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Original Article

Poor sleep and neurocognitive function in early adolescence

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ABSTRACT

Background: Evidence regarding the associations between sleep duration and quality, and neurocognitive function in adolescents remains scanty. This study examined the associations in early adolescence between: sleep duration; efficiency; fragmentation; wake-after-sleep-onset (WASO); catch-up sleep; intelligence; memory; and executive function, including attention.

Methods: This study included 354 girls and boys with a mean age 12.3 years (SD = 0.5) from a birth cohort born in 1998. Sleep was measured with accelerometers for an average of eight nights. Cognitive function was evaluated with subtests from the Wechsler Intelligence Scale for Children-III (WISC-III), the Developmental Neuropsychological Assessment 2 (NEPSY-2), the Wisconsin Card Sorting Task (WCST), Conners' Continuous Performance Task (CPT), and the Trail Making Test (TMT).

Results: In girls, a higher WASO and fragmentation index were associated with poorer executive functioning (higher number of perseverative errors in the WCST), and longer catch-up sleep was associated with longer reaction times and better performance in one verbal intelligence test (Similarities subtest of the WISC-III). In boys, shorter sleep duration, lower efficiency, higher WASO, higher sleep fragmentation and shorter catch-up sleep were associated with lower executive functioning (more commission errors, shorter reaction times, and had lower D Prime scores in CPT).

Conclusions: In adolescent girls, poorer sleep quality was only weakly associated with poorer executive functioning, while in boys, poorer sleep quantity and quality were associated with an inattentive pattern of executive functioning. The amount of catch-up sleep during weekends showed mixed patterns in relation to neurocognitive function.

1. Introduction

Memory [1], learning [2], attention and various other cognitive abilities and functions [3,4] depend on varying amounts of good-quality sleep, especially during critical developmental periods in childhood and adolescence. This has been demonstrated in several experimental studies, in which children's or adolescents' sleep duration is either restricted or, after restriction, extended [5–10]. Additionally, studies analyzing self-reported sleep data have reported associations between children's sleepiness and a decline in cognitive ability [11]. However, it remains poorly understood whether individual variations in children's and adolescents' sleep duration and quality (sleep efficiency, fragmentation, wake-after-sleep-onset [WASO]), as they occur in non-experimental conditions in normal daily living, have an impact on performance in neurocognitive tests.

Studies testing the associations between objectively measured sleep duration and quality (ie, with actigraphy) and intelligence test scores in children and adolescents have revealed a mixed pattern of findings. Of these studies, three found no significant associations between actigraph-measured sleep duration and verbal and perceptual reasoning or general intelligence quotient (IQ) test scores [12–14], and one reported no significant associations between sleep quality and IQ scores [13]. One additional study did find that actigraph-measured shorter sleep duration was associated with lower perceptual reasoning and overall IQ scores [15].

Studies of children and adolescents that tested the associations between objectively measured sleep duration and quality, and memory and executive function, have shown a more consistent pattern. With regard to memory function, shorter actigraph-measured sleep duration, lower sleep efficiency, and longer sleep latency were associated with lower scores on tests measuring

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auditory and visuospatial working memory [16], and lower actigraph-measured sleep efficiency was associated with lower scores on tests measuring auditory working memory [17]. Higher actigraph-measured sleep fragmentation, higher number of night awakenings and lower true sleep time were associated with lower scores in tests measuring executive functioning [18]. On the other hand, weekend catch-up sleep is understudied regarding its associations with neurocognitive function, although some studies have separately reported weekday and weekend nights sleep [14].

All of the above studies were either conducted in pre-pubertal children or in samples that were heterogeneous in age, including both pre-pubertal children and children in early adolescence. It is well known that during pubertal development, sleep duration decreases while sleep efficiency and sleep need increase [19]. Adolescence is also a period that is accompanied by the maturation of the frontal cortex, which is a central region for executive functioning [20]. Consequently, generalizability from the existing findings to adolescents remains limited. It is believed that, to date, there is only one study on 13- to 14-year-old adolescents. That study reported that actigraph-measured sleep duration was not associated with scores on tests measuring executive functioning [21].

While both sleep [19,22] and neurocognitive performance [23,24] may vary between sexes in early adolescence, none of the studies have separately tested the associations in both girls and boys. At this age, girls are typically ahead of boys in terms of pubertal development [19] and the possible underlying sexual dimorphisms may have an impact on sleep duration, sleep quality, and neurocognitive performance.

Furthermore, it has been suggested that the associations between sleep duration and quality and neurocognitive function may be cognitive-domain specific [15]. Some domains, like intelligence, which is highly stable across development [25], may be less dependent on variation in sleep, while some domains such as memory, attention, and executive functioning may be more sensitive. However, neither the only existing study on adolescents nor any of the previous studies on samples including adolescents have tested the associations between sleep duration and sleep quality with intelligence, memory, attention and executive functioning within the same study.

Accordingly, the present research questions were tested on a sample of 354 11- to 13-year-old adolescents. This study set out to examine whether actigraph-measured sleep duration, its variability from weekdays to weekends (the amount of catch-up sleep) and sleep efficiency, fragmentation and WASO time were associated with IQ test scores and scores on tests measuring memory and executive functioning, including attention. These associations were separately tested on girls and boys.

2. Methods

2.1. Participants

The adolescents came from an urban community-based cohort comprising 1049 healthy singletons born between March and November 1998 in Helsinki, Finland [26]. In 2009–2011, the initial cohort of people who had given permission to be contacted and whose addresses were traceable ($N = 920$, 87.7% of the original cohort) was invited to a follow-up, of which 692 (75.2%) could be contacted by phone (mothers of the adolescents). Of them, 451 (234 girls and 217 boys; 65.2% of the contacted group) participated in a follow-up at a mean age of 12.3 years (SD = 0.5, range 11.0–13.2). Of them, 363 (80%) took part in the sleep measurement, 419 (93%) underwent the neurocognitive testing, and 358 (79%) participated in both. From these, four participants who had a valid sleep measurement of less than three nights were excluded, leaving 354 adolescents (190 girls, 164 boys) in the analyses. Additionally, one male participant was categorized as an outlier and removed from sleep duration analyses due to an average sleep duration of over 5 standard deviation units above mean. Regarding the Conners' Continuous Performance Task (CPT), four children were unable to complete the test and, hence, were excluded from the CPT analyses. The participants of the present study differed from the non-participants in two respects: the participants had older mothers ($p = 0.03$); and the mothers' consumption of glycyrrhizin in licorice during pregnancy (mg/wk), as reported by the mother, was higher ($p = 0.04$) than among the non-participants. The Ethics Committees of the City of Helsinki Health Department and Children's Hospital at the Helsinki University Central Hospital approved the study protocol. Each adolescent and their parent(s) gave written consent.

2.2. Sleep duration and quality

Sleep duration and quality were objectively measured using actigraphs (Actiwatch AW7, Cambridge Neurotechnology Ltd., UK). Detailed descriptions of the procedure and scoring have been previously reported [19]. Actigraph measurements were generally initiated on the day the neurocognitive tests were administered. The actigraphs were worn on the non-dominant wrist continuously for an average of 7.9 nights (SD = 1.8 range 3–10). Of the 354 participants in this study, 2%, 3%, 5%, 6%, 10%, 16%, 25%, and 34% had three to nine and >10 valid sleep-registration nights available, respectively. Both weekdays and weekends were included in the sleep measurements in order for the measurement period to represent typical sleep over an average of eight nights. In both girls and boys, this measurement period included an average of six weekday nights (SD = 1.5, range 1–9) and an average of two weekend nights (SD = 1.1, range 0–4). Of the participants, 16 girls and five boys had no weekend catch-up sleep data.

Adolescents were instructed to mark the wake-up time and bedtime by pressing a button (event marker in the device) and by completing a sleep log, and to register any temporary pauses into the sleep log. Other significant occurrences, such as travel or illness, were also reported. Nights were excluded from further sleep analyses if: (a) the actigraph was not in use; (b) information on bedtimes was missing; (c) the data on reported bedtime indicated that the child was already asleep (suggesting that the bedtime was incorrectly reported); (d) information on waking time was missing and the activity pattern was unclear; or (e) the parent reported a change in normal life due to, for example, illness or travel. Additionally, during the sleep registration period some of the participants took part in a very-low-dose overnight dexamethasone suppression test [24]. The night following the dexamethasone intake at bedtime was excluded from the analyses.

Sleep duration refers to actual sleep time and is determined by the actigraph algorithm. Sleep efficiency is defined as the ratio between actual sleep time and time in bed. The fragmentation index is an indicator of restlessness, and is the addition of percentage minutes moving and percentage of immobility. Wake-after-sleep-onset (WASO) time is defined as the amount of minutes where actual sleep time is subtracted from the assumed sleep. Catch-up sleep was calculated as the subtraction of the weekday nights' sleep duration from the weekend nights' sleep duration.

2.3. Neurocognitive performance

The following tests were selected to effectively cover three different domains of neurocognitive performance.

2.3.1. Intelligence

Four subtests of the Wechsler Intelligence Scale for Children III [27,28] were used to assess verbal and perceptual reasoning: