Developmental Cognitive Neuroscience 26 (2017) 77–83

Contents lists available at ScienceDirect

Developmental Cognitive Neuroscience

journal homepage: www.elsevier.com/locate/dcn

Behavioral and neural concordance in parent-child dyadic sleep patterns

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ARTICLE INFO

Keyword:
Adolescent sleep
Sleep concordance
Default-mode connectivity
Parent-child dyad
Resting-state fMRI
Independent component analysis (ICA)

ABSTRACT

Sleep habits developed in adolescence shape long-term trajectories of psychological, educational, and physiological well-being. Adolescents' sleep behaviors are shaped by their parents' sleep at both the behavioral and biological levels. In the current study, we sought to examine how neural concordance in resting-state functional connectivity between parent-child dyads is associated with dyadic concordance in sleep duration and adolescents' sleep quality. To this end, we scanned both parents and their child (N = 28 parent-child dyads; parent M_{age} = 42.8 years; adolescent M_{age} = 14.9 years; 14.3% father; 46.4% female adolescent) as they each underwent a resting-state scan. Using daily diaries, we also assessed dyadic concordance in sleep duration across two weeks. Our results show that greater daily concordance in sleep behavior is associated with greater neural concordance in default-mode network connectivity between parents and children. Moreover, greater neural and behavioral concordances in sleep is associated with more optimal sleep quality in adolescents. The current findings expand our understanding of dyadic concordance by providing a neurobiological mechanism by which parents and children share daily sleep behaviors.

1. Introduction

Adequate sleep is vital for developing youth. Inadequate sleep (e.g., high variability of day-to-day sleep duration, sleep deprivation) can result in long-term cognitive, behavioral and functional deficits in developing youth (Beebe, 2011). For example, less sleep time and lower sleep quality are related to maladjustment, including unstable mood, academic difficulties, poor cognitive and emotional control, and externalizing and internalizing symptoms (Beebe, 2011; Carskadon and Dement, 1987; Dahl et al., 1994; Dahl and Lewin, 2002; Roane and Taylor, 2008; Wolfson and Carskadon, 1998; Wong et al., 2010). Moreover, such poor sleep behavior can result in neural impairments in the developing brain associated with destructive alterations in neural systems (Jan et al., 2010), including reduced cerebral metabolism, neurogenesis due to increased circulation of the adrenal stress hormone, and gray and white matter alterations (Halbower et al., 2006; Horne, 1993; Kopp et al., 2006; Mirescu et al., 2006; Telzer et al., 2015).

Inadequate sleep is particularly endemic in adolescence, perhaps because adolescents do not receive the quality environmental context needed for restorative sleep and optimal brain development (Dahl and Lewin, 2002). The transition to middle and high school presents challenges to adolescents' ability to obtain adequate rest at night. For instance, early school start times conflict with their biologically driven circadian phase delay that leads adolescents to prefer later bedtimes (Carskadon et al., 1993; Dahl and Lewin, 2002). Academic demands require adolescents to stay up late completing school work, which disrupts their sleep time (Adam et al., 2007). Finally, increased access to technology (e.g., televisions, computers, internet, smart phones) creates evening distractions that result in later bedtime (Adam et al., 2007; Tazawa and Okada, 2001; Van den Bulck, 2004), while also altering the body's biological sleep patterns (e.g., disrupting melatonin release and circadian rhythm; Chang et al., 2015). Thus, understanding the environment by which sleep patterns are socialized to youth may increase our understanding of sleep behavior and brain development during this critical phase of development.

As children enter adolescence, parental influence on sleep declines, and adolescents tend to take more control over their own schedule, resulting in more inadequate and irregular sleep patterns. Although adolescence tends to be a developmental period when youth orient more towards their friends and seek more autonomy from their parents (Nelson et al., 2005), sleep largely occurs within the constraints of the family home such that the daily sleep routine of parents can significantly shape the daily sleep routine of adolescents (Fuligni et al., 2015). Recently, researchers have focused on social factors, particularly in the home environment, in shaping adolescents' sleep. For instance,

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http://dx.doi.org/10.1016/j.dcn.2017.06.003
Received 4 October 2016; Received in revised form 20 May 2017; Accepted 2 June 2017
Available online 15 June 2017

the emotional climate, quality of family relationships, and parental monitoring of adolescents' sleep and wake times are key factors shaping adolescents' sleep behavior (Adam et al., 2007; El-Sheikh et al., 2006). An even more proximal contributor to adolescents' sleep is the sleep habits of parents themselves. For instance, correlational research has shown that irregular late bedtimes in parents is related to sleep problems and daytime sleepiness in children (Komada et al., 2009), parents who sleep less have children who sleep less (Li et al., 2010), and there tends to be strong similarities in parents' and children's sleep-wake cycles (Zhang et al., 2010). Moreover, using daily diary methods with independent daily ratings of sleep from adolescents and parents, adolescents' sleep behavior – when they go to bed, how much they sleep, and when they wake up – is closely synchronized with parents' sleep patterns (Fuligni et al., 2015). Importantly, this daily concordance in sleep patterns holds above and beyond factors such as study time, underscoring the unique and important role of parents' sleep for adolescents' sleep. In addition to research finding concordance in self-report measures, recent work has identified biological concordance in parent-child sleep patterns. For instance, using EEG measures, adolescents' sleep continuity and architecture were closely associated with parents' sleep continuity and architecture (Kalak et al., 2012). Together, this research underscores the important role of parents' sleep in shaping their children's sleep.

Parents and their children engage in high levels of dyadic coordination at the behavioral (e.g., shared affect) and biological level, such as the immediate coordination of ongoing physiological signals (e.g., heart rate; Feldman et al., 2011). Theoretical work suggests that harmonious interpersonal interactions including behavioral and psychological similarity are derived from more in-tuned neural states between two individuals (Wheatley et al., 2012), offering a likely neurobiological candidate underlying synchronized behavior in parent-child dyads, namely neural concordance. Indeed, we recently demonstrated that emotional concordance between parents and their adolescent children was associated with more in-tuned neural states within parent-child dyads, and greater neural concordance was associated with better adjustment (Lee et al., 2017). Therefore, neural concordance may represent a neurobiological marker by which parents and children share daily sleep behaviors.

In the current study, we aimed to examine neural level concordance associated with dyadic sleep concordance and how these two levels of dyadic concordance are associated with adolescents' sleep quality. To this end, we implemented a multimethod analytical approach combining resting state functional neuroimaging, in which both parents and their child underwent an fMRI scan to measure neural concordance and a daily diary method to estimate how sleep time of parent-child dyads fluctuate together across two weeks (i.e., behavioral concordance). We focused on total sleep time as an index of concordant sleep behavior because sleep time is more globally attributable to sleep pattern concordance (Fuligni et al., 2015). The benefit of this daily diary approach is two-fold. First, we had independent ratings from both the parent and adolescent child, moving beyond single-reporter studies. Secondly, by asking parents and adolescents to independently report on their sleep time every day for 14 days, we better captured daily sleep patterns than single time-point, self-report measures (Bolger et al., 2003). By asking parents and adolescents each day to report on their sleep time allowed us to estimate the concordance between parent and adolescent sleep at the daily level within dyads, reducing confounds that are present in a between-family approach (Fuligni et al., 2015).

To index neural level concordance, we quantified how functional connectivity patterns are similar in parent-child dyads. In particular, we focused on the default mode network (DMN), which represents an intrinsic regulation system that plays a pivotal function for segregating internally and externally directed cognitive processes (Buckner et al., 2008; Fox et al., 2005). Previous evidence indicates that the DMN is one of the main functional networks in the brain that regulates wakefulness including initializing, maintaining, and terminating sleep (Basner et al., 2013; Horovitz et al., 2009; McKenna and Eyler, 2012; Picchioni et al., 2013), by changing functional coupling with other independent functional networks (i.e., connectivity pattern of DMN to the other nodes; Larson-Prior et al., 2011; Laufs et al., 2003; Picchioni et al., 2013). Moreover, sleep deprivation is associated with reduced functional connectivity within the DMN as well as between the DMN and other networks (De Havas et al., 2012; Sämann et al., 2010), indicating that sleep is not based solely on the DMN *per se* but rather on how the DMN is wired to other networks. Such impaired downregulation of the DMN after sleep deprivation may result in the insufficient allocation of cognitive resources (Drummond et al., 2005), translating to behavioral changes following poor sleep (Sämann et al., 2010).

Hence, the current study examined how parent-child dyadic sleep concordance is related to functional dynamics of the DMN with other networks. To accomplish this, we identified all possible intrinsic networks in the brain including the DMN using independent component analysis (ICA), estimated functional connections between the DMN and all other intrinsic networks, and quantified how similarly the DMN is wired to other brain systems (DMN connectivity similarity) between parents and their child. We used ICA to identify DMN connectivity as opposed to seed-based connectivity patterns, because ICA can estimate each functional network independently based on the linear mixing assumption for temporal coherency (Beckmann and Smith, 2004), and thus provides metrics of both between- and within-network connectivity (Jafri et al., 2008; Joel et al., 2011), whereas seed-based methods only provide one single metric based on the user-specified temporal signal (i.e., seed).

We examined three key questions. First, is daily concordance in sleep time between parents and their adolescent child associated with neural concordance in DMN connectivity? Although prior research has investigated dyadic concordance in sleep behavior between parents and their child focusing on subjective (i.e., self-report daily report; Fuligni et al., 2015) and biological (e.g., EEG coherence; Kalak et al., 2012) aspects of sleep, no prior study has examined neurobiological concordance in relation to sleep behavior in parent-child dyads. Second, are daily concordance in sleep and neural concordance in DMN connectivity associated with adolescents' overall sleep quality? We have previously shown that adolescents who show greater affective synchrony and greater neural concordance with their parents report better emotional adjustment (Lee et al., 2017), suggesting that parent-child neural concordance may confer benefits for youth. Finally, we tested whether neural concordance in DMN connectivity is associated with sleep quality above and beyond the effects of daily concordance in sleep. Such effects would suggest a unique and important role of neural concordance that cannot be measured or explained by self-report measures of sleep.

2. Materials and method

2.1. Participants

28 parent-child dyads participated in the current study (n = 56; parent M_{age} = 42.79 years, range = 33–57, 14.29% father; child M_{age} = 14.93 years, range = 13–17, 46.43% female). Although no study has examined RSN connectivity concordance between dyads, we based our sample size on previous developmental resting-state fMRI studies (Gabard-Durnam et al., 2016; Gee et al., 2013). All parent-child dyads were biologically related and provided informed consent/assent, and no participants reported any mental health problems (e.g., current clinical diagnosis or pharmacological intervention for a mental illness).

2.2. Daily concordance in sleep-time

Adolescents and their parents each completed daily checklists indicating the amount of time they slept each night for two weeks (for a total of 14 checklists). Both parents and their adolescent child either