring to regulation difficulties in sleep and eating. Moreover, it also includes questions concerning emotional or self-regulation challenges. These questions, for example, refer to adjustment to changes, getting upset, or having cries or tantrums until exhausted. In prior literature, the greater number of signaled night awakenings have been related to the inability to soothe or regulate oneself back to sleep after an awakening (Sadeh et al., 2007). Hence, self-regulation skills are essential in the developmental task of being able to fall asleep alone. The results add to previous literature by showing that children with persistent signaled night awakenings at eight months old have trouble in behavioral regulation more generally at 24 months old rather than having problems only in sleep regulation. It could be argued that because socio-emotional behavior was investigated with parent reports, it could be that parents perceive children with signaled night awakenings as generally more dysregulated due to these signaled night awakenings. This seems unlikely, however, since the differences in the behavioral dysregulation remained even after the removal of the questions concerning sleep and night awakening.

Surprisingly, the children with and without signaled night awakenings did not differ in parent-reported externalizing behavior. Only tentative support was detected for the difference in internalizing behavior at 24 months of age, even though several large community-based studies, including the entire CHILD-SLEEP cohort, have shown that night awakening is associated with both externalizing and internalizing behavior (Morales-Muñoz et al., 2020; Sivertsen et al., 2015; Zaidman-Zait & Hall, 2015). The associations with internalizing behavior are more robust in these studies as well in our study. However, our findings align with another study with an equivalent sample size where night awakening and externalizing or internalizing behavior were unrelated (Mindell et al., 2017). Possibly, during infancy, the association between signaled night awakening and externalizing or internalizing behavior is relatively small, confounded with other factors, and therefore detected only in larger community-based studies with sufficient power. Further, although no differences in internalizing or externalizing behavior were observed within the first two years, the associations, especially with internalizing behavior, could become more robust with age, as shown by Gregory and Connor (2002). In contrast, the relationship between sleep difficulties and externalization symptoms did not change with age (Greogry and Connor, 2002). In our sample, the amount of internalizing and externalizing symptoms was low. Perhaps in a normative sample like ours, investigation of social skills would be more informative than focusing solely on socio-emotional problems.

An interesting finding was that children with signaled night awakenings had lower parent-reported social competence compared to children without signaled night awakenings at 24 months old. This finding is in line with another study showing that the number of night awakenings at 12 months was concurrently associated with parent-reported social competence (Mindell et al., 2017). Interestingly, in Mindell et al. (2017) study, only the longest stretch of sleep and night awakening were associated with lower social competence. In contrast, they did not find associations between social competence and other sleep characteristics such as total sleep duration, sleep onset, or bedtime latency. Other studies have also reported conflicting results concerning sleep duration and social competence (Lemola et al., 2011; Tomisaki et al., 2018; Vaughn et al., 2015). Our results, in addition to Mindell et al. (2017), suggest that particularly signaled night awakening might challenge the development of social competence within the first two years of life. The children with signaled night awakenings were found to have more regulation difficulties than children without signaled night awakenings. One possibility that should be further reviewed and investigated is the mediating role of behavioral regulation difficulties in the development of social competence and EF. According to prior studies, social competence abilities already before preschool have long-lasting associations into adulthood (Jones et al., 2015). The studies have linked better social competence to later success in education and employment. Contrastingly, lower social competence abilities have been related to criminal activity, substance use, and problems in mental and physical health (Jones et al., 2015). Due to these long-lasting associations, it is essential to investigate the positive aspects of socio-emotional behavior, in addition to recognizing the socio-emotional problems as early as possible.

Study III also shed new light on the association between attention to faces and parent-reported socio-emotional behavior which seem to be related in early childhood since greater attention toward happy faces at eight months was associated with greater social competence and increased externalizing behavior at 24 months old. At the concurrent age of 24 months, increased attention toward happy faces correlated with lower scores on the dysregulation domain. In typically developing children, attentional biases are not specific to threat-related material but also seen toward relevant positive stimuli (Boergers et al., 2007). The associations found in

Study III are partly consistent with a study showing that infants' greater attention to faces is related to increased prosocial behavior (Peltola et al., 2018). Generally, the individual differences in attentional bias toward positive stimuli in adults have been related to greater positive affective responses (Grafton et al., 2012). Attentional bias toward positive stimuli in foster-care children has been linked to greater prosocial behavior, less externalizing, and less emotionally withdrawn behavior (Troller-Renfree et al., 2015). Based on the knowledge of these positive attentional biases, the results may propose that stronger attention toward positive stimuli is related to favorable socio-emotional outcomes, possibly resulting from the interest in the rewarding features of interaction. Interestingly, greater attention toward happy faces was also connected with increased externalizing behavior. The children in the current dissertation were 24 months old, and the overall scores in the externalizing domain were relatively low. Hence, the greater scores may reflect or are driven in the externalizing domain more by moderately elevated impulsive behavior than aggressive or acting-out behavior, which in older children are the representative features of higher externalizing scores. Further, in early childhood, externalizing symptoms could be driven by, for example, insufficient sleep, as Touchette et al. (2007) showed. They established that children under six years old usually experience elevated externalizing symptoms, such as hyperactivity and impulsivity, rather than experiencing classical signs of sleepiness seen in older children and adults. The conclusions regarding the associations between attention to faces and socio-emotional behavior are somewhat preliminary. Further studies with a greater sample size are needed to determine the associations' true size. Furthermore, in our study, the correlations were not adjusted for multiple comparisons.

5.5 Conclusions and possible mechanisms

Taken together, the results of this dissertation suggest that especially higher-order cognitive functioning and emotional and social behavior are associated with signaled night awakening. More precisely, children with signaled night awakenings have more behavioral regulation problems, lower social competence and EF abilities, and differences in emotional attention to faces compared to children without signaled night awakenings. Therefore, based on these studies, it seems that in infancy, the same areas of development and behavior are associated with signaled night awakening that in older children and adults are interfered with by sleep disruptions (Alfarra et al., 2015; Lim & Dinges, 2010; Tempesta et al., 2010; van der Helm et al., 2010). In addition, these studies add to previous knowledge by showing that the differences between groups are already visible within the first two years of life in a normative population without any major sleep difficulties. Moreover, signaled night awakening alone seems sufficient for this altered developmental trajectory in certain areas of development. In early childhood, development is rapid and ongoing. Therefore, children with altered developmental trajectories already in infancy may continue along this altered trajectory even though the number of signaled night awakenings normalizes with age.

Additionally, signaled night awakening shows persistence in many children, and children with signaled night awakening are at risk for continued signaled night awakening throughout childhood. It has been suggested that signaled night awakening could also be a precursor for later appearing more severe sleep difficulties (Goodlin-Jones et al., 2001). Already within the first two years of life, children with signaled night awakenings sleep less in total and spend more time awake during the night. With the differences in sleep characteristics, the altered developmental trajectory of EF, social information processing, and socio-emotional difficulties, children with signaled night awakenings are at risk for the accumulation of problems. Additionally, signaled night awakening concerns the parents and is a risk factor for the well-being of the whole family, as prior studies have shown that children's sleep patterns are highly related to parental sleep patterns (Boergers et al., 2007; Gay et al., 2004; Meltzer & Mindell, 2007). Further, children's signaled night awakening could result in parents' prolonged sleep deprivation (Karraker, 2008). Additionally, prolonged sleep deprivation in adolescence and adulthood is associated with depression and anxiety symptoms (Pires et al., 2016; Roberts & Duong, 2014). With the identification of certain risk pathways, it would be possible to develop interventions to help children and their families. Most importantly, preventive actions, for example, in well-child clinics, hold particular importance and should be further developed.

As a conclusion of the results, signaled night awakening appears to be a part of developmental challenges in self-regulation. Furthermore, perhaps signaled night awakening can be seen as an early marker of these ineffective self-regulatory abilities, possibly predisposing children to later EF, social information processing, and socio-emotional behavioral problems. Self-regulation is a broad concept, but essentially it refers to the ability to focus attention, manage emotions, and control behavior by using both automatic (bottom-up) and executive control (top-down) processes (Bridgett et al., 2015; Nigg, 2017). Self-regulation is not static but is considered to develop through critical periods from early life to adulthood (Nigg, 2017). Based on our results, children with signaled night awakenings have difficulties in these three core areas of self-regulation, that is flexible control of cognition, emotion, and behavior. The associations between signaled night awakening and self-regulation abilities seem rational since self-regulation abilities are needed to soothe oneself back to sleep after awakening. This ability is known to influence the number of night awakenings (Sadeh et al., 2007). The challenges in the development of self-regulation could have long-lasting developmental outcomes. In particular, lower self-regulation abilities have been associated with a large number of unwanted developmental outcomes such as internalizing and externalizing symptoms (Robson et al., 2020; Sawyer et al., 2015), depression (Kurtovic & Hirnstein, 2021; Robson et al., 2020), ADHD symptoms (Brocki et al., 2019), self-esteem, and social and academic functioning (Blair & Diamond, 2008; Robson et al., 2020). Therefore, a better understanding of these associations would improve preventative measures on how to support these children and their families. Self-regulation, EF, social competence, and social cognition are related (Nigg, 2017). However, essential differential aspects emphasize the need to study the different aspects of development with longitudinal designs to determine whether the differences will even out or become more extensive with age. Future studies could also establish whether the perceived difficulties in behavioral regulation are precursors for later, more severe self-regulation problems.

Several possible mechanisms could underlie the associations between signaled night awakening and EF, social information processing, and socio-emotional behavior. It should be noted that this dissertation investigated differences between two different groups with and without signaled night awakenings. Therefore, the studies included in this dissertation are unable to answer the question of causality between signaled night awakening and the differences found in children's development. However, it could be speculated that one possibility for the differences is that signaled night awakening in infancy affects developing brain structures and sets in motion neural changes. Notably, this could have a long-lasting influence on higher-order cognitive and socio-emotional functioning. Even though the exact mechanism by which fragmented sleep would influence developing brain structures is yet to be discovered, in line with this reasoning, studies conducted with adults have pointed out the critical role of sleep in learning and memory functioning (Rauchs et al., 2005; Walker, 2009). According to prior studies, all long-term memory systems benefit from non-disrupted sleep, although it seems that the importance of different sleep stages varies between various memory systems (Rauchs et al., 2005). Additionally, neural circuits active in previous learning are reactivated during sleep

(Peigneux et al., 2004; Rasch & Born, 2007). Sleep has also been hypothesized to have a role in the downscaling of synaptic strength accumulated during the day to efficiently use cerebral gray matter (Tononi & Cirelli, 2006). The suggested mechanisms could also be valid in infancy, and perhaps the influence could be even more significant since the development is in progress. Possibly excessive night awakening with substantial changes also in sleep duration and the amount of different sleep stages influences the developing brain structures. In this case, it seems less likely since both groups slept the preferred or optimal duration of sleep, thus representing a normative sample. Therefore, in this population, perhaps other explanations could be more plausible.

Another possible mechanism could be that signaled night awakening reflects genetic susceptibility that predisposes children to differences in EF, social information processing, and socio-emotional behavior. Perhaps the same genetic factors play a role in the development of higher-order cognitive and socio-emotional abilities that influence sleep quality. The genetic susceptibility could, for example, promote a phenotype with a combination of impulsivity, a lower threshold to react, and difficulties in self-regulation, including behavioral and emotional challenges. Further, temperamental features are possibly associated with this phenotype. In an unpublished analysis, the temperamental dimensions at eight months old differed between children with and without signaled night awakenings. Children with signaled night awakenings had greater scores in negative emotionality and more regulation difficulties than children without signaled night awakenings. Moreover, the differences were small in magnitude yet significant. At eight months old, we had data from most children (over 90% of children), whereas we were unable to analyze the temperament data at 24 months old due to over half of the data being missing. Prior studies have shown consistency in temperamental features during the first year of life (Dias et al., 2021). However, when considering difficult temperament, it has been suggested that the associations with night awakening are not sustained across time (Scher et al., 2005). Due to the great amount of missing data and loss of power, it remains to be determined whether the small differences in negative emotionality and regulation are stable, continuing to distinguish the two groups at older ages as well. It is also possible that parental reports of temperament at eight months old are influenced by signaled night awakening, and due to the diminished number of signaled night awakenings at 24 months old, the temperamental features might no longer differ.

One possibility that should be considered in future studies is the altered activity of the hypothalamic-pituitary-adrenal (HPA) -axis in signaled night awakening. In adults, the relationship between disturbed sleep and HPA -axis activity alterations has been considered bidirectional (Elder et al., 2014; Steiger, 2002). HPA -axis is thought to mediate the reaction to acute physical and psychological stress, and its activity has been measured with awakening cortisol levels. Therefore, higher awakening cortisol levels would reflect altered physiological regulation or reactivity. Interestingly, awakening cortisol levels have been shown to be higher in children with fragmented sleep than in children with more efficient sleep in infancy (Scher et al., 2010). Furthermore, in older children, a shorter sleep duration or poor sleep has been associated with increased morning cortisol levels (Hatzinger et al., 2013; Räikkönen et al., 2010). In addition, elevated cortisol levels were found to correlate with teacher ratings of higher levels of internalizing behavior and negative emotionality in 12- to 36-month-old children (Scher et al., 2010). It would be intriguing to investigate whether elevated morning cortisol levels are also found in children with signaled night awakenings compared to children without signaled night awakenings. One possibility is that the regulation of the HPA -axis also plays a role in the suggested phenotype. All of these suggested phenotypic features could interact, and the different features are probably emphasized individually but reflect the same broader phenotype.

5.6 Limitations

One specific feature of the current sample was that it was drawn from the prevention sub-sample of the full cohort, where half of the children participated in the control health care visits and the other half in the so-called prevention health care visits. The control group received regular well-child visits, whereas the prevention group received, in addition to the regular well-child visits, preventative psychoeducation on infant's sleep. Children from prevention and control health care centers were equally distributed for the two groups formed. Further, the health care center status was taken into account in the analyses, and it did not significantly affect different sleep parameters, psychomotor development, EF, or attention to the faces. In Study I, the results for psychomotor development and sleep parameters were further analyzed that including the children from the prevention health care centers did not confound the obtained results. To this end, the analyses were conducted again using only children from the control health care centers. The obtained results remained essentially the same despite the reduction in sample size. Therefore, it was concluded that including children from the prevention health care centers did not confound the results.

The group status of our sample was determined at eight months old and kept the same regardless of the number of signaled night awakenings at 18 or 24 months old. Therefore, it is possible that some of the children in the signaled night awakening group progressed to sleep through the night. Similarly, the children without signaled night awakenings could have started to have more night awakenings at older ages. However, we were interested in early-onset signaled night awakening in the present dissertation and on a group level, the children with signaled night awakenings had more signaled night awakenings at 18 and 24 months old than children without signaled night awakenings.

For psychomotor development, executive functioning, and social information processing the assessment points comprised of research visits at eight and 24 months old. Even though the exact ages of the participants were attempted to be kept as close to the pre-set assessment points as possible, there were slight variations in the age of the participants at eight and 24 months old. However, on group level the mean age of the two groups did not differ at eight or 24 months old.

Finally, although the sample size in these studies was fairly large, it consisted of White families of mainly middle-class origin. Therefore, the generalizability of the results to other sociodemographic groups and ethnicities is limited. For example, co-sleeping and signaled night awakening may reflect a normative or desirable pattern of sleep in different cultures, whereas our sample represents a Western culture. Additionally, our findings concern the first two years of life and are not directedly generalizable to older children. Finally, there may also be moderating child or family-related factors that were not controlled in these group of studies. Overall, the mentioned limitations of the current dissertation should be considered when considering the generalizability of the results.

5.7 Clinical significance

Our results suggest that signaled night awakening could reflect difficulties in self-regulation that should be paid attention to in well-child visits. If the child has frequent signaled night awakenings, special attention, should be paid to sleeping characteristics and the development of the child. Additionally, it is possible that the frequency of signaled night awakening could be a potential signal of these ineffective self-regulation abilities. Since signaled night awakening could reflect a differential trajectory of self-regulation, knowledge should be given to parents on how to support the child's inner regulation in order for the child to better regulate their emotions and behavior. According to prior literature, parent self-regulation is related to children's self-regulation abilities (Bridgett et al., 2015). Additionally, it has been suggested that parenting behaviors mediate the association between parent and child self-regulation (Bridgett et al., 2015). Possible mechanisms for change through which self-regulation abilities could be enhanced in early childhood are yet to be determined. An essential developmental task in infancy seems to be the ability of being able to fall asleep independently.

The ability of being able to fall asleep independently includes putting the child to bed when the child is tired but awake. Thus, allowing the children to develop their skills on how to independently fall asleep and enabling them to fall asleep independently after an awakening during the night. There is no systematic guidance in well-child visits on how to support your infant's sleeping habits even though children's sleeping concerns the parents and is the most often discussed matter in well-child visits (Palmstierna et al., 2008). Parental behaviors are the most immediate and direct factors affecting children's sleep behavior (Sadeh et al., 2010). In addition to parental presence until the child falls asleep, co-sleeping with the infant and breastfeeding are known to be associated with frequent night awakening (Hysing et al., 2014; Touchette et al., 2005). With the guidance of positive sleeping habits, sleeping in infancy could be supported and perhaps the possible accumulation of more severe sleeping problems could be prevented. Additionally, support for positive sleeping habits could also enhance parents' coping and therefore be important for the well-being of the whole family.

According to prior studies, signaled night awakening can be successfully diminished or treated. These interventions include behavioral management techniques and parent education strategies (Kuhn & Elliott, 2003; Mindell et al., 2006). For night awakening, the most robust empirical support as a successful intervention has been found for extinction and parent education strategies (Mindell et al., 2006). Moreover, behavioral interventions such as graduated extinction, bedtime fading or positive bedtime routines, and scheduled awakening have also been effective (Kuhn & Elliott, 2003; Mindell et al., 2006). Most children seem to benefit from these interventions, and the results are maintained until at least three to six months (Mindell et al., 2006). All these mentioned techniques could be easily implemented at home. In future studies, it would be important to clarify whether changes in signaled night awakening after an intervention also produce changes in EF, social information processing, and socio-emotional behavior. In particular, to better understand the mechanisms linking signaled night awakening to EF, social information processing, and socio-emotional behavior. With this kind of study, it would be possible to answer whether signaled night awakening reflects genetic susceptibility. Additionally, it would be possible to determine the interventions with which to support children's development.

More importantly, even though the two groups differed in higher-order cognitive functioning, social information processing, and socio-emotional behavior, all the children performed in the normal range, and the differences between children with and without signaled night awakenings were small in magnitude. Interestingly, however, the differences between groups were evidenced in a normative sample, highlighting the ecological value of the results, and raising the question of the magnitude of differences in a clinical sample with more severe signaled night awakening.

5.8 Concluding remarks

The present dissertation investigated signaled night awakening and its associations with different aspects of development. It extended prior knowledge by studying signaled night awakening and development with versatile methods already within the first two years of life in children with and without signaled night awakenings. In summary, it was found that children with signaled night awakenings have lower performance in a computerized EF task, different pattern of attention to emotional faces, lower social competence, and greater regulation difficulties than children without signaled night awakenings. No differences in overall psychomotor development were found, thus confirming the associations of signaled night awakening, particularly to higher-order cognitive, social information processing, and socio-emotional behavior. Additionally, signaled night awakening showed persistence. Across time, children with signaled night awakenings slept less and spent more time awake during the night than children without signaled night awakenings. However, despite the differences in sleep duration, both groups slept the preferred total sleep duration. Overall, signaled night awakening is persistent and could predispose children to sleep quality and duration differences. It seems that children with signaled night awakenings are perhaps on a different developmental trajectory with the most significant associations with higher-order cognitive functioning and social or emotional processing and behavior. The results of this dissertation suggest that signaled night awakening could be seen as a larger problem of self-regulation, and these ineffective self-regulation abilities could have long-lasting unwanted developmental outcomes.

Based on these results, future studies should not investigate signaled night awakening in isolation but rather with other related factors coexisting with signaled night awakening. Moreover, new sensitive and objective measures of EF, social cognition and socio-emotional development that differentiate performance in the normal range would benefit this kind of research. Furthermore, using multiple informants such as daycare staff in addition to parents would improve the reliability of this line of research. Finally, the results of this dissertation extend to two years of age. Therefore, an important aspect for future studies is to follow children into older ages to answer whether the observed differences in developmental outcomes and sleep increase or diminish with age.

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PUBLICATION
I

Night Awakening in Infancy: Developmental Stability and Longitudinal Associations With Psychomotor Development

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Night awakening in infancy: Developmental stability and longitudinal associations with psychomotor development

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Night awakening in infancy: Developmental stability and longitudinal associations with psychomotor development

Abstract

Fragmented sleep is common in infancy. Although night awakening is known to decrease with age, in some infants night awakening is more persistent and continues into older ages. However, the influence of fragmented sleep on development is poorly known. In the present study, the longitudinal relationship between fragmented sleep and psychomotor development (Bayley-III) was investigated in infants with (≥3 night awakenings, *n* = 81) and without fragmented sleep (≤1 night awakening, *n* = 70) within the CHILD-SLEEP birth cohort at eight and 24 months of age. Differences in parent-reported (BISQ) sleep parameters were studied at eight, 18, and 24 months of age. Group differences in night awakening were stable across all assessment points. Infants with fragmented sleep slept less in total than infants without fragmented sleep and they did not compensate their nocturnal sleep during daytime. Additionally, infants with fragmented sleep spent more time awake at night than infants without fragmented sleep. However, psychomotor development did not differ between infants with and without fragmented sleep at eight or 24 months of age. Our findings indicate that early-onset fragmented sleep did not have a negative effect on psychomotor development within the first two years despite the differences in sleep length among infants with and without fragmented sleep. In the future, more specific domains of cognitive development and various factors affecting sleep fragmentation should be taken into account when studying the developmental effects of night awakening in infancy.

Keywords: night awakening, fragmented sleep, infancy, psychomotor development, sleep

Introduction

Sleep in early infancy is characterised by fragmented short periods of sleep with several nocturnal awakenings (Dahl, 1996; Hysing et al., 2014). The consolidation of sleep is an important developmental task in infancy, and the number of night awakenings decreases with age (Galland, Taylor, Elder, & Herbison, 2012; Hysing et al., 2014; Palmstierna, Sepa, & Ludvigsson, 2008). Consolidated and self-regulated sleep at night can be achieved during the first year of life (Iglowstein, Jenni, Molinari, & Largo, 2003; Moore & Ucko, 1957). However, as many as 20% to 30% of one-year-old infants continue to have fragmented sleep (Adair, Zuckerman, Bauchner, Philipp, & Levenson, 1992; Mindell, Kuhn, Lewin, Meltzer, & Sadeh, 2006).

Night awakening in infancy

Brief nocturnal awakenings are normative between the sleep cycles (Anders, 1978), and they seem not to be problematic in infants who are able to soothe themselves back to sleep without signalling to their parents (Goodlin-Jones, Burnham, Gaylor, & Anders, 2001; Sadeh, Flint-Ofir, Tirosh, & Tikotzky, 2007; Weinraub et al., 2012). Frequent and prolonged night awakenings in infancy could, however, result in shortened sleep duration and a poorer diurnal rhythm, and relate to pathologically fragmented sleep. Moreover, they may pose major concerns to the parents of infants who signal their awakenings and are not able to soothe themselves back to sleep (Sadeh et al., 2007). This signalling behaviour interrupts parents’ sleep and can be experienced as disturbing. Night awakenings are, indeed, one of the major parental concerns and most often reported when parents evaluate their child’s quality of sleep (Palmstierna et al., 2008).

The parental and child-related factors that are connected with night awakenings have been widely studied. The parental behaviours associated with frequent night awakening are, for example, breastfeeding, high level of parental involvement when falling asleep, and co-sleeping with the infant (Hysing et al., 2014; Sadeh, Mindell, Luedtke, & Wiegand, 2009; Touchette et al., 2005). In addition, a challenging temperament has been linked to frequent night awakening (Touchette et al., 2005). In the diagnostic criteria of paediatric sleep disorders (American Psychiatric Association, 2013), these conditioning factors are considered to potentially contribute to sleep difficulties although the causal direction between these factors and night awakening is not yet fully clear.

It has been proposed that signalled night awakening in infancy could be a precursor for later sleep difficulties (Goodlin-Jones et al., 2001). Indeed, it has been found that the children who had several night awakenings as infants were at risk of having more night awakenings at the age of 18 months (Hysing et al., 2014) and even at 4-6 years of age (Palmstierna et al., 2008; Tikotzky & Shaashua, 2012). Other studies have also supported the notion that sleep difficulties are rather stable over time (Gregory and O'Connor, 2002; Williams, Berthelsen, Walker, & Nicholson, 2015). Only a few cross-sectional studies have compared infants with frequent or prolonged night awakenings to infants without sleep fragmentation. Infants with fragmented sleep have been found to have more night awakenings, reduced sleep efficiency, and increased time spent awake during the night when measured by actigraphy (Sadeh, Lavie, Scher, Tirosh, & Epstein, 1991; Sadeh et al., 2007). Studies on sleep duration have produced mixed results. Acebo et al. (2005) found that infants with night awakenings compensate for their nocturnal sleep with increased napping during the day, whereas Touchette et al. (2005) found that infants with fragmented sleep appear to sleep less in total. In addition, Sadeh et al. (1991) found no differences in sleep duration between infants with and without sleep fragmentation. Thus, it is not clear whether sleep duration differs in infants with fragmented sleep and how stable these possible influences are.

Night awakening and psychomotor development

Although fragmented sleep is normative for young infants, as a persisting difficulty it could pose a risk to the development of the child and the well-being of the whole family. In general, sleeping difficulties have been related negatively to psychomotor development in cross-sectional and longitudinal studies. In the current paper, psychomotor development refers to a broad definition of development (cf., Cioni & Sgandurra, 2013) including cognitive, language, and motor functioning. Previous studies with school-aged children have associated poorer sleep quality, shorter sleep duration, and sleepiness with diminished school performance (Dewald, Meijer, Oort, Kerkhof, & Bögels, 2010). In addition, shorter sleep duration has been associated with lower cognitive functioning and emotional and behavioural problems (Astill, Van der Heijden, Van IJzendoorn, & Van Someren, 2012; Paavonen et al., 2010; Touchette et al., 2007). In pre-term infants and toddlers, more matured sleep has been associated with better cognitive functioning (Gertner et al., 2002; Holditch-Davis, Belyea, & Edwards, 2005; Schwichtenberg, Christ, Abel, & Poehlmann-Tynan, 2016) whereas snoring has been associated with lower cognitive functioning (Piteo, Lushington, Roberts, van den Heuvel et al., 2011; Piteo, Lushington, Roberts, Martin et al., 2011; Suratt et al., 2007). However, studies with healthy, typically sleeping infants have shown mixed results. Questionnaire-based studies focusing on sleep in infancy have not observed correlations between different aspects of sleep and overall cognitive functioning (Bernier, Beauchamp, Bouvette-Yurcot, Carlson, & Carrier, 2013; Bernier, Carlson, Bordeleau, & Carrier, 2010; Mindell & Lee, 2015; Spruyt et al., 2008). Interestingly, Scher et al. (2005), who studied sleep using actigraphy, found in their cross-sectional study that nocturnal awakening and higher proportion of motor activity during sleep were negatively correlated with cognitive functioning in healthy ten-month-old infants. In addition, they found that sleep efficiency, i.e., the proportion of total bed time that was spent asleep was associated with better cognitive functioning. However, few longitudinal studies of parent-reported sleep have provided support for the notion that more matured, night-centred sleep in infancy is associated with better cognitive (Dearing, McCartney, Marshall, & Warner, 2001) and language functioning later in childhood (Dearing et al., 2001; Dionne et al., 2011). The sparse longitudinal studies have not focused on night awakenings in early infancy, although it is one of the major parental concerns during infancy (Palmstierna et al., 2008) and, more importantly, infant sleep is thought to have an essential role in the rapid brain maturation that occurs during the first years of life (Dahl, 1996).

The current study

As a part of the CHILD-SLEEP longitudinal birth cohort (Paavonen et al., 2017), the aim of the present study was to investigate infant night awakening and its connection with psychomotor development at eight and 24 months of age in infants with and without fragmented sleep. Two groups of infants were formed according to the number of night awakenings reported by the parent when the infants were eight months of age. In the waking group, the infants had three or more night awakenings that were signalled to the parents, whereas in the non-waking group the infants had no more than one night awakening requiring parental intervention. We chose to form the groups at the age of eight months because, at this age, sleep transitions towards more night-centred sleep, and nurturing behaviour during the night no longer plays a major role in sleep behaviour.

We had three specific aims; the first aim was to replicate the previous findings regarding the persistence of night awakenings in infancy at eight, 18 and 24 months of age. Secondly, we wanted to clarify the associations between infant night awakening and other parent-reported sleep quality (time spent awake during the night, sleep onset latency and proportion of night-centred sleep) and duration parameters (duration of total, night-time, and daytime sleep). The third aim was to study the differences between infants with and without fragmented sleep in psychomotor development which was measured with Bayley Scales of Infant and Toddler Development (3rd edition, Bayley 2009) at eight and 24 months of age. We used a longitudinal design, a comprehensive measure of psychomotor development, and several parent-reported sleep parameters, all aimed at shedding more light on the contradictory findings concerning early-onset fragmented sleep and its connections with psychomotor development. Based on previous studies (Gregory & O'Connor, 2002; Hysing et al., 2014) concerning our first aim we hypothesised that night awakening would be a persistent problem, continuing to distinguish the two groups of infants at 18 and 24 months of age. Our hypothesis regarding the second aim was that, paralleling findings from previous studies (Hysing et al., 2016; Palmstierna et al., 2006; Acebo et al., 2005; Sadeh et al., 1991; Touchette et al., 2005), infants with fragmented sleep would differ from infants without fragmented sleep in both sleep quality and duration parameters at eight, 18, and 24 months of age. As for the third aim concerning psychomotor development, we hypothesised that there would not yet be differences in psychomotor development at the age of eight months but persistent night awakenings would become related to cognitive development longitudinally, evidenced as lower psychomotor development at the age of 24 months compared with infants without a history of fragmented sleep.

Method

Participants

This study is a part of the CHILD-SLEEP longitudinal birth cohort in which various aspects of sleep in families with newborn children are being investigated (Paavonen et al., 2017). The study protocol of Sleep for Cognitive, Social and Emotional Development (CHILD-SLEEP) was reviewed by Pirkanmaa Hospital District Ethical Committee (ETL-code: #R11032) and Tampere University Hospital Paediatric Unit granted the approval for the study. The present study comprises of 151 Finnish, Caucasian infants (73 girls and 78 boys), who were 7.5–11.5 months of age at the first assessment (mean age = 247 days, SD = 13.6 days) and 22.5–27.5 months of age at the second assessment (n = 128, mean age = 737 days, SD = 20.6 days). An additional three participants were examined but excluded from further analyses due to prematurity (n = 1), a developmental disorder apparent at birth (n = 1), and native language other than Finnish (n = 1). The descriptive statistics of the sample are shown in Table 1.

The sample of this study was recruited from the prevention sub-study of the main cohort, which will be described in detail elsewhere. The sub-study was aimed at preventing sleep problems in infancy, and the sample was based on the randomisation of 50 healthcare centres in Tampere, Finland, into prevention and control healthcare centres (cluster sampling). Altogether, there were 207 infants in the prevention group and 199 infants in the control group. Families in the prevention group received preventive psychoeducation regarding infant sleep development and strategies to support the quality of sleep during the normal well-child visits to the healthcare centre. The psychoeducation was delivered mainly through information brochures. The control group received standard information during the well-child visits.

The infants were recruited to the current study at the age of eight months. A research assistant contacted the families participating in the prevention sub-study (both prevention and control groups) through phone interview and asked the parents how many times their infant typically woke up during the night between 24.00–06.00. If their child woke up three or more times during the night, they were asked to participate in this study. In addition, a control group of infants who slept through the night or woke up no more than once during the night were also asked to participate. In order to form two groups that were clearly distinguishable from each other in the tendency to wake up at night, infants who were waking up twice a night were not recruited to the study. Consequently, at eight months of age, there were 81 infants in the waking group and 70 infants in the non-waking group who agreed to participate in the psychomotor assessment. From these infants, 70 infants from the waking group and 58 infants from the non-waking group returned for the assessment at 24 months. There were no differences between infants who were retained and those who dropped out of the study after the eight-month assessment in Bayley-III subscales (all $p > .05$) whereas the analyses of sleep quality and duration parameters showed that the infants who dropped out slept longer during the day [t (136)= -2.318, $p = .022$], spent less time awake during the night [t (70.138)= 3.423, $p = .001$], and fell asleep quicker [t (46.32)= 3.33, $p = .002$] than the infants who continued in the study.

There were no differences between the waking group and the non-waking group in child- or mother-related features (child age, gender, number of children in the family, or in maternal education); all *p's* > .05. However, the two groups differed on co-sleeping, X^2 (1, n = 124) = 20.16, $p < .001$, breastfeeding, X^2 (1, n = 138) = 12.25, $p = .002$, the infant's ability to fall asleep alone, X^2 (1, n = 138) = 17.66, $p < .001$. Healthcare centre status was marginally significant, X^2 (1, n = 151) = 3.64, $p = .056$ (Table 1). For the analyses, these variables were categorized to aid the interpretation of the results. Co-sleeping was divided into two categories of less than twice in a month and at least weekly co-sleeping with parents. The ability to fall asleep alone was also divided into two categories of the infant being able to fall asleep alone only once in a week or at least once a day. Breastfeeding had three categories with infants being only breastfed, both breastfed and formula fed, and only formula fed. All these variables were gathered at eight months of age. Over half of the infants in the waking group co-slept weekly with their parents (56.5%), whereas in the non-waking group only 7.3% of the infants co-slept on a weekly basis. 69.7% of the infants in the waking group were able to fall asleep alone only once in a week, whereas in the non-waking group 66.1% of the infants were able to fall asleep alone at least once a day. 58.4% of the infants in the waking group were breastfed and 20.8% were formula fed, whereas in the non-waking group 32.8% were breastfed and 47.5% were formula fed. In the waking group, 55.6% of the infants came from prevention healthcare centres, whereas in the non-waking group 40.0% of infants came from prevention healthcare centres.

Study design

This study comprised of two clinical assessments for both groups of children at the age of eight and 24 months. At the beginning of the eight-month visit, the parents filled out the consent form. After that, the Bayley Scales of Infant and Toddler Development (3rd edition, Bayley 2009) were conducted, and a standard medical examination was performed by a paediatrician (not reported here). In addition, at the end of the first visit, the paediatrician interviewed the parent on sleep- and health-related questions and, if necessary, provided basic sleep psychoeducation, including advice for the sleeping habits of the infant. The entire study protocol included an additional laboratory visit consisting of computer tasks and physiological measurements (not reported here).

In addition to the in-person visits, questionnaires that concerned the whole CHILD-SLEEP cohort were sent to the parents at eight, 18 and 24 months of age.

Measures

Sleep quality and duration parameters

The present study utilised the questionnaires for the main cohort that were sent to the parents when the child was eight, 18, and 24 months of age. The questionnaire at eight months was a paper-and-pencil questionnaire, sent through postal mail, whereas the questionnaires at 18 and 24 months of age were web-based, and sent to the parents via email. Sleep quality and duration were measured using the Brief Infant Sleep Questionnaire (BISQ; Sadeh, 2004). Sleep quality included the duration of wakefulness during the night (between 22.00-06.00), the latency to fall asleep, and the proportion of night-centred sleep, thus describing the stage of maturity of sleep. Sleep duration referred simply to the amount of sleep and included duration of nocturnal (between 19.00- 07.00) and daytime sleep (between 07.00-19.00) in hours and in minutes and total sleep duration as a sum of night-time and daytime sleep. The test-retest reliabilities for the BISQ questionnaire variables are r = .82 for night-time sleep duration, r = .89 for daytime sleep duration, r = .88 for number of night awakenings, r = .95 for the time spent awake during the night, and r = . 94 for sleep onset latency (Sadeh, 2004).

To validate the inclusion criteria, the number of night awakenings were also gathered from the questionnaire, in addition to the phone interview. We analysed the questionnaire data concerning the number of night awakenings at eight months of age. In line with the phone interview, the questionnaire data showed that the waking group had more night awakenings compared to the non-waking group, t (127) = 10.77, $p < .001$. However, the phone interview and the questionnaire were not conducted at the same time and the definition of the night-time was not identical, and therefore the number of night awakenings in both groups were not entirely constant as can be seen from Table 2. The phone interview data were considered to be more informative due to the tight definition of night-time (24.00–06.00), representing the severity of night awakening difficulties in that particular time more precisely than the data gathered with the questionnaire.

Psychomotor development

Psychomotor development was measured using the Bayley Scales of Infant and Toddler Development (3rd edition, Bayley 2009), which is a widely used and robust measure of infant development. It consists of five different subscales measuring cognitive, receptive and expressive language, and fine and gross motor functioning. All the subscales were conducted by a trained examiner who was unaware of the child's group status. During the assessment, the child sat on the parent's lap except for the gross motor scale, which was conducted on the floor. Raw scores of the five different subscales were transformed into standardised scores with the original norms (M = 10 ± 3). From these standardised scores, three combined indexes (M = 100 ± 15) of cognitive, language (receptive and expressive language) and motor (fine and gross motor) development were drawn. Analyses were conducted separately for the five different subscales. Analyses were also conducted with the three combined indexes which showed similar findings. Due to the sake of brevity, and to reduce the number of statistical tests, only the results of the subscales are presented.

Statistical analysis

Statistical analyses were carried out using version 23 of the SPSS statistical software package. All the outcome variables were continuous and their distributions were screened using box-plots and scatterplots and, after visual inspection of the distributions, no extreme outliers were observed. Outcome variables with naturally skewed distributions (number of night awakenings and the time spent awake during the night) were corrected with log transformation. After the transformation, the distributions of the number of night awakenings and the time spent awake during the night exhibited only minor skewness. The data were analysed using Linear Mixed Models (LMM). This method was chosen in order to compare longitudinally the average change within the two groups and it allowed us to utilise also incomplete data. LMM is fairly robust to small deviations of normality (Lo & Andrews, 2015) and therefore, we decided to analyse the log transformed number of night awakenings and the time spent awake during the night also with LMM.

To analyse the group differences and the effect of time (i.e., assessment time points at 8, 18, and 24 months of age) on the outcome measures (night awakening, sleep quality and duration parameters, and psychomotor development), we conducted linear mixed models for each of the dependent variables. Both within-subjects (time) and between-subjects effects (group status) and their interaction were analysed. In the analysis of different sleep quality and duration parameters, a random intercept was included in the analyses whereas the models concerning psychomotor development did not include a random intercept due to better model fit without a random intercept. In the case of statistically significant main effects, the differences between subgroups were further analysed using Bonferroni-corrected post hoc tests. Effect sizes for the pairwise comparisons are indicated by Cohen's *d*. First, we ran a model that included the within factor of time, between factor of group, interaction of time x group, and the different covariates. Initially, the questionnaire data variables that differentiated between the two groups and factors that are known to be associated with night awakenings were tested as potential covariates in our analyses (co-sleeping, breastfeeding, the ability to fall asleep alone, and healthcare centre status). In case of a statistically significant main effect, the covariate was included in the final model. The alpha level was set to p = .05.

Results

Descriptive statistics of the sleep quality and duration parameters are presented in Table 2. Means, standard deviations, and range of the different Bayley-III subscales at eight and 24 months of age are presented in Table 3 separately for both groups. Table 4 summarises the statistics of the final models for the different sleep quality and duration parameters and Bayley-III subscales.

The persistence of night awakening

The LMM of the number of night awakenings revealed main effects of time, (F [1, 206.48] = 12.07, p = .001, d = .35) and group, (F [1, 203.53] = 21.24, p < .001, d = .63). In general, the number of night awakenings decreased from 18 months (M = 1.2, SD = 1.1) to 24 months of age (M = .9, SD = .9). In addition, the waking group (M = 1.3, SD = 1.0) had more night awakenings than the non-waking group (M = .7, SD = .9). The covariates co-sleeping, breastfeeding and the ability to fall asleep did not have a significant effect on the night awakening at 18 or 24 months of age (all p's > .67). Pairwise comparisons verified that the waking group and the non-waking group differentiated in the number of night awakenings at 18 months (t [114] = 2.99, p = .003, d = .55) and 24 months of age (t [90] = 3.08, p = .003, d = .64). Figure 1 illustrates the group differences in the night awakenings across time.

Night awakening and its connection to parent-reported sleep quality parameters

In the LMM of the time spent awake during the night, significant main effects of time (F [2, 134.23] = 34.63, p < .001) and group (F [1, 134.20] = 24.75, p < .001) were observed. The infants spent more time awake during the night at eight months (M = 24 min, SD = 24 min) as compared to 18 months (M = 9 min, SD = 16 min), p < .001, d = .57, and 24 months of age (M = 8 min, SD = 11 min), p < .001, d = .66, whereas the time spent awake at 18 months and 24 months did not differ, p = 1.00, d = .06. The infants in the waking group spent more time awake during night time (M = 17 min, SD = 22 min) than the non-waking group (M = 10 min, SD = 17min), p = .001, d = .35.

The analysis of sleep onset latency at bedtime showed only a covariate main effect of the ability to fall asleep alone (F [1, 138.61] = 8.77, p = .004, d = .39). Overall, sleep onset latency was longer for infants who were able to fall asleep alone only once in a week (M = 23 min, SD = 17 min) compared to infants who were able to fall asleep alone at least once in a day (M = 17 min, SD = 13 min).

The proportion of night centred-sleep showed a main effect of time (F [2, 132.03] = 136.18, p < .001). The proportion increased with age, as the eight-month-olds (M = 75%, SD = 6.1%) differed from the 18-month-olds ([M = 83%, SD = 4.9%], p <.001, d = 1.35) and 24-month-olds ([M = 84%, SD = 5.1%], p <.001, d = 1.25). No differences between the 18-month-old and 24-month-old infants were found (p = .154, d = .17).

Night awakening and its connection to parent-reported sleep duration parameters

In the LMM of total sleep duration, the main effects of time (F [2, 153.25] = 92.10, p < .001) and group (F [1, 135.72] = 6.05, p = .015, d = .28) were significant. The duration of total sleep decreased with age from eight months (M = 790 min, SD = 68.4 min) to 18 months ([M = 736 min, *SD* = 58.4 min], *p* < .001, *d* = .75) and to 24 months ([*M* = 708 min, *SD* = 50.8 min], *p* < .001, *d* = 1.25), as well as from 18 months to 24 months of age, *p* < .001, *d* = .51. Overall, the waking group (*M* = 735 min, *SD* = 71.6 min) slept less in total than the non-waking group (*M* = 754 min, *SD* = 66.1 min).

Analysis of the duration of night-time sleep showed a main effect of time (*F* [2, 177.81] = 6.91, *p* = .001). The duration of night-time sleep increased in infants from eight months (*M* = 594 min, *SD* = 57.8 min) to 18 months ([*M* = 611 min, *SD* =48.5 min], *p* = .002, *d* = .27), and decreased from 18 to 24 months ([*M* = 596 min, *SD* = 43.1 min], *p* = .026, *d* = .31), whereas the duration of night-time sleep at eight months and 24 months of age did not differ; *p* = 1.00, *d* = .03.

Analysis of the amount of daytime sleep also showed a significant main effect of time (*F* [2, 142.97] = 137.67, *p* < .001). The amount of daytime sleep diminished from eight months (*M* = 196 min, *SD* = 58.1 min) to 18 months ([*M* = 124 min, *SD* = 41.8 min], *p* < .001, *d* = 1.32) and again to 24 months of age ([*M* = 112 min, *SD* = 41.8 min], *p* < .001, *d* = 1.32). In addition, the decrease from 18 months to 24 months of age was significant, *p* = .026, *d* = .25.

Night awakening and its association with psychomotor development

The descriptive statistics of the Bayley-III subscales are summarised in Table 3 separately for both groups. The statistical information of the final models are presented in Table 4. The LMM of the cognitive subscale showed a main effect of time (*F* [1, 238.74] = 17.06, *p* < .001, *d* = .35). Infants received better age-corrected scores on cognitive functioning at eight months (*M* = 12.2, *SD* = 1.8) than at 24 months (*M* = 11.2, *SD* = 2.3).

Regarding the receptive language subscale, a significant main effect of time (F [1, 278] = 313.774, $p < .001$, $d = 1.48$) was observed. The infants received better age-corrected scores at 24 months of age ($M = 12.1$, $SD = 2.5$) than at eight months ($M = 7.8$, $SD = 1.5$). For expressive language, no significant main effects or interactions were observed (all p's > .44).

In the analysis of the fine motor subscale, no significant main effects or interactions were found (all p's > .06). The LMM of the gross motor subscale showed a main effect of time (F [1, 268.56] = 9.79, $p = .002$, $d = .30$), with the infants receiving better age-corrected at 24 months of age (M = 9.4, $SD = 2.0$) than at eight months of age ($M = 8.5$, $SD = 2.6$). Most importantly, the absence of group main effects in the psychomotor development data indicated that there were no significant differences between the waking group and the non-waking group in any of the subscales (all p's > .20).

Discussion

The aim of the present longitudinal study was to investigate the persistence of night awakening in infancy and its connection to other sleep quality and duration parameters, and to psychomotor development. To this aim, the waking group and the non-waking group were formed on the basis of parent-reported number of night awakenings when the infants were eight months of age. We measured the quality and duration of sleep at the age of eight, 18, and 24 months using parental questionnaires. The assessment of psychomotor development was conducted at eight and 24 months of age. It was hypothesised that the two groups of infants would show a persistent difference in the number of night awakenings at each time point and that they would also differ in other parent-reported aspects of sleep. In addition, we expected that the waking group would not differ from the non-waking group on psychomotor development at the age of eight months whereas they were expected to differ at the age of 24 months, indicating a less optimal developmental trajectory due to early-onset fragmented sleep.

Our results supported the hypothesis that night awakening is persistent in many infants: the waking group had more night awakenings than the non-waking group even at the ages of 18 and 24 months. This finding is in line with previous studies indicating that children with several night awakenings are at risk of continued sleep fragmentation also during childhood (Gregory & O'Connor, 2002; Hysing et al., 2014). However, the number of night awakenings diminished with age also in the waking group, even though the differences between the groups remained significant.

The hypothesis regarding differences in other sleep quality and duration parameters between the two groups was also supported. Although both groups evidenced the normative decrease in daytime and total sleep (Anders & Keener, 1985; Sadeh et al., 2009) from eight to 24 months of age, an important finding was that the waking group slept less in total. They also spent more time awake during the night than the non-waking group. Previous studies have reported mixed results regarding differences in total sleep time between infants with and without sleep fragmentation, some yielding support for the compensation of nocturnal sleep loss by napping longer during daytime (Acebo et al., 2005) and others suggesting that the groups do not differ in total sleep time (Sadeh et al., 1991). Our results are in line with Touchette et al. (2005), who stated that infants with several night awakenings sleep less in total and that they do not compensate for their lack of sleep during the day.

Our hypotheses concerning psychomotor development were only partially supported. In line with our hypothesis, the waking group and the non-waking group did not differ on cognitive, receptive and expressive language, or fine and gross motor development at the age of eight months. Contrary to our expectations and some other studies indicating that more matured sleep in infancy is connected with later cognitive (Dearing et al., 2001; Sadeh et al., 1991) and language development (Dionne et al., 2011), the waking group and the non-waking group also did not differ in cognitive, language, or motor development at the age of 24 months. Instead, our results are consistent with Bernier et al. (2010, 2013) showing that the sleep of one-year-old infants was unrelated to overall cognitive development at four years of age. In addition, cross-sectional studies with one-year-old infants have indicated that sleep characteristics are not associated with overall cognitive development (Mindell & Lee, 2015; Spruyt et al., 2008). The current study thus indicates that early fragmented sleep is not related to the general psychomotor development of children, at least not when their development is followed until they are two years of age. One explanation for the previous contradictory results could relate to the variability of the methods used to study development in infancy. In our study, psychomotor development in infancy was measured using a robust and widely used method that utilises different aspects of development. In addition, previous studies have studied correlations between different sleep parameters and development, whereas in our study we investigated differences between two clearly distinguishable groups, i.e., infants with and without fragmented sleep.

In our study, the infants with frequent night awakenings did not sleep more during the day than other infants: it seems that they do not compensate for their lack of sleep during the day. It has been suggested that fragmented sleep in infants would result in restricted sleep duration (Acebo et al., 2005). Sleep restriction and/or disturbed nocturnal sleep could then longitudinally have harmful effects on development. In the current study, fragmented sleep did not have a negative effect on overall psychomotor development at the age of 24 months even though the infants in the waking group slept less in general compared to the non-waking group. It is possible that the influence of fragmented sleep on psychomotor development would be evident longitudinally when the infants get older or with infants who continue to have severe sleep fragmentation at older ages. Only sparse studies have investigated shorter and longer sleep duration in connection with psychomotor development. In school-aged children, shorter sleep duration has been negatively associated with cognitive development (Paavonen et al., 2010; Touchette et al., 2007). In addition, Touchette et al. (2007) suggested that shortened sleep duration before 3-4 years of age would be longitudinally associated with slower cognitive development even if sleep duration normalises. Within the first two years of life, our results are not consistent with this suggestion, but more research is clearly necessary to determine the long-term influences of sleep fragmentation during the early years.

Even though in the current study the effects of fragmented sleep are not seen in overall development, it is possible that differences could be observed in more specific neurocognitive functions such as attention and executive functioning. This notion is supported by prior studies suggesting that sleep is connected with higher-order cognitive functioning, but not with general cognitive ability as early as the preschool years (Bernier et al., 2013; Bernier et al., 2010; Sadeh, Gruber, & Raviv, 2003) and at school age (Astill et al., 2012; Randazzo, Muehlbach, Schweitzer, & Walsh, 1998). Associations between night awakenings and sustained attention and working memory have been found in school-age children (Sadeh, Gruper, & Raviv, 2002). In addition, a longitudinal study by Sadeh et al. (2015) found that larger number of night awakenings at one year of age predicted poorer attention regulation at three to four years. Finally, the role of sleep on more specific cognitive processes is also supported by experimental studies investigating the effects of napping on infant word-learning and memory consolidation (Gomez, Bootzin, & Nadel, 2006; Seehagen, Konrad, Herbert, & Schneider, 2015). In future studies, including data collected within the CHILD-SLEEP cohort, the influence of early-onset fragmented sleep on more specific domains of cognitive development, as well as the stability of these possible effects, should be further investigated.

Interestingly, in our study, co-sleeping with the parent, the infants' ability to fall asleep alone, and whether the child was breastfed at 8 months of age did not have an influence on the number of night awakenings longitudinally at 18 or 24 months of age whereas in other studies concurrent and also long-term associations between these factors have been found (Hysing et al., 2014; Sadeh, et al., 2009; Touchette et al., 2005). However, the ability to fall asleep alone was connected to sleep onset latency, suggesting that night awakening should not be studied in isolation but rather in conjunction with relevant associated factors.

In the present study, we relied only on parental reports of infant sleep and did not utilise more objective information, such as actigraphy, which was also gathered as part of the CHILD-SLEEP cohort. We were interested in night awakenings signalled to the parents, and thus parental questionnaires were considered the best measure to this aim. The studies that have compared parental questionnaires, parent-reported sleep diaries, and actigraphy measures have found them to have moderate to strong correlations (Sadeh, 2004). The main differences between the actigraphy and questionnaire data have regarded the number of night awakenings, with the parental questionnaires underestimating the number of night awakenings.

One specific feature of the current study was that the sample was drawn from the prevention sub-study in which half of the infants were from the so-called prevention healthcare centres and the rest from the control healthcare centres. The families in the prevention healthcare centres received preventive psychoeducation on infant sleeping habits through brochures, whereas the control healthcare centres received no preventive sleep material. However, infants in both groups came from both healthcare centres. In addition, the healthcare status of the child was taken into account in our analyses and in the models, and it did not have significant effects on the different sleep quality and duration parameters and psychomotor development. To verify that including the prevention healthcare centre did not confound our results regarding psychomotor development and sleep parameters, we conducted the analyses again using only infants from the control healthcare centre. The results remained largely unchanged despite reduced sample size. Therefore, it could be concluded that the inclusion of infants from the prevention healthcare centres did not confound our results. Another potential limitation concerning our sample was that the group status was determined at the age of eight months and kept the same irrespective of the number of night awakenings at 18 and 24 months of age. Therefore, it is possible that an infant with fragmented sleep at eight months of age could have developed to sleep without night awakenings by the age of 24 months. However, we were interested in the effects of early-onset fragmented sleep and on the group level, the two groups differed in the number of night awakenings even at the age of 24 months. There may also be moderating factors that were not controlled in this study. Our sample consisted of Caucasian infants of mainly middle class origin and, therefore, the generalisability of the results to other ethnicities and sociodemographic groups is limited. In overall, the limitations of the study should be taken into account in considering the generalisability of the results.

In conclusion, while infants with fragmented sleep showed persistence in night awakening and stable differences also in other sleep quality and duration parameters compared to infants without fragmented sleep, general psychomotor development in infancy from eight to 24 months of age did not differ between the groups. In our sample, the infants with fragmented sleep slept less in total than the infants without fragmented sleep, and they did not compensate for their lack of sleep during the day. Within the CHILD-SLEEP cohort, we will be able to investigate whether waking infants continue to have shorter total sleep time at older ages. Further studies are also needed to find out whether short overall sleep duration could be an additional factor contributing to night awakening, together with other factors such as temperament and parental behaviour. In addition, our findings suggest that night awakening should not be studied in isolation but rather in conjunction with relevant associated factors. Finally, in addition to overall psychomotor development, more precise neurocognitive factors such as attention and executive functions should also be studied in order to find out whether fragmented sleep could be connected to more specific facets of cognitive development.

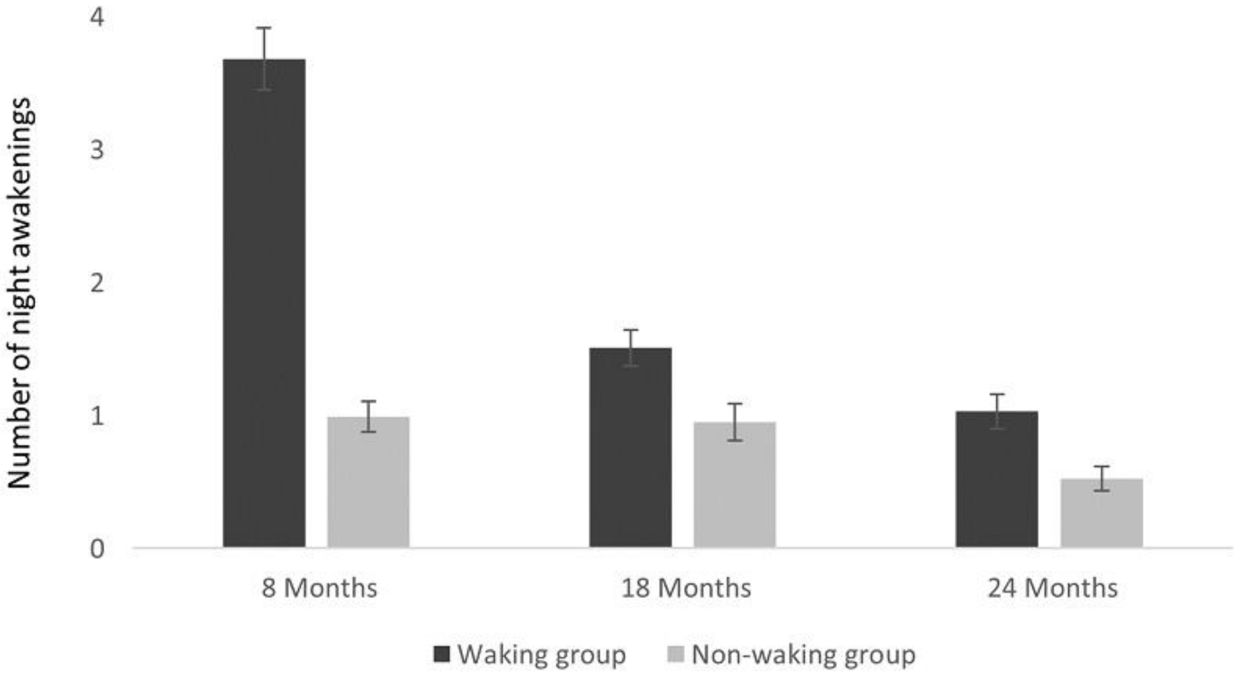
Table 1

Descriptive statistics according to group

	Waking group		Non-waking group	
	n	%	*n*	%
Gender				
girls	37	51.4	35	48.6
boys	43	55.1	35	44.9
Siblings				
yes	28	45.9	33	54.1
no	50	58.8	35	41.2
Mother's education				
> 15 years	38	54.3	32	45.7
< 15 years	42	53.2	37	46.8
Health care centre				
prevention	45	61.6	28	38.4
control	36	46.2	42	53.8
Co-sleeping				
< 2 times a month	39	43.3	4	56.7
> once in a week	30	88.2	51	11.8
Breastfeeding				
breastfed only	45	69.2	20	30.8
breastfed and formula fed	16	57.1	12	42.9
formula fed only	16	35.6	29	64.4
Falling asleep alone				
once in a week	53	71.6	21	28.4
once in a day	23	35.9	41	64.1

Figure 1.

Group differences in the averaged number of night awakenings across time



Note. Error bars depict the standard error of mean.

Table 2
Means and standard deviations of sleep quality and duration parameters from the BISQ questionnaire according to group

	Waking group		Non-waking group	
	M (SD)	Range	M (SD)	Range
8 mo				
Sleep quality				
Night awakenings	3.8 (2.0)	0 – 12	0.9 (0.8)	0 – 4.5
Awake during the night (min)	30.6 (25.7)	0 – 120	15.4 (20.3)	0 – 120
Sleep latency (min)	24.8 (16.9)	0 – 90	18.4 (15.3)	2 – 90
% of night-time sleep	75.9 (5.8)	62 – 87	74.6 (6.5)	50 – 85
Sleep duration				
Total sleep (min)	778.8 (72.7)	600 – 960	801.9 (63.5)	540 – 930
Night-time sleep (min)	589.9 (58.4)	450 – 750	596.9 (57.4)	420 – 690
Daytime sleep (min)	188.4 (53.6)	90 – 310	205.0 (62.3)	110 – 420
18 mo				
Sleep quality				
Night awakenings	1.5 (1.1)	0 – 5	0.9 (1.0)	0 – 4
Awake during the night (min)	11.7 (16.0)	0 – 90	7.1 (15.3)	0 – 90
Sleep latency (min)	22.2 (17.2)	1 – 67.5	15.5 (11.1)	0 – 60
% of night-time sleep	83.7 (4.7)	68 – 93	83.1 (5.2)	67 – 100
Sleep duration				
Total sleep (min)	728.4 (63.0)	570 – 930	739.3 (52.1)	600 – 900
Night-time sleep (min)	608.8 (52.7)	450 – 720	613.3 (43.3)	480 – 720
Daytime sleep (min)	119.6 (40.8)	45 – 300	126.4 (43.1)	0 – 300
24 mo				
Sleep quality				
Night awakenings	1.0 (0.9)	0 – 4	0.5 (0.6)	0 – 2.5
Awake during the night (min)	11.1 (12.3)	0 – 50	4.9 (9.0)	0 – 50
Sleep latency (min)	23.9 (18.1)	0 – 90	18.0 (12.3)	1 – 60
% of night-time sleep	84.9 (5.1)	60 – 96	84.4 (5.0)	64 – 100
Sleep duration				
Total sleep (min)	694.8 (45.3)	600 – 780	720.1 (54.2)	630 – 900
Night-time sleep (min)	589.4 (46.4)	450 – 660	605.9 (37.2)	540 – 660
Daytime sleep (min)	105.4 (38.9)	30 – 300	114.2 (45.1)	0 – 300

Table 3

Means, standard deviations and range of standard points of Bayley-III subscales according to group

	Waking group		Non-waking group	
	M (SD)	Range	M (SD)	Range
8 mo				
Cognitive	12.2 (1.8)	8 – 16	12.1 (1.7)	8 – 16
Receptive language	7.8 (1.5)	4 – 11	7.8 (1.5)	4 – 11
Expressive language	10.3 (1.7)	6 – 14	10.1 (1.9)	6 – 14
Fine motor	10.9 (2.1)	6 – 17	10.9 (2.4)	5 – 17
Gross motor	8.7 (2.4)	4 – 14	8.2 (2.8)	3 – 15
24 mo				
Cognitive	11.2 (2.3)	7 – 19	11.1 (2.3)	5 – 17
Receptive language	12.4 (2.5)	6 – 19	11.7 (2.5)	1 – 17
Expressive language	10.0 (2.8)	4 – 15	9.9 (2.7)	2 – 15
Fine motor	11.6 (2.1)	7 – 18	11.1 (1.8)	7 – 15
Gross motor	9.4 (2.3)	5 – 18	9.3 (1.6)	5 – 15

Table 4
Statistics of the final models for different sleep parameters and Bayley-III subscales

	ICC	Estimate	SE	95% CI	*t*	*p*
Night awakening	.70					
Intercept		.51	.11	.30 – .72	4.74	< .001
Time						
18 mo vs 24 mo		.45	.13	.20 – .70	3.59	< .001
waking group vs non-waking group		.54	.13	.30 – .79	4.32	< .001
Awake during the night	.41					
Intercept		4.74	1.56	1.65 – 7.83	3.04	.003
Time						
8 mo vs 24 mo		15.79	2.36	11.14 – 20.45	6.70	< .001
18 mo vs 24 mo		1.37	1.68	-1.95 – 4.69	.82	.415
Group						
waking group vs non-waking group		6.46	1.89	2.72 – 10.20	3.43	.001
Sleep onset latency	.62					
Intercept		15.69	2.00	11.73 – 19.67	7.81	< .001
Time						
8 mo vs 24 mo		.26	1.86	-3.41 – 3.93	.14	.889
18 mo vs 24 mo		-2.74	1.69	-6.08 – .61	-1.62	.108
Group						
waking group vs non-waking group		3.94	2.12	-.24 – 8.14	1.86	.065
Ability to fall asleep						
once in a week vs once in a day		6.25	2.11	2.07 – 10.42	2.96	.004
Proportion of night-centred sleep	.31					
Intercept		83.92	.67	82.60 – 85.24	125.61	< .001
Time						
8 mo vs 24 mo		-9.07	.63	-10.32 – -7.83	-14.39	< .001
18 mo vs 24 mo		-1.09	.55	-2.18 – .007	-1.97	.051
Group						
waking group vs non-waking group		.87	.72	-.56 – 2.31	1.21	.230
Total sleep time	.56					
Intercept		717.77	6.49	704.95 – 730.60	110.56	< .001
Time						
8 mo vs 24 mo		82.24	6.07	70.26 – 94.21	13.57	< .001
18 mo vs 24 mo		27.46	5.46	16.65 – 38.26	5.03	< .001
Group						
waking group vs non-waking group		-19.43	7.90	-35.06 – -3.80	-2.46	.015
Night-time sleep	.55					
Intercept		600.74	6.28	588.37 – 613.10	95.64	< .001
Time						
8 mo vs 24 mo		-2.45	6.08	-14.50 – 9.59	-.40	.687
18 mo vs 24 mo		15.08	5.70	3.84 – 26.32	2.64	.009
Group						

waking group vs non-waking group		-9.07	6.62	-22.17 – 4.02	11.37	.173
Daytime sleep	.35					
Intercept		117.34	5.63	106.21 – 128.47	20.85	< .001
Time						
8 mo vs 24 mo		84.04	5.49	73.21 – 94.87	15.32	< .001
18 mo vs 24 mo		11.87	4.45	3.05 – 20.68	2.67	.009
Group						
waking group vs non-waking group		-10.06	6.35	-22.63 – 2.51	-1.58	0.116
Cognitive subscale	.10					
Intercept		11.11	.24	10.64 – 11.58	46.72	< .001
Time						
8 mo vs 24 mo		1.02	.25	.53 – 1.50	4.13	< .001
Group						
waking group vs non-waking group		.09	.23	-.37 – .55	.40	.689
Receptive language subscale	.01					
Intercept		11.94	.22	11.50 – 12.38	53.82	< .001
Time						
8 mo vs 24 mo		-4.29	.24	-4.77 – -3.82	-17.71	< .001
Group						
waking group vs non-waking group		.31	.24	-.17 – .79	1.28	.202
Expressive language subscale	.25					
Intercept		9.89	.28	9.33 – 10.45	35.04	< .001
Time						
8 mo vs 24 mo		.20	.29	-.36 – .76	.69	.488
Group						
waking group vs non-waking group		.15	.25	-.33 – .64	.62	.534
Fine motor subscale	-.05					
Intercept		11.25	.22	10.81 – 11.68	50.81	< .001
Time						
8 mo vs 24 mo		-.48	.26	-.98 – .03	-1.86	.064
Group						
waking group vs non-waking group		.22	.25	-.27 – .71	.88	.380
Gross motor subscale	.27					
Intercept		9.24	.24	8.77 – 9.70	38.90	< .001
Time						
8 mo vs 24 mo		-.88	.28	-1.43 – -.33	-3.13	.002
Group						
waking group vs non-waking group		.22	.28	-.33 – .77	.79	.428

Note. ICC = intraclass correlation, SE = standard error.

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PUBLICATION
II

Night Awakening and Its Association With Executive Functioning Across the First Two Years of Life

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Longitudinal associations between signaled night awakening and executive functioning (EF) at 8 and 24 months in children with (≥ 3 awakenings, n = 77) and without parent-rated fragmented sleep (≤ 1 awakening, n = 69) were studied. EF was assessed with the Switch task at 8 and 24 months. At 24 months, behavioral tasks and parental ratings of EF (Behavior Rating Inventory of Executive Function–Preschool version) were also used. In the Switch task, children with fragmented sleep were less able to learn stimulus sequences and inhibit previously learned responses than children without fragmented sleep. The groups differed only marginally in parental ratings of EF, and no differences were found in behavioral EF tasks. These results suggest that eye movement-based measures may reveal associations between sleep and EF already in infancy and toddlerhood.

Sleep can be considered one of the most important functions during early development. By the age of 2 years, an infant has spent over half of his or her life in a sleeping state (Dahl, 1996a). In infancy, a typical feature of sleep is its fragmentation (i.e., night awakenings that are followed by periods of wakefulness after sleep onset). Night awakenings are normative between sleep stages (Anders, 1978), but persistent signaled night awakenings are a burden for the entire family (Sadeh, Flint-Ofir, Tirosh, & Tikotzky, 2007). Signaled night awakening refers to night awakenings that are signaled to their parent, for example, with crying. Approximately 20%–30% of 1-year-old infants (Adair, Zuckerman, Bauchner, Philipp, & Levenson, 1992; Mindell, Kuhn, Lewin, Meltzer, & Sadeh, 2006) and still 15%–50% of 2- to 5-year-old children continue to have night awakenings (Hysing, Sivertsen, Garthus-Niegel, & Eberhard-Gran, 2016; Petit, Touchette, Tremblay, Boivin, & Montplaisir, 2007). Several child- and parent-related factors have been associated with increased night awakening. These factors include the child's temperament and parental practices when putting the child to sleep, co-sleeping with the infant, and whether the child is breastfed or not (Hysing et al., 2014; Sadeh, Mindell, Luedtke, & Wiegand, 2009; Touchette et al., 2005). According to previous studies, however, the direction of causality between these factors and night awakening is still not clear. Researchers have attempted to determine whether fragmented sleep is also a risk factor for the child's psychological development, and whether some aspects of development are more

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vulnerable to the effects of fragmented sleep than others (Sadeh, Gruber, & Raviv, 2002). In infancy, however, the connections between sleep and development have not been sufficiently studied. Recent research has suggested that one area that might be especially vulnerable to the effects of sleep fragmentation is executive functioning (EF), due to its long course of maturation and strong associations with the development of the frontal lobes (Bernier, Beauchamp, Bouvette-Turcot, Carlson, & Carrier, 2013).

The development of EF begins during infancy and continues into early adulthood. EF refers to higher-order cognitive processes, and it consists of interrelated functions such as impulse control, set shifting, and working memory (Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000). EF is considered part of the broader concept of self-regulation, which refers to the flexible control of cognition, emotion, and behavior (Bridgett, Burt, Edwards, & Deater-Deckard, 2015; Nigg, 2017). The first 6 years of human life play a critical role in the development of EF (Garon, Bryson, & Smith, 2008; Zelazo, Carter, Reznick, & Frye, 1997). During early development, parents externally regulate their infant's behavior by directing their attention and helping infants in inhibiting their own behavior. After the first year, more emphasis is given to the child's internal regulation, with working memory and inhibition developing first. Set shifting requires and builds upon working memory and inhibition, and it therefore develops later than the other EF components (Garon et al., 2008). Previous studies have shown modest stability in EF during infancy, with the size of the association depending on the EF component being measured (Bernier, Carlson, Bordeleau, & Carrier, 2010; Wolfe, Zhang, Kim-Spoon, & Bell, 2014). The stability of EF has been found to increase during childhood (Best & Miller, 2010). In general, EF skills have been found to predict, for example, later school success (Borella, Carretti, & Pelegrina, 2010; Duncan et al., 2007) and quality of life (Brown & Landgraf, 2010; Davis, Marra, Najafzadeh, & Liu-Ambrose, 2010).

Previous studies with school-aged children and adolescents have shown that sleep difficulties impair performance in EF-related tasks (Astill, Van der Heijden, Van IJzendoorn, & Van Someren, 2012). For example, studies with school-aged children have supported the notion that shorter nocturnal sleep duration (Astill et al., 2012; Steenari et al., 2003) and sleep fragmentation (Sadeh et al., 2002) are negatively connected to EF. Sadeh, Gruber, and Raviv (2003) also showed that 30 min of extended sleep enhanced children's performance in a task measuring sustained attention and inhibition, but no enhancement was seen in tasks that required low cognitive load. In preschool-aged children, shorter nocturnal sleep duration has been associated with poorer attentional control (Lam, Mahone, Mason, & Scharf, 2011) and mother-reported EF skills (Taveras, Rifas-Shiman, Bub, Gillman, & Oken, 2017). Thus, based on these studies with preschool- and school-aged children, sleep duration and sleep fragmentation appears to influence EF. It is not clear, however, if the connections between fragmented sleep and EF can be observed already in infancy.

In infancy, the significance of sleep might be even greater than later in development due to major ongoing developmental processes in both sleep and neuro-behavioral functioning (Dahl, 1996b). However, only a few longitudinal studies have investigated the associations between sleep quality and EF in infancy. Bernier et al. (2010) showed that the amount of night-centered sleep at 12 and 18 months of age was positively related to performance in a behavioral EF task that required impulse control when the infants were 26 months old. In addition, infants whose sleep was more focused to the nighttime at 18 months of age showed increased performance in a concurrent working memory task. In their follow-up study, the amount of nighttime sleep at 12 months of age was positively related to EF even at the age of 4 years (Bernier et al., 2013). Thus, it appears that over time, more matured sleep benefits performance in EF tasks.

The relation between EF and night awakening in infancy, however, is not clear. Night awakening is a common concern for parents, and persistent night awakening also disrupts parents' sleep and can result in prolonged sleep deprivation (Karraker, 2008). Previous studies have shown that parental sleep patterns are highly connected to their children's sleep patterns (Boergers, Hart, Owens, Streisand, & Spirito, 2007; Gay, Lee, & Lee, 2004; Meltzer & Mindell, 2007). Sadeh et al. (2015) found that a greater amount of night awakenings in 1-year-olds predicted poorer performance in a computerized method of attention regulation at 3–4 years of age, whereas Bernier et al. (2010) did not find a relation between night awakenings at 1 year of age and behavioral EF measures at 2 years of age. These behavioral measures consisted of tasks measuring working memory, inhibitory control, and set shifting. The results of these two studies are not entirely comparable since they used very different methods for measuring EF and the domain of EF being studied varied. EF was also measured at two different developmental periods, which may further explain the conflicting results. In addition, Sadeh et al. (2015) measured night awakenings with actigraphy whereas Bernier et al. (2010) measured night awakenings with sleep diaries that were filled by mothers. Additionally, night awakening and its influence on EF has not been studied in infants under 1 year of age.

In recent years, new methods have emerged that enable the study of EF in infants under 1 year of age (Best & Miller, 2010; Kovács & Mehler, 2009), but they have not been utilized in the field of sleep research. In this study, we used the Switch task, developed by Kovács and Mehler (2009), which is an eye movement-based measure of infant EF. In the Switch task, infants are first required to learn a predictable stimulus sequence and, in the second phase, to inhibit their previously learned response in order to learn a new conflicting response. Hence, the Switch task may require each EF domain, although in infancy and toddlerhood, EF may manifest as a more unitary construct and the different domains of EF may not be easily distinguishable (Espy, Sheffield, Wiebe, Clark, & Moehr, 2011; Shing, Lindenberger, Diamond, Li, & Davidson, 2010; Wiebe, Espy, & Charak, 2008). However, the Switch task has been used in previous studies as an early indicator of these abilities (Kovács & Mehler, 2009; Wass, Porayska-Pomsta, & Johnson, 2011). In a study of bilingual infants, Kovács and Mehler (2009) showed that bilingual infants are better able to inhibit their responses and learn a new conflicting response than monolingual infants. In addition, Forssman et al. (2017) have shown the Switch task to be a feasible method in various cultures and in socioeconomically challenging settings in infants under 1 year of age. The Switch task has also been used as an indicator of EF in a study of attentional control training in infants (Wass et al., 2011). One advantage of the Switch task in this study is that it can be used longitudinally, as the same task could be presented to both 8- and 24-month-old children. In addition, at 24 months of age we also used three different behavioral measures that are suitable for 2-year-olds, and a parental evaluation of toddler EF. These behavioral tasks are administered to the child in a playful manner (Carlson, 2005) and were chosen so that all aspects of EF could be measured, including working memory (Spin the Pots; Hughes & Ensor, 2005), set shifting (Trucks task; Hughes & Ensor, 2005), and inhibitory control (Snack Delay; Kochanska, Murray, & Harlan, 2000).

In this study, we studied signaled infant night awakening and its concurrent and longitudinal associations with children's EF. Our study concentrates on sleep in infancy and toddlerhood and its connection with EF, a topic that has received little attention in previous studies. In addition, our goal was to combine novel eye-movement-based methods with an adequate sample size in the study of infant EF. For that purpose, two groups of infants with and without signaled night awakenings were formed at the age of 8 months within the CHILD-SLEEP birth cohort (Mäkelä et al., 2018; Paavonen et al., 2017). In an additional analysis, actigraphy data were used to assess the validity of the group formation based on parent-reported night awakening. In this study, we measured EF with the Switch task (Kovács & Mehler, 2009) at 8 and 24 months of age. Our goal was to measure EF with various methods and, therefore, at 24 months of age, we also included age-appropriate behavioral tasks for the measurement of EF together with a parent-rated measure of EF. Our aim was to investigate whether signaled night awakening at 8 months of age is connected to infant EF, and whether the possible differences in EF could be observable already during the first year of life. For the hypotheses regarding the 8-month data, we adopted an exploratory approach and had no definitive hypothesis on the associations between signaled night awakening and infant EF, since in prior studies, signaled night awakening and EF have not been studied in infants under 1 year of age. At 24 months of age, however, we expected that the children with several signaled night awakenings at 8 months of age would show lower performance in various EF tasks and parent-rated EF, as suggested by studies conducted with older children (Sadeh et al., 2015; Sadeh et al., 2002).

Method

Participants

The participants of this study were recruited from within the CHILD-SLEEP longitudinal birth cohort, $n = 1{,}667$ (Mäkelä et al., 2018; Paavonen et al., 2017). The participants for the cohort were recruited through maternity clinics approximately on 32nd gestational week by their maternity nurse. Participating families received questionnaires before birth and when their child was 3, 8, 18, and 24 months of age. There were separate questionnaires for mothers, fathers, and the child. In order to form two groups of infants based on the number of signaled night awakenings, the parents of 8-month-old infants from one substudy of the cohort (n = 406) were approached through a phone call and asked how many times their infant woke during the night. Infants with three or more signaled night awakenings during the night (between midnight and 6 a.m.) were asked to participate in the study; they formed the waking group. Infants with no more than one signaled night awakening during the night formed the nonwaking group. Infants with two signaled night awakenings were not included in this study, as our aim was to compare two clearly distinguishable groups in the analyses. The Ethics Committee of Pirkanmaa Hospital District reviewed the study protocol (R11032) and the parents completed a consent form before participation. The children received a small toy for their participation at both assessment points. In total, 146 white Finnish infants participated at 8 months of age, with 77 infants in the waking group (M_{age} = 0.5 months, SD = 0.4 months) and 69 infants in the nonwaking group (M_{age} = 8.6 months, SD = 0.4 months). At 24 months of age, 65 infants from the waking group (M_{age} = 24.6 months, SD = 2.2 months) and 56 infants from the nonwaking group (M_{age} = 24.5 months, SD = 2.9 months) returned for another assessment (n = 121, 83% retention rate). There were no differences between the participants who remained or dropped out of the study after the 8-month assessment in the Switch task performance or parent-reported sleep parameters (nocturnal, daytime, and total sleep duration, time spent awake during the night, and sleep latency), all ps > .192. Two additional participants were examined but excluded from further analysis due to prematurity (n = 1) and the parents' native language being other than Finnish (n = 1). The demographic statistics of the sample are shown in Table 1. At 8 months of age, we had actigraphy data from 88% of the participants in the waking group (n = 68) and 89% of participants in the nonwaking group (n = 61). At 24 months of age, the retention rate was lower so that only 55% of the waking group (n = 36) and 50% of the nonwaking group (n = 28) returned the actigraphy assessment. Therefore, the actigraphy data are reported only for the 8-month assessment point. The waking group and the nonwaking group did not differ in overall psychomotor development (measured with the Bayley-III) or in other child- or mother-related features (child's gender and age, number of children in the family, or maternal education; for details, see Mäkelä et al., 2018). At 8 months of age, however, the two groups differed in the amount of cosleeping ($\chi^2(1, n = 119) = 20.376$, $p < .001$), breastfeeding ($\chi^2(1, n = 133) = 13.413$, $p = .001$), and the infant's ability to fall asleep alone ($\chi^2(1, n = 133) = 16.454$, $p < .001$; Table 1). The infants in the waking group were more likely to co-sleep with their parents, be breastfed and not be able to fall asleep alone than the infants in the nonwaking group. For the analysis, these variables were categorized. Cosleeping was categorized as less than twice in a month or at least weekly cosleeping with the parent. The ability to fall asleep alone was categorized as the infant being able to fall asleep alone only once in a week or at least once a day. Breastfeeding was categorized as the infant being only breastfed, both breastfed and formula fed, or only formula fed. Therefore, these three factors were included in the analysis as covariates, even though in our previous work, these covariates were not connected to psychomotor development (Mäkelä et al., 2018). The infants in this study were recruited from a prevention substudy of the main cohort in which healthcare centers in Tampere, Finland, were randomized into prevention and control healthcare centers. Families in the prevention group received preventive psychoeducation on how to support infant sleep quality through brochures, whereas the control group received standard well-child visit information. The infants in this study came from both the prevention and control healthcare centers ($\chi^2(1, n = 146) = 3.394$, $p = .065$; Table 1). The healthcare center status was included as a covariate in the analyses to determine whether it affected the findings. Finally, our previous work showed that the infants with fragmented sleep had a shorter total sleep duration and spent more time awake during the night (Mäkelä et al., 2018). These sleep characteristics were also included as covariates in our analysis. A comprehensive description of the different sleep parameters in the waking and nonwaking groups is provided in Table 2.

Procedure

The study protocol consisted of two separate research visits at both 8 and 24 months of age. During the first visit, psychomotor development was measured (reported in reported in Mäkelä et al., 2018). During the second research visit, the EF-related tasks were conducted in the research laboratory. At 8 months of age, the research visit consisted of computer tasks measuring EF (i.e., the

Table 1
Descriptive Statistics for the Two Groups

	Waking group		Nonwaking group		
	n	%	*n*	%	*p*
Gender					.889
Girls	33	43.4	34	49.3	
Boys	43	56.6	35	50.7	
Siblings					.354
Yes	27	36.5	33	34.2	
No	47	63.5	34	50.7	
Mother's education					.210
> 15 years	36	47.4	31	45.2	
< 15 years	40	52.6	37	54.8	
Father's education					.671
> 15 years	55	70.5	45	70.3	
< 15 years	23	29.5	16	25.0	
Mother's monthly net income					.377
> 2,000€	23	29.5	23	35.9	
1,000–2,000€	39	50.0	24	37.5	
<1,000€	14	17.9	14	21.9	
Father's monthly net income					.492
> 2,000€	49	62.8	42	65.6	
1,000–2,000€	20	25.6	16	25.0	
<1,000€	8	10.3	3	4.7	
Healthcare center					.065
Prevention	43	55.8	28	40.6	
Control	34	44.2	41	59.4	
Co-sleeping					< .001
> Once in a week	29	44.6	4	7.4	
< 2 times a month	36	55.4	50	92.6	
Breastfeeding					.002
Breastfed only	43	58.9	20	33.3	
Breastfed and formula fed	16	21.9	11	55.0	
Formula fed only	14	19.2	29	48.3	
Falling asleep alone					< .001
Once in a week	49	68.1	20	32.8	
Once in a day	23	31.9	41	67.2	

Switch task) and attention to emotional faces (reported elsewhere), and a separate assessment of child–parent interaction (reported elsewhere). At the age of 24 months, the same tasks were conducted. In addition, at 24 months, three different age-appropriate behavioral EF tasks (Spin the Pots, Trucks, and Snack Delay) were conducted with the child, and the parents filled a questionnaire concerning the child's EF in everyday life (the Behavior Rating Inventory of Executive Function–Preschool version, BRIEF-P; Gioia, Espy, & Isquith, 2003). The questionnaire was given to the parents during the first research visit and they were asked to return it during the second research visit. A fixed order of tasks was kept throughout the data collection. The EF tasks were conducted in a separate room after the computer tasks. The Spin the Pots task was conducted first, followed by the Trucks task and the Snack Delay task. After the data collection had been completed, it transpired that there were inconsistencies in the presentation of the material in the Trucks task between experimenters. Consequently, the Trucks task was excluded from the data analyses. Finally, in the information letter send to the participants before the first research visit at both ages, the participant received an actigraph device to be worn at home for three consecutive days together with a comprehensive sleep-log, and were asked to return them via mail.

Measures

8-Month EF Assessment

The *Switch task* assesses the ability of children to learn new stimulus sequences and to inhibit their response to a previously learned cue in order to learn a new conflicting response. During the Switch task, the infant sat on his or her parent's lap at an approximately 60-cm distance from a 19-in. computer screen, which was surrounded by a black frame. A video camera was hidden on top of the computer screen in order for the experimenter to observe the child and control stimulus presentation. In addition, video recordings of the Switch task were saved for offline analyses of eye movements. The task was presented with E-prime software (Psychology Software Tools, Pittsburgh, PA). Before starting the task, the lights were dimmed. Parents were instructed not to interact with their child unless it was necessary to soothe the child during the stimulus presentation. In addition, the parents were told that the researcher controlled the stimulus presentation and would start each trial only after the child's eyes were focused on the screen.

Each trial started with a red circle appearing on a gray background. The red circle expanded from 0.4° to 4.3° in a continuous fashion in order for the child to focus his or her eyes on the screen. When the child's eyes were focused on the screen, the experimenter initiated each trial. If the child did not focus on the screen, the experimenter called the child by name and initiated the trial only after the child focused on the screen. After that, each trial started with the background turning white, and a brief (350 ms) auditory beep stimulus was presented from a speaker positioned behind the

Table 2
Descriptive Statistics in Parent-Reported and Actigraphy-Based Sleep Parameters at 8 and 24 Months of Age

	Waking group			Nonwaking group		
	n	*M*	*SD*	*n*	*M*	*SD*
8 months						
Parent-reported						
Duration of nocturnal sleep (min)	75	589.9	58.4	60	597.8	55.7
Duration of daytime sleep (min)	76	188.4	53.6	60	204.8	63.1
Duration of total sleep (min)	75	778.8	70.9	60	802.6	60.5
Sleep latency (min)	74	24.8	16.9	57	18.2	15.5
Time spent awake at night (min)	69	30.6	25.7	48	15.8	20.6
Night awakenings (count)	73	3.8	1.9	54	0.9	0.6
Proportion of nighttime sleep (%)	75	75.9	5.8	60	74.7	6.6
Actigraphy-based						
Actual sleep time (min)	67	511.1	55.0	61	518.5	56.6
Sleep latency (min)	66	19.3	19.3	58	17.8	22.1
Sleep efficiency (%)	66	78.7	6.2	58	79.1	6.8
Proportion of nighttime sleep (%)	37	85.7	5.7	31	85.1	6.6
Activity score in active periods (count)	68	127.0	48.7	60	102.6	46.6
24 months						
Parent-reported						
Duration of nocturnal sleep (min)	53	589.4	46.4	41	605.5	37.9
Duration of daytime sleep (min)	53	105.4	38.8	41	114.6	46.1
Duration of total sleep (min)	53	694.8	45.3	41	720.6	55.5
Sleep latency (min)	48	23.9	18.1	38	17.9	12.5
Time spent awake at night (min)	46	11.8	12.3	38	4.0	9.0
Night awakenings (count)	50	1.0	0.9	40	0.6	0.6
Proportion of nighttime sleep (%)	53	84.9	5.1	41	84.3	5.1
Actigraphy-based						
Actual sleep time (min)	35	539.7	43.0	28	542.8	46.6
Sleep latency (min)	36	26.6	18.7	28	22.3	15.0
Sleep efficiency (%)	36	81.7	5.6	28	83.8	4.2
Proportion of nighttime sleep (%)	31	87.4	7.4	17	89.4	5.9
Activity score in active periods (count)	36	82.8	31.8	28	76.4	31.0

midpoint of the screen. Simultaneously with the sound, two rectangles (11.6° × 11.2°) with black borders appeared on the left and right side of the screen (11.5° from the midpoint of the screen). After 1,855–1,900 ms (with an approximately 50 ms jitter in the stimulus timing caused by an inadvertent error), an animated target stimulus of a monkey doing somersaults (4.6° × 3.8°) appeared in one of the rectangles together with a bell sound for 4,000 ms. For the first nine trials, the target stimulus always appeared on the same side of the screen (*preswitch block*), after which the target appeared on the other side of the screen for the remaining nine trials (*postswitch block*). The order of the target location from pre to postswitch blocks (left-right, right-left) was balanced across participants. An example of a trial in the Switch task is shown in Figure 1. Altogether, the duration of the Switch task was 2.5 min.

24-Month EF Assessment

At 24 months of age, there were only few modifications to the Switch task. First, the stimuli were presented on a 21-in. screen compared to the 19-in. screen used at 8 months of age. Second, the toddler's eye movements were recorded with a Tobii TX300 eye-tracker (Tobii Technology AB, Stockholm, Sweden). Eye-tracker calibration and stimulus presentation were controlled with Tobii Studio software. Before starting the experiment, the eye-tracker cameras were calibrated with a five-point calibration procedure in which a cat appeared with a beep sound in every corner and in the center of the screen. Third, the Switch task was shortened from 18 to 12 trials in total (six trials to both sides).

In the *Spin the Pots* task, considered to measure working memory (Hughes & Ensor, 2005), six different treats (raisins or cereals) were hidden under

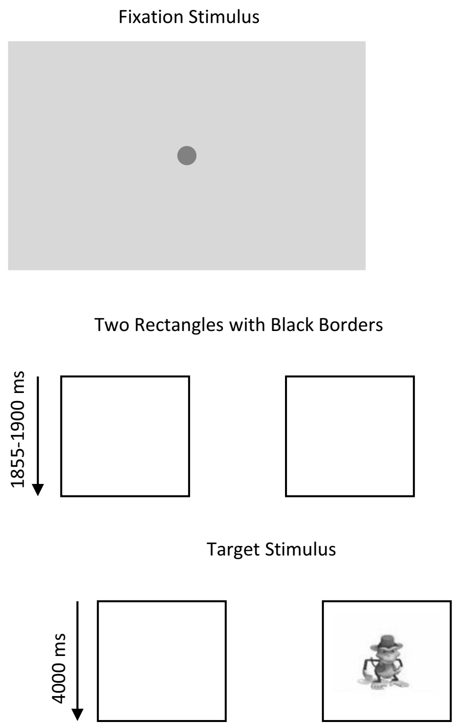

Figure 1. An example of a trial in the Switch task.

eight visually different looking opaque pots. The hiding of the treats was done in front of the toddler and two of the empty pots were also shown to the toddler. After that, the tray containing the pots was covered with a scarf and rotated 180°. Then, the toddler was asked to find the treats by looking under the pots. The toddler was allowed to eat the treats that were discovered under the pots. After each attempt, the tray was again covered and rotated 180°. The task was coded offline from video recordings. The maximum number of trials was 12. The score was calculated as the number of maximum trials minus the errors the toddler made. These errors consisted of perseverative looking or looking under the pots with no treats. The task scores varied between 0 and 12, with higher scores indicating better performance. The duration of the task varied between 2 to 8 min depending on the number of trials the toddler needed to perform the task.

In the *Snack Delay* task (Kochanska et al., 2000), which was developed to measure inhibitory control, a small candy was placed on top of a tiny candy box in front of the toddler. The toddler was told that she or he had to wait until the bell rang, and only afterward could he or she have the candy. Three different trials were performed with an increasing waiting time of 10, 20, or 30 s. The toddlers were reminded of the rule before every trial. On the 30 s trial, the experimenter placed her hand on the bell when 20 s had elapsed, but rang the bell only after 30 s. The toddlers' behavior was coded from video recordings and the score was calculated as the number of seconds the toddlers waited before touching the candy box. The task scores varied between 0 and 60, with higher scores indicating better performance. The duration of the task was approximately 2 min.

BRIEF-P is a parent-rated questionnaire that assesses EF in children from 2 years to 5 years and 11 months of age (Gioia et al., 2003; Isquith, Crawford, Espy, & Gioia, 2005). It consists of 63 items, and parents answer on a 3-point scale (*never/sometimes/often*), with higher scores representing a lower EF ability. BRIEF-P yields five different scales labeled "Inhibit," "Shift," "Emotional control," "Working memory," and "Plan/Organize," from which three different indexes are combined. These indexes are ISCI (*Inhibition Self-control Index*), FI (*Flexibility Index*), and EMC (*Emergent Metacognition Index*). The ISCI index comprises the inhibit and emotional control scales, FI comprises the shift and working memory scales, and EMC comprises the working memory and plan/organize scales. In addition, a *Global Executive Composite index* (GEC) can be formed by combining the scores of all five scales. In this study, a Finnish translation of the test was used. The raw scores of each scale were converted to age- and gender-specific standardized *t*-scores (M = 50, SD = 10) according to the original norms. Different BRIEF-P scales and indexes showed good internal consistency (Inhibit, α = .838; Shift, α = .780; Emotional control, α = .811; Working memory, α = .878; Plan/Organize, α = .782; ISCI, α = .873; FI, α = .881; EMI, α = .910; GEC, α = .943). These values are highly similar to the original alphas reported by Gioia et al. (2003).

Actigraphy-based sleep measures were gathered with Actiwatch AW7 activity monitors (Cambridge Neurotechnology Ltd, Cambridge, UK). Parents of 8-month-old infants were instructed to place the actigraphy on their infant's ankle for three consecutive days and to keep a detailed sleep-log. Actigraphs and sleep-logs were initiated at midnight and therefore the number of continuous nights varied between two to four nights depending on how many nights the parents had filled to the sleep-log.

From the sleep-log variables, parent-reported time to fall asleep and morning wake up time were used in the analysis.

Data analysis

Video Coding at 8 Months

The eye movements in the Switch task were analyzed using VirtualDubMod software 1.5.10.2 (http://virtualdubmod.sourceforge.net/). A trained observer, blind to the child's group status, coded all the videos offline. Eye movements were examined manually, frame by frame, with one frame lasting 40 ms. If the child did not focus his or her attention to the screen at the beginning of the trial, the trial was rejected. Anticipatory eye movements toward the target location (the correct rectangle where the monkey would appear) within a time window of 160 ms after trial onset until 160 ms after the target onset were coded. Eye movements were considered anticipatory if the first saccade was to the correct target location. Trials were rejected if eye movements were undetectable due to movement. The proportion of correct anticipatory eye movements toward the target location were calculated separately for the preswitch block (first nine trials) and the postswitch block (last nine trials) for all scorable/successful trials. Infants with more than three bad trials within the pre or postswitch block were excluded from the analyses. For the infants included in the analyses, the average numbers of scorable trials in the pre and postswitch blocks were 8.6 and 8.5, respectively, with no difference between the blocks ($t(242) = 1.310$, $p = .192$). To ensure coding reliability, two independent observers coded 25% of all cases ($n = 37$). Intercoder agreement (intraclass correlation) on the proportion of anticipatory looks in both the pre and postswitch blocks between the main coder and the reliability coders was .97.

Eye-Tracking Analysis at 24 Months

The eye-tracking data of the Switch task were saved as text files and analyzed with gazeAnalysisLib, a library of Matlab routines for gaze data analysis (Leppänen, Forssman, Kaatiala, Yrttiaho, & Wass, 2015). The areas of interest were manually defined, and these areas covered the central area of the screen, the rectangle where the monkey appeared, and the area between the center and the rectangle. Eye movements were coded as anticipatory if the toddler made the first saccade toward the box where the monkey would appear. The proportion of correct anticipatory eye movements was calculated similarly as in the 8-month analyses, that is, separately for the preswitch block (first six trials) and the postswitch block (last six trials) conditions. The average numbers of scorable trials in the pre and postswitch blocks were 4.3 and 3.9, respectively, with no difference between the blocks ($t(236) = 1.477$, $p = .141$). The correlations between video-based (i.e., manually coded) and eye-tracking data from children saccadic response tasks have been shown to be very high (Leppänen et al., 2015).

Actigraphy Analysis at 8 Months

Activity counts were summed over 1-min-intervals (for detailed description of the algorithm, see Oakley, 1997, and Kushida et al., 2001). Actigraphy-based sleep measures are not directly comparable to parent-reported sleep measures, especially when considering parent-reported signaled night awakening. To this end, we considered the actigraphy-based nocturnal activity measure (mean score during active periods at night) to most closely reflect the same phenomenon as signaled night awakening. Mean score during active periods is the total activity score divided by the number of epochs with greater than zero activity. In addition to this activity parameter, the actigraphy data were also analyzed with a smoothing algorithm in order to decrease the number of actigraphy-based night awakenings, many of which may represent movements that are unrelated to signaled night awakenings (Sitnick, Goodlin-Jones, & Anders, 2008). When the smoothing algorithm is applied, the start of the awakening requires two or more consecutive minutes with activity counts > 100. If these epochs are preceded by an epoch with activity count greater than zero, that epoch was considered to indicate the start of the awakening. The awakening was considered to end at the first of three consecutive minutes with no activity. The mean value of these awakenings was as calculated for two consecutive nights ensuring constant amount of data between participants.

Statistical Analysis

Statistical analyses were conducted with SPSS 25 (IBM Corp., Armonk, NY). The distributions of continuous outcome variables were screened with box-plots and scatterplots, and no extreme outliers were observed. To analyze the group differences in the Switch task longitudinally, a Linear Mixed Model (LMM) was used since the LMM allowed us to utilize the longitudinal incomplete data. In the analysis, within-factors, between-factors, and their interactions were analyzed. Age (8 and 24 months) and Block (preswitch block and postswitch block) were used as within-factors. The between-factor was Group status (waking group and nonwaking group). In addition, their interactions were included in the model. In the case of statistically significant main effects, the differences between subgroups were further analyzed using Bonferroni-corrected post hoc tests. Effect sizes for the pairwise comparisons are indicated by Cohen's d. First, we ran a model that included all the within- and between-factors and their interactions, as well as the covariates that differentiated between the two groups (cosleeping, breastfeeding, ability to fall asleep alone, healthcare center status, sleep duration, and time spent awake during the night). None of the covariates (all p-values > .184) or interactions were significant (all p-values > .113) and, therefore, the final models consisted of the within- and between-factor main effects. Group differences in the BRIEF-P questionnaire, Spin the Pot, Snack Delay, and actigraphy-based activity measures were analyzed with t-tests. The alpha level was set at $p < .05$.

Results

In the Switch task, the LMM revealed main effects of Block ($F(1, 190.949) = 63.312$, $p < .001$, $d = 1.54$) and Group ($F(1, 226.791) = 4.492$, $p = .035$, $d = 0.36$). Children had more correct anticipations in the preswitch block ($M = 0.734$, $SE = .019$) than in the postswitch block ($M = 0.478$, $SE = .021$). In addition, the nonwaking group ($M = 0.631$, $SE = .018$) had overall a higher percentage of correct anticipations than the waking group ($M = 0.580$, $SE = .017$). However, the interactions were nonsignificant [Group × Block ($F(1, 129.258) = 0.110$, $p = .741$, Group × Age ($F(1, 136.684) = 2.539$, $p = .113$), and Group × Age × Block ($F(2, 129.692) = 1.572$, $p = .212$)], indicating that the differences between groups were not specific only to the preswitch or postswitch block, or to either age. Since these interactions were nonsignificant, they were excluded from the final model.

For our research question concerning how early the potential differences in EF between infants with and without fragmented sleep would be observable, we nevertheless considered it important to further explore whether the differences between groups were already visible at 8 months of age, or whether the differences between groups were more pronounced at 24 months of age as indicated by visual inspection of Figure 2. Therefore, we decided to conduct the analyses separately for the 8- and 24-month data. Both analyses consisted of the within-factor Block and between-factor Group, and their interaction. For the final model reported here, only statistically significant factors and the between-factor Group were included. The LMM at 8 months of age indicated a main effect of Block ($F(1, 109.001) = 24.523$, $p < .001$, $d = 0.96$). Infants had a higher proportion of correct anticipations in the preswitch block ($M = 0.704$, $SE = .025$) than in the postswitch block ($M = 0.504$, $SE = .030$). However, the main effect of Group ($F(1, 108.001) = 0.102$, $p = .751$) was nonsignificant.

In the LMM at 24 months of age, significant main effects of Block ($F(1, 119) = 48.837$, $p < .001$, $d = 1.39$) and Group ($F(1, 119) = 5.269$, $p = .023$, $d = 0.43$) were observed. Toddlers had a higher proportion of correct anticipations in the preswitch block ($M = 0.769$, $SE = .030$) than in the postswitch block ($M = 0.449$, $SE = .030$). In addition, the nonwaking group ($M = 0.655$, $SE = .029$) had a higher proportion of correct anticipations than the waking group ($M = 0.563$, $SE = .027$). Together, these analyses indicated that the differences between the groups were more pronounced at 24 months of age. The Group × Block interaction remained nonsignificant in both age-specific analyses (8 months, $F(1, 119.589) = 0.038$, $p = .845$; 24 months $F(1, 119) = 0.096$, $p = .757$); thus, the differences between groups were not specific only to the preswitch or postswitch block. Statistics of the final LMM models are included in Table 3.

The behavioral EF tasks showed no significant differences between the two groups. In the Spin the Pot task, the performance of the waking ($M = 7.53$, $SD = 2.612$) and nonwaking group ($M = 7.33$, $SD = 2.678$) did not differ ($t(116) = 0.405$, $p = .686$). In addition, in the Snack Delay task no differences between the waking ($M = 36.7$ s, $SD = 24.0$ s) and the nonwaking group ($M = 39.3$ s, $SD = 23.3$ s) were found ($t(116) = -0.577$, $p = .565$).

There were no clearly significant differences between the waking group and the nonwaking group in any of the different BRIEF-P indexes (t-scores), with only the FI suggesting a marginal difference between the waking and the nonwaking group ($t(83) = 1.668$, $p = .099$; waking group $M = 64.33$, $SD = 11.97$; nonwaking group $M = 60.38$, $SD = 9.17$). Parental ratings in the ISCI index ($t(83) = 0.05$, $p = .961$; waking $M = 50.13$, $SD = 9.10$; nonwaking group $M = 50.03$, $SD = 8.92$)

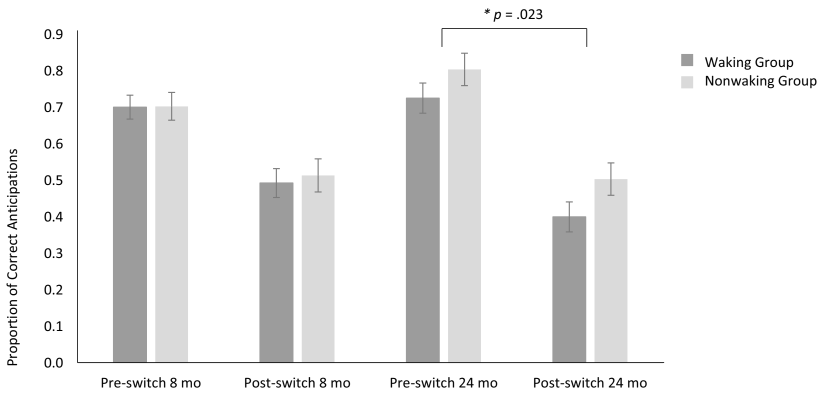

Figure 2. Group differences in the average performance of the Switch task at 8 and 24 months of age.
Note. Error bars depict the standard error of the mean.

Table 3
Statistics of the Final Models for the Switch Task Data

	Estimate	*SE*	95% CI	*t*	*p*
Across both ages					
Intercept	.503	.025	[.454, .552]	20.128	< .001
Group[a]	–.054	.025	[–.103, –.003]	–2.119	.035
Block[b]	.262	.033	[.197, .327]	7.957	< .001
8 months					
Intercept	.486	.031	[.425, .547]	15.708	< .001
Group[a]	–.001	.031	[–.051, .072]	–0.319	.751
Block[b]	.199	.040	[.120, .280]	4.942	< .001
24 months					
Intercept	.495	.037	[.422, .568]	13.354	< .001
Group[a]	–.091	.039	[–.170, –.013]	–2.295	.023
Block[b]	.319	.046	[.229, .410]	6.988	< .001

[a]Waking group versus nonwaking group. [b]Preswitch block versus postswitch block.

and EMI index showed no differences between the two groups ($t(83) = 1.343$, $p = .183$; waking group $M = 55.23$, $SD = 12.98$; nonwaking group $M = 51.73$, $SD = 10.35$). In addition, no differences in the overall GEC index between the waking group ($M = 51.83$, $SD = 11.02$) and nonwaking group ($M = 49.68$, $SD = 9.18$) were observed ($t(83) = 0.961$, $p = .339$).

In the 8-month actigraphy data, the mean activity score during active nocturnal periods differed between the groups, $t(126) = 2.883$, $p = .005$, $d = 0.52$. The mean activity scores during active periods were greater in the waking group ($M = 126.97$, $SD = 48.75$) than in the nonwaking group ($M = 102.06$, $SD = 46.59$), demonstrating that the infants in the waking group showed more nocturnal activity during activity periods than the infants in the nonwaking group. Actigraphy-based night awakening data analyzed with the smoothing algorithm further validated our group formation based on parent reports, $t(121) = 3.179$, $p = .002$, $d = 0.58$, with the waking group having more night awakenings ($M = 6.2$, $SD = 2.1$) than the nonwaking group ($M = 4.9$, $SD = 2.2$). Night awakenings based on the smoothing algorithm correlated positively with parent-reported signaled night awakenings, $r = .245$, $p = .011$. However, the mean activity score correlated only marginally with the number of parent-reported night awakenings, $r = .158$, $p = .094$, respectively.

Discussion

The aim of this study was to longitudinally investigate EF in infants with and without signaled night awakenings at 8 and 24 months of age with a comprehensive set of methods. For this study, we used an eye movement-based method (i.e., the Switch task) for investigating EF at both ages. Our aim was to find out whether signaled night awakening is associated with EF development, and whether the influence of signaled night awakening on infant EF would be evident already at 8 months of age. An exploratory approach was adopted and no definite hypothesis was formed for the 8-month-old infants, since different sleep parameters and EF have not been previously studied in infants under 1 year of age. At 24 months of age, however, in concordance with previous studies with older children (Sadeh et al., 2002; Sadeh et al., 2015), we expected that toddlers with several signaled night awakenings would show poorer performance in EF tasks and parent-rated EF than toddlers without signaled night awakening due to the early-onset fragmented sleep. Our results shed new light on the connections between night awakening and EF already during the first 2 years of life, as measured with versatile and novel methods.

Consistent with our hypothesis, the Switch task results showed that the waking group performed worse on this EF task than the nonwaking group. They had fewer anticipatory looks toward the correct stimulus location and were less able to inhibit their previous response and learn a new conflicting response compared to the nonwaking group. Our finding is consistent with that of Sadeh et al. (2002, 2015), who showed that fragmented sleep is connected to diminished EF in preschool- and school-aged children when measured with a computerized method. The expected interactions were nonsignificant and, therefore, it cannot be concluded whether the differences are more pronounced at 8 or 24 months of age, or in the first or second block of the Switch task. Considering that our central research question was whether the possible differences in EF between groups are observable already at 8 months, we nevertheless decided to conduct the analyses separately for 8 and 24 months of age, although we acknowledge that probing subgroup differences may not be advisable when the higher-order interaction is nonsignificant (Nieuwenhuis, Forstmann, & Wagenmakers, 2011). According to these age-specific analyses, the differences between the waking and the nonwaking group were not yet evident at 8 months of age. At 24 months of age, however, the waking group performed worse than the nonwaking group, thus suggesting that the differences between groups were more evident at 24 months of age. It should be stressed that these conclusions are only tentative, since the Group × Age interaction was nonsignificant. The overall analysis as well as the age-specific analysis at 24 months of age showed that the waking group performed worse on both the learning and inhibition part of the task. One possible explanation for this finding could be that EF is still maturing in infancy and toddlerhood, and the different domains of EF are not yet distinguishable (Espy et al., 2011; Shing et al., 2010; Wiebe et al., 2008). Another possibility is insufficient statistical power to detect effects of age and block especially in the three-way interaction analysis.

Contrary to our expectations, there were no differences in EF between the waking and nonwaking group when traditional behavioral measures of EF were used. However, our findings are consistent with those of Bernier et al. (2010), who also used behavioral methods and did not find a connection between night awakenings and later EF. Regarding the discrepancies between our behavioral and the Switch task results, it could be the case that computerized methods recording looking behavior on a millisecond scale are more sensitive than behavioral methods for assessing infant and toddler EF, thus being better able to detect differences in the normal range of performance. Another possibility is that the tasks used tapped into different aspects of EF. The subdomains of EF are highly interrelated and it may not be possible to design tasks that only tap into one aspect of EF (Diamond, 2013). In addition, EF undergoes rapid development in infancy, potentially making it even more difficult to distinguish its different aspects (Espy et al., 2011; Shing et al., 2010; Wiebe et al., 2008).

Also contrary to our expectations, the parental ratings of EF between the waking and nonwaking group did not differ clearly. Only a marginal difference was found in the parental ratings of flexibility, suggesting that toddlers in the waking group could be less able to perform working memory and set shifting tasks than toddlers in the nonwaking group. These findings were surprising, since in previous studies, the BRIEF-P has been found to relate to the laboratory assessments of EF and to distinguish performance in typically developing preschoolers (Ferrier, Bassett, & Denham, 2014; Garon, Piccinin, & Smith, 2016). It is possible, however, that from a parent's point of view it is difficult to distinguish the small differences in currently emerging EF skills in toddlers as young as 24 months of age. In addition, the response rate of the BRIEF-P questionnaire was lower than in the other measures used in the study (waking group $n = 49$ and nonwaking group $n = 38$), and this could have resulted in the differences between pairwise comparisons not being statistically significant. The lower response rate was possibly caused by the protocol, which resulted in some families forgetting to return the questionnaire at the second research visit.

In this study, we were primarily interested in parent-reported signaled night awakening. However, in addition to parent reports, actigraphy data were available for a majority of children at 8 months of age. In the 8-month data, the actigraphy measurements provided support for the group formation based on parent reports, as infants in the waking group had more actigraphy-based night awakenings than the nonwaking group. There was a substantial drop in the available actigraphy measurements at 24 months of age and due to the loss of power, the actigraphy data at 24 months of age were not analyzed. Thus, while bearing in mind that parent-reported signaled night awakening and more objective measures of sleep, such as actigraphy, do not represent identical measures of night awakening (Acebo et al., 2005; Sadeh, 2004), the current results support the use of parent reports of infant night awakening. It should also be noted that the actigraphy-based sleep measures are based on limited number of nights, whereas parent reports describe sleep across longer periods. In this study, we used a smoothing algorithm for the actigraphy-based activity data to derive a number of night awakenings more consistent with signaled night awakenings (Sitnick et al., 2008). Using this algorithm, the actigraphy derived night awakenings and parent-reported signaled night awakenings correlated positively. However, the number of night awakenings indicated by the smoothing algorithm was greater than what the parent had reported (waking group 6.2 vs. 3.8, nonwaking group 4.9 vs. 0.9). The smoothing algorithm was originally developed for preschool-aged children, whereas we used it with 8-month-old infants, which could partly explain the discrepancy in the number of night awakenings between the parent-reported and actigraphy-based data.

According to our results, signaled night awakening may affect EF in infancy and toddlerhood, as shown by the Switch task results, even in a sample where signaled night awakenings diminished in both groups prior to the age of 24 months (Mäkelä et al., 2018). The two groups of toddlers still differed in the number of night awakenings at the age of 24 months, even though the differences had become smaller. Consistent with this line of reasoning, Touchette et al. (2005) showed that shorter sleep before the age of 41 months is a risk factor for cognitive functioning despite the sleep characteristics in that group normalizing later on. Thus, it seems that sleep characteristics in infancy could affect development, even when particular sleep characteristics tend to normalize later on.

Our results support the notion that the development of EF follows somewhat distinctive pathways in infants with and without fragmented sleep. It should be noted, however, that although there were differences between the two groups, the effect sizes were rather small. In addition, two out of three measures did not support the notion that signaled night awakening is connected to EF even though our sample size was fairly large. This finding could be due to the sensitivity of the different measures to detect individual differences in EF or, alternatively, the discrepancies between the results may reflect a true lack of association between signaled night awakening and components of EF. Another possible limitation of our study is that our sample consisted of white infants of mainly middle-class origin, limiting the generalizability of the results to other ethnicities and socio-demographic groups. Finally, the interpretation of the results particularly regarding the 24-month behavioral assessments is limited by the absence of data from the Trucks task, which we were not able to analyze due to inconsistencies in the task presentation.

According to our age-specific results, it seems that the differences between the two groups were more pronounced at 24 months than at 8 months of age. It could be the case that EF skills are still poorly developed at the age of 8 months, making it difficult to distinguish between the groups accurately (Espy et al., 2011; Shing et al., 2010; Wiebe et al., 2008). Another possibility is that the effect of signaled night awakening is evident longitudinally and, therefore, more clearly observed at 24 months of age, as suggested by prior research (Bernier et al., 2010; Bernier et al., 2013; Dearing, McCartney, Marshall, & Warner, 2001; Dionne et al., 2011; Gertner et al., 2002; Sadeh et al., 2015). The group differences in EF were not affected by differences in overall development, since our previous study with the same sample showed that there were no differences in overall psychomotor development between the waking and nonwaking group at 8 and 24 months of age (Mäkelä et al., 2018). It should be noted that the groups did differ in several sleep characteristics other than just night awakenings as shown in our previous study (Mäkelä et al., 2018). The waking group also had a shorter total sleep duration and they spent more time awake during the night. These other sleep characteristics were covaried in the analyses, and they did not affect our findings. Nevertheless, in future studies, shorter sleep duration should be taken into account, since studies with school-aged children have shown that shorter sleep duration is connected to lower performance in EF tasks (Astill et al., 2012; Steenari et al., 2003; Taveras et al., 2017).

An important factor in the phenomenon of night awakening is the ability to fall asleep alone, for which self-regulation skills are essential. Moreover, EF and emotion regulation are both considered under the concept of self-regulation, and previous studies have shown that they are interconnected (Carlson & Wang, 2007). The connection between

EF and emotion regulation highlights the importance of a broader view of self-regulation skills both in infant night awakening and performance in EF-related tasks. It would be interesting to study further how signaled night awakening in infancy is connected to different aspects of self-regulation besides EF.

In conclusion, our results support the notion that fragmented sleep is connected to EF when measured with sensitive methods that are able to discriminate performance in the normal range, and that the differences can be observable already in children under 2 years of age. Children with several signaled night awakenings were less able to learn new stimulus sequences and inhibit their previously learned responses compared to children without signaled night awakenings, as measured with an eye movement-based computer task. In the parental ratings of EF, the groups differed only marginally, and the two groups of toddlers did not differ in behavioral measures of EF, perhaps due to the behavioral measures being less sensitive than computerized measures to early differences in EF. According to our previous work (Mäkelä et al., 2018), the two groups did not differ in overall psychomotor development at 8 and 24 months of age, showing that the differences in EF are not a reflection of differences in overall psychomotor development. According to our results, it seems that in children with early-onset fragmented sleep, the development of EF follows somewhat distinctive pathways when compared to children without fragmented sleep already during the first 2 years of life. However, the effect sizes were rather small and, thus, the results of the study should be replicated in an independent sample. Computerized tasks and eye-tracking paradigms are promising methods that will advance knowledge on the associations of different sleep characteristics and infant development. In the future, fragmented sleep and its associations with different aspects of self-regulation should be further investigated.

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Signaled night awakening and its association with social information processing and socio-emotional development across the first two years

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Signaled night awakening and its association with social information processing and socio-emotional development across the first two years

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Abstract

Study Objectives: Night awakening is common in infancy, and some infants continue to have signaled night awakenings throughout early childhood. However, the influence of signaled night awakening on children's social development is less explored. In the present study, longitudinal associations between signaled night awakening, social information processing, and socio-emotional development were measured within the CHILD-SLEEP birth cohort in two groups formed based on parent-reported night awakenings.

Methods: At 8 months, there were 77 infants in the waking group (≥3 awakenings) and 69 infants in the nonwaking group (≤1 awakening). At 8 and 24 months, social information processing was measured as children's attention to neutral and emotional faces, and at 24 months, parent-reported socio-emotional behavior was measured with the Brief Infant-Toddler Social and Emotional Assessment (BITSEA) questionnaire.

Results: The two groups showed different patterns of attention to emotional faces. The waking group had a more pronounced attentional bias to fearful versus happy faces, whereas in the nonwaking group, attention to fearful and happy faces did not differ. In addition, at 24 months, the waking group had more dysregulation problems and lower social competence than the nonwaking group, but no clear differences in internalizing or externalizing problems were found.

Conclusions: Our results contribute to the literature by showing that during the first 2 years of life, signaled night awakening is associated with social information processing and socio-emotional behavior.

Statement of Significance

Our study focused on associations between signaled night awakening, social information processing, and socio-emotional development in infancy, a topic that has received little attention in previous studies even though signaled night awakening is a common concern for parents and it has a potentially critical influence on children's development. We studied social information processing longitudinally at the age of 8 and 24 months and parents reported children's socio-emotional behavior at 24 months. Our study provides a novel contribution regarding the influence of signaled night awakening on children's social information processing and social development already in infancy by showing that children with signaled night awakenings show a different pattern of attention to emotional faces and they have lower parent-reported social competence and more behavioral dysregulation symptoms.

Key words: night awakening; fragmented sleep; social cognition; social information processing; socio-emotional development; infancy

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Introduction

Sleep is an important part of healthy development and is associated with multiple developmental outcomes in childhood. Sleep in infancy has unique characteristics, including the fragmented nature of infant sleep caused by frequent night awakenings. Short night awakenings between sleep cycles are normative [1] and seem not to be problematic for infants who can soothe themselves back to sleep without parental assistance [2–4]. Night awakenings that are signaled to parents, for example by crying, and which require parental assistance may cause problems for the wellbeing of the whole family [3], and are most often reported by parents when evaluating their infant's quality of sleep [5]. Night awakenings that require parental assistance are referred to as signaled night awakening. Increased night awakenings have been associated with parent- and child-related factors, such as breastfeeding, co-sleeping with the infant, high parental involvement when putting the child to sleep, and the child's negative emotionality [6–8]. Prolonged and recurrent signaled night awakenings can be persistent in infants [6, 9, 10] and even in children aged 4–6 years [5, 11]. In addition, it has been proposed that signaled night awakening could be a precursor for later appearing sleep difficulties [2] and a risk factor for the development of higher-order cognitive processes, such as executive functioning [12, 13]. However, the associations between signaled night awakening and socio-emotional development in infancy have received little attention even though the bases of social behavior, that is, perception and understanding of social information start to develop during the first year [14]. To address this gap in the literature, we sought to investigate the connections between signaled night awakening and social cognition as well as parent-reported socio-emotional behavior during the first 2 years of life.

Social cognition refers to cognitive processes involved in the perception, processing, interpretation, and storing of information of other people [15]. Accurate processing of social information allows us to recognize the identity of other people and understand their intentions, emotions, and behaviors [16]. Individual differences in social information processing may be related to the way we behave in social situations, for example, through attentional or interpretative biases in processing emotional cues. Already newborns show a visual preference for faces and are sensitive to eye contact [17] and infant-directed speech [18]. Detecting and coordinating eye contact serves as a basis for engaging in social communication, and such ability for joint engagement emerges during the first year of life [19, 20]. In addition, infants' sensitivity to emotional expressions increases during the second half of the first year [14] and by the end of the first year, infants can use emotional cues to guide their behavior [21–23].

The ability to accurately discriminate between facial expressions is an important aspect of social cognition and it is associated with social adjustment [24]. Experimental studies conducted with adults have suggested that sleep deprivation disturbs the processing of visual emotional information [25, 26] and impairs the recognition of facial expressions [27]. Moreover, a study conducted with adolescents showed that the number of night awakenings and poor sleep quality were negatively associated with the recognition of facial emotions [28]. Less is known, however, about whether difficulties in sleep are associated with social information processing in early childhood, at a time when sleep goes through a wide array of developmental changes.

The number of studies on the connection between sleep and social information processing in childhood is limited, and even less is known about the association between signaled night awakening and social information processing in infancy, even though night awakenings are an age-typical feature of infant sleep [1, 6, 10]. Cremone et al. [29] found that four-year-old nap-deprived children showed a greater attentional bias toward emotional stimuli compared to an after-nap condition. In another study, infants' better sleep quality (i.e. less waking after sleep onset) and lower sleep-wake pattern variability were connected to infants' processing of faces and emotional information at the age of 12 months [30]. Infants with higher sleep quality fixated more on the eye region than infants with lower sleep quality, and infants with shorter sleep duration exhibited less autonomic arousal, measured with pupillary reactivity when viewing emotionally negative faces than infants with longer sleep duration. According to these few studies, certain sleep parameters and social information processing seem to be associated in childhood. However, there are hardly any studies on the association between signaled night awakening and social information processing in infancy, during a period of rapid development of social cognition.

In addition to face and emotion processing, sleep disruptions have also been shown to be associated with socio-emotional behavior in adolescents [31, 32], school-aged children [33], and toddlers [6, 34–37]. However, only a few studies have concentrated on signaled night awakening and its connection with socio-emotional behavior in infancy and early childhood. Hysing et al. [38] found that parent-reported night awakening was related to a higher amount of parent-reported overall social-emotional problems at 24 months of age. A recent study from the CHILD-SLEEP birth cohort [39] showed that parent-reported night awakenings at 3, 8, 18, and 24 months of age were associated with greater internalizing and dysregulation symptoms at 24 months of age, whereas night awakenings at 3 and 24 months of age were associated with greater externalizing symptoms. Other studies have found similar associations between night awakenings and socio-emotional problems across the first 5 years [37, 40, 41]. Mindell et al. [34], however, did not find associations between parent-reported night awakenings at 6, 12, and 18 months and parent-reported socio-emotional development at 12 or 18 months of age. Existing studies have also mostly focused on socio-emotional problems, such as externalizing and internalizing, whereas the positive aspects of socio-emotional development, such as social competence, have received less attention.

In the present study, signaled night awakening at 8 months and its associations with social information processing and parent-reported socio-emotional behavior were investigated across the first 2 years of life in two groups differing in the number of night awakenings within the CHILD-SLEEP birth cohort [42]. Social information processing was investigated by using the Overlap task [43, 44], which is a widely used method to study attention to faces and facial emotions in infancy [43, 45, 46]. Previous studies using this paradigm have shown that infants are slower to disengage their attention from faces than non-faces and from fearful as compared to happy, neutral, or angry faces [43, 47, 48]. The attentional bias toward fearful faces (slower disengagement) is typically observed from 5 to 7 months of age [14, 43, 48, 49], or even earlier [50]. According to the limited number of longitudinal studies, attentional bias toward fear seems to attenuate after the first years of life [44, 47]. Importantly, the interindividual variation in attention to faces and particularly fearful faces has also been suggested to be related to different aspects of children's social development, with a relatively larger bias for fear being associated with secure as compared to insecure attachment [51] and increased altruistic behavior [52] and greater attention to faces being associated with more prosocial behavior [44].

This study had three specific aims. First, we examined whether signaled night awakening is associated with attention to faces longitudinally at 8 and 24 months of age. Second, we examined whether infants with and without signaled night awakenings differed in socio-emotional behavior at 24 months of age (internalizing, externalizing, dysregulation, and social competence). Third, we were interested in whether attention to faces would be associated with the parent-reported domains of socio-emotional behavior. Regarding the hypotheses on the associations between signaled night awakening and attention to faces, we adopted an exploratory approach, since such associations have not been studied previously. We hypothesized, according to previous studies [37–41], that infants with frequent signaled night awakening would exhibit more parent-rated socio-emotional problems at 24 months of age than infants without signaled night awakenings. For the social competence domain, we made no definite hypothesis since previous studies are limited in number and there are hardly any studies, except for Mindell et al. [34], focusing on signaled night awakening and social competence. Finally, regarding associations between attention to faces and parent-reported socio-emotional behavior, prior studies have indicated that robust attention biases to faces and negative emotions are normative during early development, and the strength of such biases may even be associated with positive outcomes [44, 51, 52]. On the other hand, a large body of literature has demonstrated associations between attention to negative emotions and internalizing and anxiety problems in adults and older children [53]. Consequently, we hypothesized that greater attention to faces would be associated with better social competence, but made no definite hypothesis concerning the emotional valence of faces, or whether attention to faces would be associated with negative aspects of socio-emotional behavior.

Methods

Participants

The current sample of infants was recruited within the CHILD-SLEEP birth cohort (n = 1667) in which different sleep characteristics and their associations with multiple aspects of child development are being studied [42, 54]. The participating families filled questionnaires before the birth of their infants and when the infants were 3, 8, 18, and 24 months old [42]. Parents of a subsample of the cohort (n = 406) were contacted when the child was 8 months through phone calls and asked how many times their infant had typically woken up during the night (24.00–06.00) and needed soothing during the past 2 weeks. The inclusion criteria for the current sample was that the 8-month-old infants had three or more signaled night awakenings or no more than one signaled night awakening. The infants with three or more signaled night awakenings formed the waking group. Infants with no more than one signaled night awakening formed the nonwaking group [12, 54]. The exclusion criteria were prematurity or native language other than Finnish. In addition, infants with two signaled night awakenings were excluded from the study to have two distinct groups. The Ethical Committee of the Pirkanmaa Hospital District (ETL-code: #R11032) approved the study protocol, and all participating families signed a written consent form before participation. In total, 146 White Finnish infants participated at 8 months of age, with 77 infants in the waking group (mean age = 8.5 months, SD = 0.4 months) and 69 infants in the nonwaking group (mean age = 8.6 months, SD = 0.4 months). Two additional participants were examined but were excluded from further analysis due to prematurity (n = 1) and the parents' native language being other than Finnish (n = 1).

The demographic statistics of the sample are shown in Table 1. At 8 months of age, the two groups differed in the amount of breastfeeding (X^2 (1, n = 133) = 13.413, p = .001), co-sleeping (X^2 (1, n = 119) = 20.376, p < .001), and the infant's ability to fall asleep alone (X^2 (1, n = 133) = 16.454, p < .001) [12]. The infants in the waking group were more likely to be breastfed, to co-sleep with their parents, and less able to fall asleep alone than the infants in the nonwaking group. Breastfeeding had three categories: the infant was only breastfed, breastfed and formula fed, or only formula fed. Co-sleeping was dichotomized as co-sleeping with the parent less than twice in a month versus at least once every week. The ability to fall asleep alone was dichotomized as the infant was able to fall asleep alone only once a week versus at least once a day. These three factors were included in the analysis as covariates to statistically control for potential confounding effects. Participants of the current study were randomly recruited from the prevention sub-study of the main cohort in which part of the families received psychoeducation through brochures on how to support infant sleep quality. In the control group, the families participated in standard well-child visits. The infants in the waking group and nonwaking group came from both the prevention and control healthcare centers (X^2 (1, n = 146) = 3.394, p = .065). The healthcare center status was included as a covariate in our analyses to control for its potential effects on the results. Additional parent-reported and actigraphy-based sleep duration and quality parameters are shown in Table 2 according to the group. Our previous work showed that based on parent reports, the infants in the waking group slept less in total and they spent more time awake during the night than the nonwaking group [54], but they did not differ in actigraphy-based sleep duration measures [12]. In addition, the waking group had more parent-reported signaled night awakenings than the nonwaking group at 18 and 24 months of age [54]. The group formation at 8 months was also validated with actigraphy-based night awakening data which showed that the waking group had more night awakenings than the nonwaking group when measured with actigraphy [12].

At 24 months of age, 65 infants from the waking group (mean age = 24.6 months, SD = 2.2 months) and 56 infants from the nonwaking group (mean age = 24.5 months, SD = 2.9 months) returned for another assessment (n = 121, 83% retention rate). Attrition was not related to the performance in the Overlap task at 8 months, all ps > .411.

Procedure

The current sub-sample of infants participated in assessments at 8 and 24 months of age. At both assessment points, there were two separate research visits. During the first research visit,

Table 1. Descriptive statistics for the two groups according to questionnaire data

	Waking group		Nonwaking group		
	n	%	*n*	%	*P*
Gender					.889
Boys	43	56.6	35	50.7	
Girls	33	43.4	34	49.3	
Missing 6					
Siblings					.354
Yes	27	36.5	33	34.2	
No	47	63.5	34	50.7	
Missing 10					
Mother's education					.210
>15 years	36	47.4	31	45.2	
<15 years	40	52.6	37	54.8	
Missing 7					
Father's education					.671
>15 years	55	70.5	45	70.3	
<15 years	23	29.5	16	25.0	
Missing 12					
Mother's monthly net income					.377
>2000 €	23	29.5	23	35.9	
1000–2000 €	39	50.0	24	37.5	
<1000 €	14	17.9	14	21.9	
Missing 14					
Father's monthly net income					.492
>2000 €	49	62.8	42	65.6	
1000–2000 €	20	25.6	16	25.0	
<1000 €	8	10.3	3	4.7	
Missing 13					
Breastfeeding					.002
Breastfed only	43	58.9	20	33.3	
Breastfed and formula fed	16	21.9	11	55.0	
Formula fed only	14	19.2	29	48.3	
Missing 18					
Co-sleeping					<.001
>once in a week	29	44.6	4	7.4	
<2 times a month	36	55.4	50	92.6	
Missing 32					
Falling asleep alone					<.001
Once in a week	49	68.1	20	32.8	
Once in a day	23	31.9	41	67.2	
Missing 18					
Health care center					.065
Prevention	43	55.8	28	40.6	
Control	34	44.2	41	59.4	
Missing 5					

psychomotor development was measured [54]. On the second research visit, executive functioning [12], parent-infant interaction, and heart-rate variability (both of which are not reported here), and attention to emotional faces were measured. Socio-emotional behavior was measured with a parent rating when the children were 24 months old as a part of a larger online questionnaire sent to the whole CHILD-SLEEP cohort.

The second research visit was conducted in the laboratory. The child sat on the parent's lap approximately 60-cm from the computer screen. The computer screen was a 19-inch screen surrounded by a black frame. At 8 months of age, a video camera was hidden on top of the computer screen for the experimenter to observe the child. In addition, the video recordings of the Overlap task were saved for offline eye movement analyses. When the children were 24 months old, the stimuli were presented from a 21-inch screen with a video camera on top of it. Eye-tracking measurement was added to the protocol at 24 months and attention to faces was measured using a corneal reflection eye-tracker (Tobii TX300; Tobii Technology, Stockholm, Sweden). Stimulus presentation was controlled at both ages with E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). Before starting the experiment at 24 months, the eye-tracker camera was calibrated with the Tobii five-point calibration procedure in which a cat appeared with a beep sound to every corner and to the center of the screen. In the case of unsatisfactory calibration data for the five locations (i.e. one or more calibrations were missing or were not properly calibrated), the calibration was repeated a maximum of two times. After these attempts, if one or more calibrations were still missing, the last attempt was accepted, and the presentation of the task was initiated. Children were not excluded from the sample based on the lack of calibration points because the analysis of the primary

Table 2. Descriptive statistics of parent-reported sleep and actigraphy-based sleep parameters at 8 and 24 months of age

	Waking group			Nonwaking group		
	n	*M*	*SD*	*n*	*M*	*SD*
8 months						
Parent-reported						
Duration of nocturnal sleep (min)	75	589.9	58.4	60	597.8	55.7
Duration of daytime sleep (min)	76	188.4	53.6	60	204.8	63.1
Duration of total sleep (min)	75	778.8	70.9	60	802.6	60.5
Sleep latency (min)	74	24.8	16.9	57	18.2	15.5
Time spent awake at night (min)	69	30.6	25.7	48	15.8	20.6
Night awakenings (count)	73	3.8	1.9	54	0.9	0.6
Proportion of nighttime sleep (%)	75	75.9	5.8	60	74.7	6.6
Actigraphy-based						
Actual sleep time (min)	67	511.1	55.0	61	518.5	56.6
Sleep latency (min)	66	19.3	19.3	58	17.8	22.1
Sleep efficiency (%)	66	78.7	6.2	58	79.1	6.8
Proportion of nighttime sleep (%)	37	85.7	5.7	31	85.1	6.6
24 months						
Duration of nocturnal sleep (min)	53	589.4	46.4	41	605.5	37.9
Duration of daytime sleep (min)	53	105.4	38.8	41	114.6	46.1
Duration of total sleep (min)	53	694.8	45.3	41	720.6	55.5
Sleep latency (min)	48	23.9	18.1	38	17.9	12.5
Time spent awake at night (min)	46	11.8	12.3	38	4.0	9.0
Night awakenings (count)	50	1.0	0.9	40	0.6	0.6
Proportion of nighttime sleep (%)	53	84.9	5.1	41	84.3	5.1
Actigraphy-based						
Actual sleep time (min)	35	539.7	43.0	28	542.8	46.6
Sleep latency (min)	36	26.6	18.7	28	22.3	15.0
Sleep efficiency (%)	36	81.7	5.6	28	83.8	4.2
Proportion of nighttime sleep (%)	31	87.4	7.4	17	89.4	5.9

outcome of the task (i.e. gaze disengagement and shift between two objects that were separated in space) was not reliant on precise spatial tracking accuracy and has been found to be robust against variations in calibration quality [55].

Before starting the task, the lights were dimmed. At both ages, parents were instructed not to interact with their child unless it was necessary to soothe the child during the presentation of tasks. Each trial in the Overlap task started with a red circle appearing on a gray background. The red circle expanded from 0.4° to 4.3° in a continuous fashion for the child to focus their eyes on the screen. When the child's eyes were focused on the screen, the experimenter initiated the following trial. If the child did not focus on the screen, the experimenter called the child by name and initiated the trial only after the child focused on the screen.

Measurements

Attention to emotional faces

Attention to emotional faces was measured with the Overlap task. The face stimuli consisted of four different color images of one female model. The model depicted happy, fearful, and neutral with eyes open and neutral with eyes closed expressions (Figure 1). In addition, two different distractor stimuli (black-and-white checkerboard and a circle pattern) were used. After the initiation of a trial in the Overlap task, the facial stimulus (15.8° × 11.4°) appeared on the center of the screen for 1000 ms on a white background. Next, the facial stimulus was flanked by a lateral distractor stimulus (15.8° × 4.0°) that appeared either to the left or to the right side of the screen. The facial stimulus and the distractor were visible for 3000 ms. The distance between the face and distractor stimulus was 13.6°. The presentation order of the stimuli was randomized with the restrictions that the same emotional face was repeated no more than four times in a row, and the distractor appeared at the same location no more than three times in a row. Altogether, there were 24 trials, that is, 6 for each of the 4 different face conditions. At 24 months, the distractor stimulus was modified to have colors to make it more interesting to the child with two different color schemes (blue–red and green–yellow). In addition, these color schemes alternated rapidly, giving the impression that the distractor stimulus was animated. An example of a trial in the Overlap task is shown in Figure 1.

Socio-emotional behavior

Socio-emotional behavior was measured using the Brief Infant-Toddler Social and Emotional Assessment (BITSEA) questionnaire at 24 months of age [56]. A Finnish translation of the questionnaire [57] was used with the original US norms. The BITSEA consists of 42 statements, with 31 items measuring socio-emotional problems and 11 items measuring socio-emotional competence. Parents answer with a three-point scale (not true/rarely = 0, somewhat true/sometimes = 1, very true/always = 2). Externalizing, internalizing, dysregulation, and social competence domains were derived from the questionnaire. Internal consistency scores showed moderate internal consistency (Externalizing, α = .650, Internalizing, α = .515, Dysregulation, α = .660, and Social Competence, α = .657). These values are consistent with the original US norms for Social Competence [58] and somewhat lower than the alphas reported for the

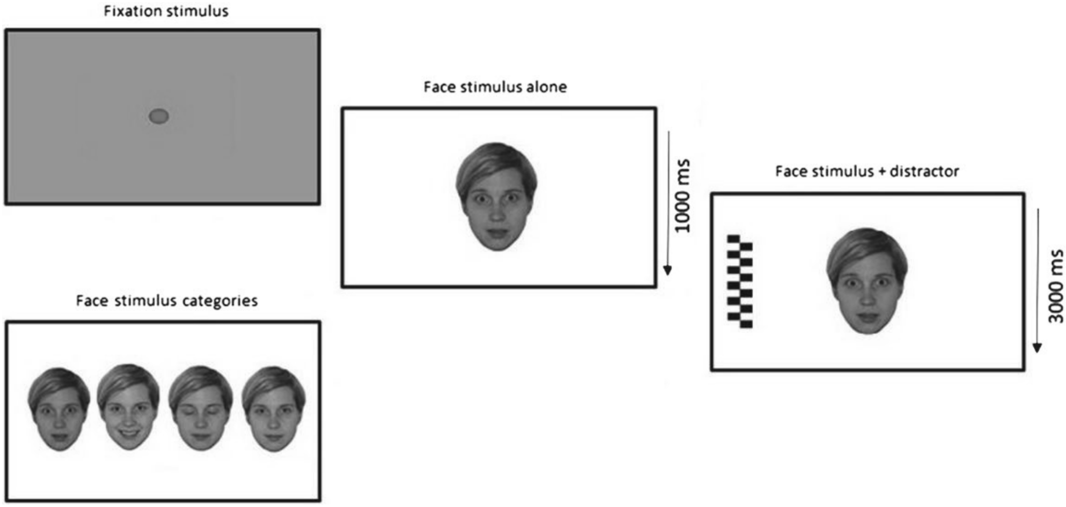

Figure 1. An example of a trial in the overlap task and the different face stimulus categories used.

Internalizing and Externalizing domains [59]. Altogether, 53 participants from the waking group and 47 participants from the nonwaking group provided data for the BITSEA questionnaire.

Data analysis

Video coding at 8 months. Eye movements in the Overlap task were analyzed using VirtualDubMod software 1.5.10.2 (http://virtualdubmod.sourceforge.net/). A trained observer who was unaware of the child's group status coded all the videos offline. Eye movements were examined manually, frame by frame, with one frame lasting 40 ms. The procedures of previous studies using the same methodology [43, 60] were followed. If the child did not focus on the screen at the beginning of the trial, the trial was rejected. The child's saccades during a trial were coded to calculate dwell times for different face conditions. The duration of attention dwell time on the stimulus (happy, fearful, neutral with eyes open, and neutral with eyes closed) was determined for the period starting 160 ms from the onset of the lateral distractor stimulus and ending 1000 ms after distractor stimulus onset. Following previous studies [55], the duration was then converted to a normalized dwell time index score using the following formula:

$$\text{Dwell time index} = \frac{\sum_{i=1}^{n}\left(1 - \frac{1000 - x_i}{840}\right)}{n}$$

In the formula, x is the time point of saccadic eye movement (i.e. the last time point when the gaze is in the area of the first central stimulus preceding a saccade toward the distractor stimulus) and n is the number of scorable trials in a given stimulus condition. In this index, the shortest acceptable saccadic eye movement latency (160 ms) results in a score of 0, and the longest possible latency (or a lack of saccade, which is equal to the last measured time point of the first stimulus at 1000 ms) with a score of 1. The dwell time indices were calculated separately for each of the four stimulus conditions (i.e. happy, fearful, neutral with eyes open, and neutral with eyes closed). Trials with anticipatory eye movements (<160 ms), excessive movements during the trial, and saccades not directed toward the distractor stimulus were rejected. At least two scorable responses per face condition were required to be included in the analyses. At 8 months, the average number of scorable trials in the different face conditions were: happy: 5.4 (waking group) and 5.3 (nonwaking group); fear: 5.5 (waking group) and 5.3 (nonwaking group); neutral with eyes open: 5.4 (waking group) and 5.2 (nonwaking group); and neutral with eyes closed: 5.4 (waking group) and 5.2 (nonwaking group). At 8 months of age, 74 participants in the waking group and 62 participants in the nonwaking group provided at least two scorable trials in each face condition and were included in the analysis.

Eye movement coding at 24 months. The eye-tracking data of the Overlap task at 24 months of age were saved as text files and analyzed using a library of MATLAB routines for offline analysis of raw gaze data [55]. These files included timestamps corresponding to the onset times of the central and lateral stimuli. Data analysis of the saccadic eye movements from the central stimulus to the distractor was implemented by automatic coding of the x and y coordinates of the eye-tracking data. Trials with a sufficient length of fixation on the central stimulus (i.e. > 70% of the time) during the time preceding gaze disengagement or the 1000-ms timeout, sufficient number of valid samples in the gaze data (i.e. no gaps > 200 ms), and valid information about eye movement from the central to the lateral stimulus (i.e. the eye movement did not occur during a period of missing gaze data) were retained for analysis. The dwell times were then calculated in the same way as in the 8-month coding, separately for each face condition. The only difference was the threshold of anticipatory eye movements, which was set at 150 ms in the 24-month data. In previous research, automated and manual coding of attention disengagement has shown high (over 97%) agreement [55]. At 24 months, the average number of scorable trials in the different face conditions were: happy: 4.5 (waking group) and 4.6 (nonwaking group); fear: 4.8 (waking group) and 4.5 (nonwaking group); neutral with eyes open: 4.5

(waking group) and 4.5 (nonwaking group); and neutral with eyes closed: 4.4 (waking group) and 4.3 (nonwaking group). Successful data at 24 months of age were gathered from 64 participants in the waking group and 55 participants in the nonwaking group.

Statistical analysis

Statistical analyses were performed using SPSS version 25 (IBM Corp., Armonk, NY). All outcome variables were continuous. The distribution of the variables was visually screened using boxplots and potential outliers were identified using scatterplots. No extreme values were observed. In addition, in the Overlap task, dwell times were also converted to z-scores and no outliers were observed, as all the values were within $z = \pm 3.29$ [61]. To analyze the Overlap data longitudinally, a Linear Mixed Model (LMM) was used to maximally utilize the incomplete longitudinal data. As fixed factors, both within-subject and between-subject effects and their interactions were analyzed. Age (8 and 24 months) and emotion (happy, fearful, neutral with eyes open, and neutral with eyes closed) were used as within-factors. The between-factor group consisted of the waking and nonwaking groups. In addition, their interactions were included in the model. In the case of statistically significant main effects, Bonferroni-corrected post hoc tests were used. Cohen's *d* was used as an effect size indicator for the pairwise comparisons. First, a model with all the covariates such as breastfeeding, co-sleeping, ability to fall asleep alone, healthcare center status, and sum scores of questionnaires assessing maternal depressive (CES-D) [62] and anxiety (STAI) [63] symptoms at 8 months and within- and between-factors was performed. None of the covariates used were statistically significant; therefore, they were not included in the final model. Akaike's information criterion was used in the model and covariance structure selection. The group differences in the BITSEA subdomains were analyzed using *t*-tests for independent samples. Finally, the connections between dwell times in the different face conditions in the Overlap task at 8 and 24 months and the BITSEA subdomains at 24 months were analyzed with Pearson correlations. The alpha level for statistical significance was set at $p < .05$.

Results

The LMM of the longitudinal Overlap data revealed a main effect of emotion, $F(3, 114.319) = 21.544$, $p < .001$. Dwell times were longest in the fearful face condition ($M = .629$, SE = .017) as compared to the happy face ($M = .576$, SE = .015), $p = .005$, $d = .33$, neutral face with eyes open ($M = .525$, SE = .017), $p < .001$, $d = .62$, and neutral face with eyes closed ($M = .527$, SE = .016), $p < .001$, $d = .62$, conditions. In addition, dwell times were longer in the happy face condition than in the neutral face with eyes open, $p < .001$, $d = .32$, and in the neutral face with eyes closed, $p = .008$, $d = .32$, conditions. A group × emotion interaction was also observed, $F(3, 114.319) = 3.615$, $p = .015$. Bonferroni-corrected pairwise comparisons indicated that the waking and nonwaking groups had a different pattern of dwell times across the four face conditions (see Figure 2). In the waking group, dwell times were longer in the fearful face condition ($M = .611$, SE = .024) than in the happy face ($M = .550$, SE = .020), $p = .026$, $d = .45$, neutral face with eyes open ($M = .541$, SE = .022), $p = .002$, $d = .49$, and neutral face with eyes closed ($M = .505$, SE = .022), $p < .001$, $d = .71$, conditions. No other differences were statistically significant, all *p*s > .145. In the nonwaking group, however, dwell times in the fearful face condition ($M = .646$, SE = .025) differed from the neutral face with eyes open ($M = .510$, SE = .024), $p < .001$, $d = .81$, and neutral face with eyes closed ($M = .551$, SE = .023), $p = .001$, $d = .58$, conditions, but not from the happy face condition ($M = .602$, SE = .022), $p = .315$ $d = .28$. In addition, dwell times in the happy face condition differed from the neutral face with eyes open condition, $p < .001$, $d = .58$, in the nonwaking group. In other pairwise comparisons, the differences were not statistically significant, all *p*s > .109. The main effect of group, $F(1, 113.633) = .868$, $p = .354$, and the group × age, $F(1, 313.943) = .028$, $p = .866$, and group × age × emotion, $F(3, 203.264) = .458$, $p = .712$, interactions were not significant and therefore the interactions were not included in the final model.

Parent-reported socio-emotional behavior was analyzed separately for the different subdomains, and the descriptive statistics for both groups are presented in Table 3. The two groups differed in the dysregulation domain, $t(97)= 3.542$, $p = .002$, $d = .72$ and social competence domain, $t(96) = -1.998$, $p = .049$, $d = .48$, with the waking group having more dysregulation problems and lower social competence scores than the nonwaking group. In the externalizing domain, the two groups did not differ, $t(96)= .930$, $p = .355$. The difference between the waking and nonwaking groups was, likewise, not statistically significant in the internalizing domain $t(94.992)= 1.874$, $p = .065$, $d = .38$, even though the waking group appeared to have slightly more internalizing problems than the nonwaking group. The dysregulation subdomain of the BITSEA contains two items concerning sleep "Wakes up at night and needs help to fall asleep again" and "Has trouble falling asleep or staying asleep." Since the waking and nonwaking groups differed in the number of signaled night awakenings, the analysis of the dysregulation domain was conducted again with the two items concerning sleep removed to ensure that the differences in the dysregulation domain were not merely a reflection of night awakening. The differences between the two groups in the dysregulation domain remained even after the removal of the two sleep items, even though the difference between groups was smaller, $t(97) = 1.991$, $p = .049$, $d = .40$.

The correlational analyses between dwell time and BITSEA subdomains showed that dwell times in the happy face condition, but not other face conditions, correlated with different BITSEA subscales (Table 4). More specifically, dwell times in the happy face condition at 8 months of age correlated positively with the social competence domain, $r(62) = .337$, $p = .007$, and with the externalizing domain, $r(62) = .260$, $p = .041$. Dwell times in the happy face condition at 24 months of age correlated negatively with the dysregulation scores (with the two sleep items removed), $r(85) = -.214$, $p = .049$.

Discussion

In the present study, signaled night awakening and its associations with social information processing and socio-emotional behavior were investigated across the first 2 years of life. Children were divided into two groups based on the number of signaled night awakenings reported by their parents at 8 months

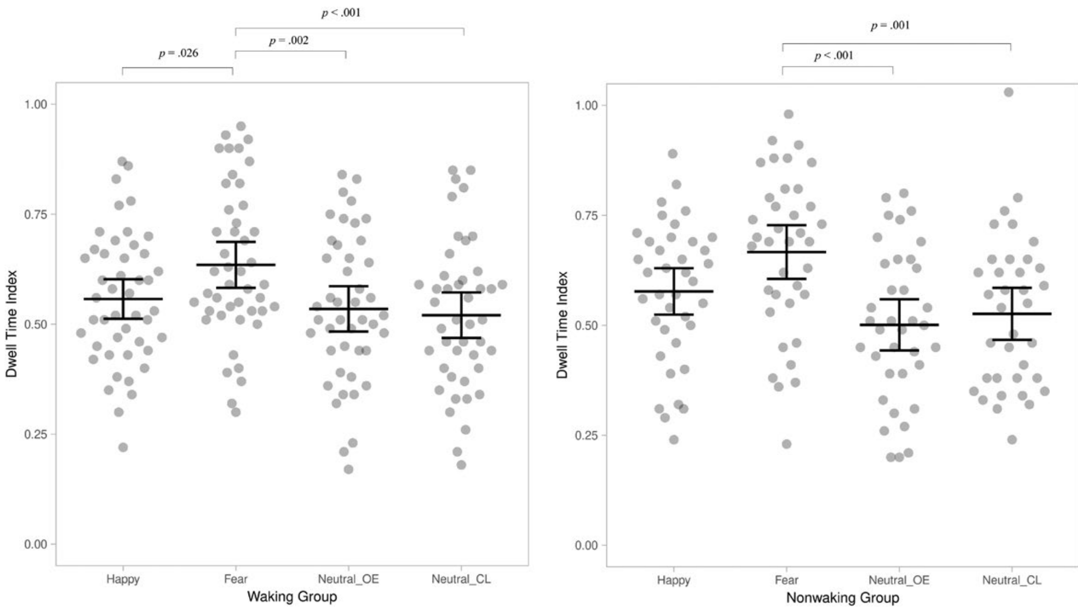

Figure 2. Individual dwell times and their means (and 95% CI) to different faces according to group (The data were visualized by an R Shiny app by Postma and Goedhart [64].). Neutral_OE, neutral with open eyes; Neutral_CL, neutral with closed eyes.

Table 3. Means and standard deviations of domains of socio-emotional behavior in the BITSEA questionnaire for the two groups

BITSEA domain	Waking group		Nonwaking group		
	M	*SD*	*M*	*SD*	P
Dysregulation	4.23	2.74	2.47	2.14	.002
Social competence	18.11	2.42	19.13	2.60	.049
Externalizing	3.41	2.27	3.00	2.10	.355
Internalizing	1.59	1.75	1.05	.99	.065
Dysregulation (no sleep)	2.42	1.81	1.79	1.53	.049

of age. In a longitudinal design, social information processing was measured at 8 and 24 months of age with a task measuring attention to emotional and neutral faces. In addition, socio-emotional behavior was assessed with a parent-rated questionnaire at 24 months of age. Regarding links between signaled night awakening and attention to faces, we adopted an exploratory approach, since such associations have not been studied previously. In addition, based on previous studies, we hypothesized that signaled night awakening would be associated with more parent-rated socio-emotional difficulties [37–41]. For the hypothesis regarding associations between attention to faces and socio-emotional behavior, we hypothesized that attention to faces would be associated with better social competence, as suggested by limited prior evidence [44, 51, 52], but made no definite hypothesis concerning the emotional valence of faces, or whether attention to faces would also be associated with negative aspects of socio-emotional behavior.

Regarding social information processing, our results replicated the robust finding of longer attention dwell times toward fearful faces as compared to happy or neutral faces [44, 48, 51, 60]. The attentional bias toward fearful faces during the second half of the first year has been indicated as a marker of normative social information processing in infancy and has been suggested to be associated with positive aspects of social development, such as attachment security and prosociality [44, 51, 52].

Importantly, our study also sheds new light on the associations between signaled night awakening and social information processing. In the waking group, dwell times to fearful faces were longer than dwell times to happy or both types of neutral faces whereas in the nonwaking group, dwell times to fearful faces were longer than dwell times to neutral faces, but dwell times between fearful and happy faces did not differ. Thus, in the waking group, the attentional bias to fearful faces in relation to other face types was more pronounced than in the nonwaking group. A previous study showed that naps reduced attention bias to emotional stimuli in 4-year-old children [29]. Our results add to previous work by showing that signaled night awakening may alter attention to emotional stimuli in very young children, with children reported to have fewer signaled night awakenings showing a less pronounced attention bias to fearful faces.

As previously mentioned, attentional bias toward fearful faces may be a normative aspect of early social information processing [43, 44, 48]. This pattern of attention was evident in

Table 4. Correlations between attention dwell times to faces at 8 and 24 months and BITSEA domains at 24 months of age

	Internalizing	Externalizing	Dysregulation (no sleep)	Social competence
8 months				
Happy face	.203	**.260***	–.031	**.337****
Fearful face	.242	.157	–.096	.047
Neutral with eyes open	.150	.174	.019	.072
Neutral with closed eyes	.146	.155	.050	.228
24 months				
Happy face	–.135	.204	**–.214***	.132
Fearful face	–.096	.042	–.096	.130
Neutral with eyes open	–.088	.131	–.092	.069
Neutral with closed eyes	–.070	–.037	–.087	.047

*Correlation is significant at the .05 level.
**Correlation is significant at the .01 level.
The correlations are unadjusted for multiple comparisons.

the waking group, whereas in the nonwaking group, dwell times to fearful and happy faces did not differ. To understand this finding, it is important to note that our analysis of the Overlap task was longitudinal, with the attention patterns observed in data averaged across 8 and 24 months of age because no interactions involving age were observed. Given that longitudinal studies suggest that the robust attention bias to fearful faces observed in infancy may become smaller and less selective to fearful faces across early childhood [44, 47, 65], it would be intriguing to speculate whether the group differences observed in the present study reflect differential age-related patterns of attention bias. However, this possibility remains to be determined, as the interaction between group, emotion, and age was not significant in the present analysis. The longitudinal effects of signaled night awakening on social information processing remain an important topic for future studies.

As hypothesized, signaled night awakening was connected to different aspects of parent-reported socio-emotional behavior at 24 months of age. The two groups differed in the amount of dysregulation, with the waking group having more problems than the nonwaking group. This finding is consistent with the results of Morales-Muñoz et al. [39] from the current cohort, showing that night awakenings at 3, 8, 18, and 24 months of age were related to greater dysregulation [39], but inconsistent with those of Mindell et al. [34], according to which night awakening at 6, 12, and 18 months was not associated with dysregulation at 12 or 18 months of age. In the BITSEA questionnaire the dysregulation scale consists of items concerning regulation difficulties in sleep, eating, and emotional or self-regulation difficulties ("Cries or tantrums until s/he is exhausted," "Has trouble adjusting to changes," and "Often gets very upset"). In previous literature, frequent signaled night awakenings have been thought to be associated with the inability to soothe or regulate oneself back to sleep after waking. Thus, the ability to fall asleep alone is a highly important developmental task, for which self-regulation skills are essential. Our results extend previous work by showing that children with frequent signaled night awakenings at 8 months have persistent difficulties in regulating their behavior more generally and not only in terms of regulating sleep since the two groups differed in dysregulation even after the removal of the two items concerning sleep difficulties and night awakening. In future studies, longitudinal associations with signaled night awakening and different aspects of self-regulation should be further investigated to determine whether such early difficulties in behavioral regulation are precursors for later, more severe problems of self-regulation.

Contrary to our expectation, the waking and nonwaking groups did not differ in the amount of externalizing problems at 24 months of age, and the difference in internalizing problems was only marginal. Our results are consistent with a previous study with an equivalent sample size showing that night awakening was not associated with internalizing or externalizing problems [34], but discrepant with large community-based studies, including the full CHILD-SLEEP cohort, which showed night awakening to be connected to both externalizing and internalizing difficulties [37, 39, 41]. In these larger studies, stronger associations have been found for internalizing compared to externalizing difficulties. It could be that the effect of signaled night awakening on internalizing and externalizing problems during early development is relatively small and possibly confounded by other factors. Therefore, such associations may be more difficult to detect in studies with smaller sample sizes. Furthermore, it is also possible that the associations between signaled night awakening and internalizing and externalizing difficulties become stronger with age.

Interestingly, in our study, the waking group had lower parent-reported social competence than the nonwaking group. Our finding is consistent with a recent study showing that night awakening is associated with lower social competence [34]. In that study, the frequency of night awakening and the longest stretch of sleep, but not total sleep duration, bedtime, or sleep onset latency, were the only sleep parameters associated with social competence at the concurrent age of 12 months. Results from other studies reporting associations between sleep duration and social competence in children have been mixed [66–68]. Early childhood is an important period for the development of social competence. According to our study and that by Mindell et al. [34], night awakening may be associated with slower development of social competence already during the first 2 years. Prior studies have mainly focused on the associations between sleep and socio-emotional problems, whereas studies focusing on the positive aspects of socio-emotional development are limited in number. In future studies, it is important to recognize possible socio-emotional problems as early as possible, but also to extend the focus to the positive aspects of socio-emotional development. In our longitudinal cohort, we can follow these children through childhood to find out whether these differences in social competence will even out or become larger with age. In addition, the neurocognitive mechanisms by which night awakenings influence social competence are an important target for future studies, and the possible mediating role of behavioral regulation difficulties in the development of social competence should be considered.

Taken together, the findings of this study suggest that children with frequent signaled night awakenings at 8 months are at increased risk for behavioral regulation problems and the development of poorer social competence. In addition, attention to emotional faces, but not attention to faces in general, was associated with signaled night awakening. In our previous work, the same children with frequent signaled night awakenings also exhibited lower executive functioning performance than children without signaled night awakenings [12], but they did not show differences in overall psychomotor development [54]. Therefore, emotional and executive functioning may be especially associated with signaled night awakening in infancy, and children who signal their awakenings may have difficulties in self-regulation in multiple developmental domains. Previous studies have shown that signaled night awakening can be successfully diminished or treated with interventions that focus on parent training strategies [69]. Whether changes in signaled night awakening following intervention also produce changes in social information processing and socio-emotional behavior would be an important question to understand the mechanisms linking signaled night awakening to social behavior.

Regarding the last research question, our findings suggested that attention to faces and parent-rated socio-emotional behavior may be associated. Attention toward happy faces at 8 months correlated positively with increased social competence and greater externalizing problems at 24 months of age. Concurrently at 24 months of age, greater attention toward happy faces was associated with lower scores on the dysregulation domain. These findings are partially consistent with those of Peltola et al. [44], which indicated that infants' greater attention to faces is associated with prosocial behavior. Attentional biases toward positive stimuli have been observed in typically developing children [70] and individual differences in attentional bias to positive information have been associated with stronger positive affective responses [71] and increased prosocial behavior, less externalizing disorders, and less emotionally withdrawn behavior in foster care children [72]. Our results may thus suggest that greater attention toward positive stimuli is associated with better socio-emotional outcomes, which may reflect the child's interest in the rewarding features of interactions. Surprisingly, our results also showed that greater attention to happy faces was associated with greater externalizing behavior. However, it is important to keep in mind that, in our sample, the children were 2 years old and the overall scores on the externalizing domain were low, and therefore it might be that the associations with the externalizing domain could be driven more by moderately elevated impulsive behavior than acting-out or aggressive behavior, which are descriptive of high externalizing scores in early childhood. A limitation of the current correlational results is that the correlations were not adjusted for multiple comparisons. In addition, the sample size in these correlation analyses was somewhat underpowered to detect small (i.e. $r < .30$) correlations. Therefore, these exploratory analyses should be interpreted with caution. It should also be noted that our findings concern children under 2 years of age and in future studies it will be important to examine whether similar findings are observed in older children and more versatile and larger samples.

As a limitation, our group formation relied on parent reports. The two groups were formed at 8 months of age since our interest was to study signaled night awakening already in infancy. We also analyzed actigraphy data at 8 months of age [12] and showed that the waking and nonwaking groups differed also in actigraphy-based night awakenings at 8 months, thus validating our group formation based on parent reports. The two groups, however, did not differ in other actigraphy-based sleep duration measures. In addition to 8 months, signaled night awakening was also assessed longitudinally with questionnaires at 18 and 24 months of age, and the waking and nonwaking groups differed in parent-reported signaled night awakening at 18 and even at the age of 24 months, thus the two groups were distinguished by the number of signaled night awakenings also later in infancy. One specific feature of the current study was that the participants were drawn from the prevention substudy of the larger cohort. Thus, half of the participants were from the so-called prevention health care centers and the rest from the control health care centers. The families in the prevention health care centers received preventive psychoeducation on infant sleeping habits through brochures, whereas the control health care centers received no preventive sleep material. Infants in both night awakening groups came from both of these health care centers. In addition, the health care status of the child was taken into account in our analyses, and it did not have a significant effect on the results. In addition, our previous work showed that children's health care center status was not associated with different sleep quality and duration parameters, psychomotor development [54], or executive functioning [12]. As another potential limitation, we relied on parental reports of socio-emotional behavior. Therefore, it is possible that children with frequent signaled night awakenings are perceived as generally more dysregulated by their parents due to more frequent signaled night awakenings. However, in the present study, this seems unlikely since the differences between groups in dysregulation remained even though the questions concerning night awakening were removed. Future studies would, however, benefit from using multiple informants such as daycare staff in addition to parents, and the development of more objective experimental methods for studying socio-emotional development would also improve the reliability of this line of research. An important factor potentially affecting attention biases in early development is infant temperament (e.g. negative affectivity or behavioral inhibition), which was outside the scope of the present paper and thus not included in the analyses. In the future, it will be important to characterize the associations between temperament and attention biases with sufficiently large samples covering representative variation in relevant temperament dimensions to evaluate whether findings linking temperament and attention biases in older children [73] are replicated in infants. Finally, our sample consisted of White families of mainly middle-class origin and therefore the generalizability of our results to other ethnicities and sociodemographic groups is limited. For example, co-sleeping and signaled night awakening can be considered to reflect normative patterns of sleeping in infancy in other cultures than our sample that represents a Western culture.

In conclusion, our results showed that signaled night awakening is associated with social information processing and socio-emotional behavior already during the first 2 years of life. Children with frequent signaled night awakenings exhibited different patterns of attention to emotional faces than children without signaled night awakenings. In addition, at 24 months of age, children with frequent signaled night awakenings had greater parent-reported regulation difficulties and lower social competence than children without signaled night awakenings. However, no clear differences in internalizing or externalizing problems were found between the two groups. Attention to happy faces at 8 and 24 months of age was connected to parent-rated socio-emotional behavior at 24 months. According to our results, it is possible that signaled night awakening could be an early marker of ineffective self-regulatory abilities that predispose children to later socio-emotional behavioral problems. However, the differences between groups were rather small, and longitudinal studies are needed to determine whether the differences in social information processing and socio-emotional behavior will even out or increase as children grow older. Nevertheless, our study provides a novel contribution regarding the influence of signaled night awakening on children's social information processing and social development.

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Authors' Contributions

All authors contributed to the planning of the study design and contributed critically to the writing of the article. TEM, MJP, and AK were primarily responsible for data analysis.

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