Title

Sleep problems and recall memory in children with Down syndrome and typically developing controls

Authors
Lukowski, Angela F
Slonecker, Emily M
Milojevich, Helen M

Publication Date
2020

DOI
10.1016/j.ridd.2019.103512

Peer reviewed

Published in final edited form as:
Res Dev Disabil. 2020 January ; 96: 103512. doi:10.1016/j.ridd.2019.103512.

Sleep Problems and Recall Memory in Children with Down Syndrome and Typically Developing Controls

Angela F. Lukowski, **Emily M. Slonecker**, **Helen M. Milojevich**
Department of Psychological Science UC Irvine

Abstract

Background.—Research conducted with typically developing (TD) infants and children generally indicates that better habitual sleep and sleep after learning are related to enhanced memory. Less is known, however, about associations between sleep and recall memory in children with Down syndrome (DS).

Aims.—The present study was conducted to determine whether parent-reported sleep problems were differentially associated with encoding, 1-month delayed recall memory, and forgetting over time in children with DS and those who were TD.

Methods and Procedures.—Ten children with DS (mean age = 33 months, 5 days) and 10 TD children (mean age = 21 months, 6 days) participated in a two-session study. At each session, recall memory was assessed using an elicited imitation paradigm. Immediate imitation was permitted at the first session as an index of encoding, and delayed recall was assessed 1 month later. In addition, parents provided demographic information and reported on child sleep problems.

Outcomes and Results.—Although parents did not report more frequent sleep problems for children with DS relative to TD children, regression-based moderation analyses revealed that more frequent sleep problems were associated with increased forgetting of individual target actions and their order by children with DS. Evidence of moderation was not found when examining encoding or delayed recall.

Conclusions and Implications.—Although group differences were not found when considering parent-reported sleep problems, more frequent sleep problems were positively associated with increased forgetting by children with DS relative to those who were TD. Although future experimental work is needed to determine causality, these results suggest that improved sleep in children with DS might reduce forgetting, ultimately improving long-term recall memory.

Keywords

Down syndrome; recall memory; sleep; consolidation

Corresponding Author Angela F. Lukowski, Ph.D., Associate Professor, Department of Psychological Science, UC Irvine, 4332 Social and Behavioral Sciences Gateway, Irvine, CA 92697-7085, Phone: 949-824-7191, Fax: 949-824-3002, angela.lukowski@uci.edu.
Author note. H. M. Milojevich is currently a postdoctoral scholar at the Center for Developmental Science at the University of North Carolina-Chapel Hill, East Franklin Street Suite 100, CB #8115, Chapel Hill, NC 27599–8115.

I. Introduction

The importance of obtaining adequate sleep for optimal daytime functioning is not contested: in typically developing (TD) samples, sleep problems have been associated with poorer mental and physical health (Stein, Belik, Jacobi, & Sareen, 2008) as well as with impaired cognitive functioning (Beebe, 2011; Curcio, Ferrara, & De Gennaro, 2006). When considering associations between sleep and cognitive functioning in particular, the conducted research has revealed significant associations between sleep and recall memory from infancy to adulthood (for a review, see Kopasz et al., 2010). The work conducted with TD infants and children has indicated that better habitual sleep (Lukowski & Milojevich, 2013) and sleep immediately after learning (Kurdziel, Duclos, & Spencer, 2013; Seehagen, Konrad, Herbert, & Schneider, 2015) is associated with enhanced performance. Less is known, however, about relations between sleep and recall memory in children with Down syndrome (DS). This limited literature is surprising when considering the widespread documentation of sleep problems in children with DS (Ashworth, Hill, & Karmiloff-Smith, 2013; Austeng et al., 2014; Breslin et al., 2011; Churchill et al., 2012; Cotton & Richdale, 2006; Levanon et al., 1999; Maris et al., 2016) and recent findings indicating that children with DS experience difficulty recalling temporal order information over the long term (Milojevich & Lukowski, 2016). The present study was conducted to determine (1) whether parents reported greater sleep problems for children with DS relative to those who were TD and (2) whether parent-reported sleep problems were differentially related to recall performance in TD children and children with DS when considering the encoding, delayed recall, and forgetting of individual elements of events and their temporal order.

Examining associations between sleep and recall memory is particularly important, as the processes associated with encoding and remembering information over the long term are used not only in everyday life but are also required for successful performance in intervention and educational settings. One in every 1000 to 1100 infants born around the world has DS (World Health Organization, 2018), a genetic mutation that results from extra genetic material on the 21st chromosomes. DS is most commonly due to errors in cell division that occur around the time of conception (Antonarakis, Avramopoulos, Blouin, Talbot, & Schinzel, 1993; Sherman et al., 1994; Yoon et al., 1996; for a review, see Sherman, Allen, Bean, & Freeman, 2007) and is the most common genetic cause of intellectual impairment. DS has also been associated with reduced intelligence or IQ, issues with receptive and expressive language, and challenges with particular aspects of executive functioning (see Lukowski, Milojevich, & Eales, 2019). In addition, DS has been associated with specific physical characteristics, including reduced muscle tone and restricted upper airways, that may contribute to the sleep disturbances and problems commonly observed within this population (Charleton, Dennis, & Marder, 2014).

Parent-report measures suggest that up to 85% of children with DS experience clinically concerning sleep problems (Breslin et al., 2011; Hoffmire, Magyar, Connolly, Fernandez, & Van Wijngaarden, 2014). Studies conducted using polysomnography provide corroborating evidence, with indications of sleep-disordered breathing or obstructive sleep apnea (OSA) in 55% (de Miguel-Díez, Villa-Asensi, & Álvarez-Sala, 2003; see also Shott et al., 2006) to 79% of children tested (Dyken, Lin-Dyken, Poulton, Zimmerman, & Sedars, 2003).

Although there are no studies to our knowledge documenting associations between sleep problems or OSA and recall memory in individuals with DS, an extensive body of work has examined relations between OSA and executive functioning in this population given the proposed impact of OSA on prefrontal functioning in particular (see Beebe & Gozal, 2002). Results indicate that children with DS who also experienced OSA performed less well on measures of verbal IQ and measures of cognitive flexibility relative to children with DS who did not have OSA (Breslin et al., 2014). Other research has revealed that adolescents and young adults with DS experienced deficits in verbal fluency and inhibition in relation to parent-reported symptoms of OSA (Chen, Spanò, & Edgin, 2013). A recent review on this topic suggests that the increased cognitive impairments associated with OSA in individuals with DS may significantly impact their daily functioning and independent living (Lal, White, Joseph, Van Bakergem, & LaRosa, 2015), indicating that the impact of sleep problems on functional outcomes in this population is significant.

Despite findings documenting associations between sleep problems and executive functioning in elementary school aged children and adolescents, there is limited research examining relations between sleep problems and recall memory in younger children with DS. One relevant study indicated that TD children recalled more animal-name pairs after a period of overnight sleep relative to baseline, but overnight improvements in performance were not observed for children with DS. However, time of day was associated with recall by children with DS, such that children tested in the morning showed improved performance over time (Ashworth, Hill, Karmiloff-Smith, & Dimitriou, 2017). More recent work similarly suggests that the timing of sleep differentially impacts memory in TD children and children with DS. Using a word learning paradigm, Spanò and colleagues (2018) found that TD children who napped after learning recognized a greater proportion of objects correctly relative to children with DS. Conversely, the children with DS who remained awake after learning demonstrated better memory relative to TD children. These two studies provide converging evidence to indicate that TD children experience cognitive benefits from sleep after learning, whereas children with DS experience benefits from remaning awake – a pattern that was maintained after a 24-hour delay in Spanò et al. (2018). These findings suggest that sleep may not serve to consolidate memories in children with DS as has been observed in TD samples.

Whereas previous research has examined sleep-cognition associations in preschoolers and school-aged children with DS, part of the challenge in assessing recall memory in younger samples is methodological. Because children with DS may experience challenges with productive language (e.g., Chapman, 2006; Chapman, Hesketh, & Kistler, 2002), developmentally appropriate behavioral measures may be best suited to assess cognitive functioning within this population. The elicited or deferred imitation paradigm is a popular behavioral method of assessing recall memory in infancy and early childhood that has previously been used in studies of children with DS (e.g., Rast & Meltzoff, 1995; Milojevich & Lukowski, 2016). In one version of this task (Bauer, DeBoer, & Lukowski, 2007; Lukowski & Milojevich, 2016), children are presented with three-dimensional stimuli that can be used to create a novel sequence of events. Children initially interact with the props during a pre-demonstration baseline period. Immediately thereafter, a researcher demonstrates how to complete a sequence of actions that results in an end- or goal-state that children usually find enjoyable. Children are allowed to imitate the demonstrated actions immediately after their presentation as an index of encoding and/or after extended delays ranging from minutes to months. The data are then coded to determine whether the children complete the individual target actions demonstrated by the researcher as well as whether they are performed in the correct temporal order (see Bauer et al., 2007; Lukowski & Milojevich, 2016).

Research conducted with children with DS using the elicited imitation paradigm, although relatively limited, has informed our collective understanding of encoding and delayed recall memory in this population. The seminal study on this topic revealed that children with DS remember the individual target actions that comprise 1-step event sequences after a 5-minute delay (Rast & Meltzoff, 1995). More recent work has indicated that both TD children and children with DS encode the target actions and temporal order of 2-step event sequences relative to baseline. Children with DS experience difficulty recalling information over the long term, however. That is, whereas TD children recall both the individual target actions and temporal order of 3-step step events relative to novel control sequences after a 1-month delay, children with DS only demonstrate recall of individual target actions. These data suggest that children with DS may experience particular challenges with downstream memory processes associated with consolidation and storage and/or memory retrieval (Milojevich & Lukowski, 2016).

Given indications that children with DS experience sleep problems and deficits in the long-term recall of temporal order information, additional research is needed to examine whether sleep problems are associated with memory processes in children with DS and to determine whether those processes differ from what is observed in TD children. Such research is motivated by findings suggesting that sleep after learning does not passively protect memories from interfering information in TD children, but instead serves to actively strengthen memories (Kurdziel et al., 2013) by facilitating the transfer of learned information from hippocampal to neocortical structures (see Gais & Born, 2004). Previous studies conducted with TD samples indicate that both variations in habitual sleep and sleep versus wake after learning are associated with recall memory. When considering habitual sleep, research has indicated that longer daytime naps and obtaining more sleep at night relative to during the day were associated with the encoding of temporal order information in 10-month-olds (Lukowski & Milojevich, 2013). In addition, experimental work conducted with 6- and 12-month-old infants who napped at least 30 minutes within four hours of learning events in an elicited imitation paradigm remembered individual target actions after delays of 4 and 24 hours relative to baseline. In addition, infants who napped after learning performed more target actions after 24 hours relative to infants who did not nap (Seehagen et al., 2015). Other work conducted with preschoolers using a different recall memory task has yielded complementary findings: children who napped or did not nap after learning performed similarly at encoding (before the manipulation occurred), but children who napped performed better on the recall test both after the nap and after a 24-hour delay relative to children who remained awake.

Research examining associations between sleep and recall memory in children with DS is necessary given the prevalence of sleep problems and challenges with long-term recall memory previously documented in this population. The present study was conducted to determine (1) whether parents reported greater sleep problems for children with DS relative to those who were TD and (2) whether parent-reported sleep problems were differentially related to recall performance in TD children and children with DS when considering the encoding, delayed recall, and forgetting of individual elements of events and their temporal order. Based on previous research (Ashworth et al., 2013; Austeng et al., 2014; Breslin et al., 2011; Churchill et al., 2012; Cotton & Richdale, 2006; Levanon et al., 1999; Maris et al., 2016), we predicted that children with DS would experience more sleep problems relative to TD children. We also anticipated that sleep problems would moderate the effect of group (DS or TD) on aspects of recall memory. We made this prediction based on our expectation that the sleep problems experienced by the TD children in our sample would be relatively minor and age-appropriate, whereas those experienced by the children with DS would be more severe and potentially associated with sleep issues commonly observed in individuals with DS, such as OSA or other forms of sleep-disordered breathing (de Miguel-Díez et al., 2003; Dyken et al., 2003; see also Shott et al., 2006). In particular, we specifically predicted that sleep problems would be associated with the forgetting of learned information by children with DS as sleep may not serve to support consolidation and storage processes in these individuals (Ashworth et al., 2013; Spanò et al., 2018) as has been previously documented in TD children and adults (see Gais & Born, 2004).[1]

2.0 Method

2.1 Participants

Ten children with DS (mean age = 33 months, 5 days; range from 22 months, 4 days to 49 months, 3 days) and 10 TD children (mean age = 21 months, 6 days; range from 12 months, 19 days to 28 months, 6 days) served as participants. Children with DS were recruited from local support organizations and through snowball sampling, whereas TD children were recruited through mass mailings. Parents who were interested in participating gave the recruitment team their phone number and were later contacted with more information about the study. Seventy-five percent of the participants were Caucasian, 15% were Asian, 5% were African American, and 5% were mixed race; 30% were of Hispanic ethnicity. Eighty-five percent of mothers had obtained at least a four-year college degree. Parents received $30 across the two study sessions and the child received a small gift, such as a junior scientist t-shirt, in thanks for their participation.

2.2 Materials and Measures

2.2.1 Questionnaires.—Parents completed a demographic questionnaire that inquired about child and maternal characteristics (see Table 1) as well as an inventory that inquired

[1]Importantly, this report extends on the findings published in Milojevich & Lukowski (2016) and features examination of the novel question of whether sleep problems moderate the effect of group on recall performance by children with DS and those who are TD. Whereas Milojevich & Lukowski (2016) reported on group differences in recall performance, this manuscript attempts to explain why the reported group differences may have been realized. As such, this paper includes the same sample and elicited imitation data reported on in Milojevich & Lukowski (2016) as well as a subset of the sleep data included in Lukowski & Milojevich (2017). An additional paper from this dataset has been published as well, focusing on associations between social skills therapy and cognitive functioning in children with DS (Milojevich, Lukowski, & Slonecker, 2019). Each of these manuscripts will be provided upon request from the first author.

about child sleep problems. As described in previous research (Lukowski & Milojevich, 2017), sleep problems were assessed using an abbreviated version of the Children's Sleep Habits Questionnaire (CSHQ-A). The abbreviated version of this questionnaire was developed for use in the National Institute of Child Health and Human Development Study of Early Child Care (see also Goodlin-Jones, Sitnick, Tang, Liu, & Anders, 2008; Owens, Spirito, & McGuinn, 2000; Seifer, Sameroff, Dickstein, & Hayden, 1996). Parents were asked to report the frequency with which their child experienced 22 sleep behaviors over the past week (1 = always or 7 days per week to 5 = never or 0 days per week). The individual items that contributed to the composite score and the method by which the composite score was derived are described in (Lukowski & Milojevich, 2017).

2.2.2 Bayley Scales of Infant Development-III (BSID-III; Bayley, 2006).—All children completed the mental subtest of the BSID-III at the first session.

2.2.3 Elicited imitation.—Children were presented with six three-step event sequences across the two study sessions (see Figure 1 for an example sequence). The event sequences were constrained by enabling relations, such that the goal- or end-state of each event was realized only when the three steps were completed in the correct temporal order (although the events were created such that the steps could be completed in any order). We elected to use sequences constrained by enabling relations as TD children perform at chance on their memory for temporal order information when presented with arbitrary relations (Wenner & Bauer, 1999). In particular, this report concerns the sequences for which baseline and immediate imitation were assessed at the first session along with the novel control sequences that were presented after the one-month delay. The six sequences were block randomized and counterbalanced across conditions, and the order of the two sequences within each phase was randomized. As such, each of the six sequences is represented in the reported analyses.

2.3 Procedure

The conducted research was approved by the appropriate Institutional Review Boards. At the first session, parents signed consent forms indicating their willingness to have their children participate in the behavioral portion of the study. All participants were tested by the second author. Both study sessions were video recorded to allow for data coding and offline checks for adherence to study protocol.

2.3.1 Questionnaires.—The questionnaire packet was sent to parents by mail with instructions to return the completed inventories to the researcher at the first session. Because the questionnaire packet was sent to parents before they signed informed consent statements at the first session, the questionnaire was accompanied by a waiver of written informed consent. Parents who did not submit the questionnaires at that time were asked to complete and return them at the second session.

2.3.2 BSDI-III (Bayley, 2006).—At the first session, the child was seated across from the researcher at an adult-sized table. After a brief warm-up task to familiarize the child with the researcher (Bauer, Wenner, Dropik, & Wewerka, 2000; Bauer & Lukowski, 2010;

Lukowski, Phung, & Milojevich, 2015; Phung, Milojevich, & Lukowski, 2014), the child was tested on the mental subtest of the BSDI-III as described in the administration manual. When the assessment was finished, each parent was given an informational pamphlet that outlined common developmental milestones along with the recommendation to discuss any concerns about child development with their pediatrician.

2.3.3 Elicited imitation.—Once the standardized developmental testing was complete, children were presented with four novel three-step event sequences. The researcher presented the child with the props for one of the sequences and prompted interaction with them by saying, “What can you do with this stuff?”. This baseline phase of testing was terminated when the child engaged in repetitive or off-task behaviors such as dropping the props on the floor or putting them in his/her mouth (Bauer et al., 2000; Bauer & Lukowski, 2010; Lukowski et al., 2015; Phung et al., 2014). The researcher then modeled each sequence of actions twice in succession with narration. The child was allowed the opportunity to imitate each event after its demonstration as an index of encoding (Bauer et al., 2000; Bauer & Lukowski, 2010; Bauer et al., 2011; Lukowski & Milojevich, 2013; Lukowski et al., 2005; Lukowski et al., 2015; Phung et al., 2014). Imitation was cued by presenting children with the sequence materials along with the name of the event. For example, when presented with the props used to Make a Shaker, children were told, “You can use this stuff to Make a Shaker. How do you Make a Shaker with this stuff?”. The imitation period ended when children engaged in the repetitive or off-task behaviors described previously.

The second session occurred approximately one month after the first (mean delay = 29 days; range from 27 to 35 days). Children were presented with familiar event sequences that were shown at the first session along with two novel control sequences. The novel control sequences were included to determine whether children evidenced memory for the familiar events. Because children mature in their cognitive competencies over time, children may perform more target actions and/or pairs of actions over the long term due to enhanced problem-solving abilities – not due to memory per se. As such, the most stringent test of recall occurs when performance on familiar events is compared to performance on novel events presented at the same session (Bauer et al., 2000; Lukowski et al., 2005; Lukowski et al., 2015; Phung et al., 2014).

The same procedure was used when presenting the familiar and novel events at the second session; the presentation of familiar and novel events was counterbalanced across sessions. After a brief warm-up period, the researcher presented the child with the props used to complete one sequence along with the name of the event (e.g., “You can use this stuff to Make a Shaker. How do you Make a Shaker with this stuff?”). The name of the event served as a mnemonic cue for familiar events and as a suggestion of possible activities for novel control events. The child interacted with the props until he/she engaged in the repetitive or off-task behaviors described previously. This process was repeated until the participants had interacted with each event.

2.4 Data Reduction

2.4.1 BSID-III (Bayley, 2006).—Performance on the mental subtest of the BSID-III was calculated as described in the administration manual. Scores were used as an indicator of developmental age (DA) for each participant. During data collection, the second author matched each child with DS to a TD child within three months of DA (MacTurk, Hunter, McCarthy, Vietze, & McQuiston, 1985; Vanvuchelen, Feys, & De Weerdt, 2011; Venuti, de Falco, Esposito, & Bornstein, 2009) to ensure that the groups were at comparable developmental levels.

2.4.2 Elicited imitation.—The elicited imitation data were coded from video by an undergraduate research assistant who was unaware of the hypotheses of the study. The coder recorded the individual target actions produced by the child as well as pairs of actions completed in the correct temporal order. The second author recoded the data from approximately 25% of the sample (n = 5 children) to establish inter-rater reliability. Mean percent agreement on the production of target actions and their order was 98% (range from 89% to 100%).

The average number of target actions (maximum = 3) and pairs of actions (maximum = 2) were calculated separately by phase (baseline and immediate imitation at the first session; delayed recall at the second session) and condition (familiar and novel sequences presented at the second session). Only the first occurrence of each target action was included so as to reduce the likelihood that children received credit for actions completed by chance or through trial-and-error (Bauer et al., 2000; Lukowski & Milojevich, 2013; Lukowski et al., 2005, Lukowski et al., 2015; Phung et al., 2014).

In the present study, difference scores were computed to examine the encoding, delayed recall, and forgetting of target actions and pairs of actions completed in the correct temporal order. Encoding was examined by subtracting performance at baseline from performance at immediate imitation (scores greater than 0 indicate better performance at immediate imitation relative to baseline). Delayed recall was examined relative to baseline and relative to performance at delayed recall. To examine delayed recall relative to baseline, we subtracted performance at baseline from performance at delayed recall (scores greater than 0 indicate better performance at delayed recall relative to baseline). To examine delayed recall relative to performance on novel control sequences, we subtracted performance on novel control sequences at the second session from performance on familiar events (scores greater than 0 indicate better performance on familiar relative to novel events). Finally, evidence of forgetting was examined by subtracting performance at delayed recall from performance at immediate imitation (scores greater than 0 indicate better performance at immediate imitation relative to delayed recall, and, hence, greater forgetting).

3.0 Results

3.1 Preliminary Analyses

Demographic differences between the groups are shown in Table 1. As indicated, the children with DS were chronologically older than the TD children and a greater proportion of the children with DS were of Hispanic ethnicity relative to the TD children. Given these group differences, we examined whether demographic characteristics were correlated with the sleep composite obtained from the CSHQ-A and variables from the elicited imitation assessment. As shown in Table 2, none of the correlations were statistically significant. As such, these demographic variables were not included as covariates in the following analyses. Statistical analyses were conducted using the Statistical Package for the Social Sciences (version 24). Significant findings are reported when $p \leq .05$.

3.2 Group Differences in Sleep Problems

A one-way between subjects analyses of variance was conducted to determine whether parent-reported sleep problems differed by group. The analysis revealed that parents reported that children with DS (2.09 ± .16) did not experience more frequent sleep problems relative to TD children (1.69 ± .16).

3.3 Sleep Problems and Elicited Imitation Performance

Regression-based moderation analyses were conducted to determine whether group moderated the effect of participant sleep problems on elicited imitation performance. In particular, analyses were conducted using PROCESS version 3 (Model 1) according to the approach outlined in Hayes (2018). The sleep composite score was mean-centered before analysis to allow for meaningful interpretation of the results, as 1 is the lowest meaningful score on the CSHQ-A. When the included interaction between sleep problems and group was not significant, the interaction was removed from the analysis and ordinary least squares (OLS) regressions were conducted as recommended in Hayes (2018). The unstandardized coefficients from the regressions analyses are presented below to maintain consistency across the results obtained from PROCESS and from the OLS regressions. Separate analyses were conducted for target actions and pairs of actions completed in the correct temporal order.

3.3.1 Encoding.—The results of the moderation analyses revealed that sleep problems and group were not independently associated with the encoding of target actions and their order. Moreover, group did not moderate the effect of sleep problems on either dependent variable. We conducted simplified OLS regressions with the moderator removed as a result. The overall models were not significant for target actions or pairs of actions completed in the correct temporal order, and neither sleep problems nor group predicted encoding for either dependent variable.

3.3.2 Delayed recall.—When considering delayed recall memory relative to baseline, the results of the moderation analyses revealed that sleep problems and group were not independently associated with the recall of target actions or their order. In addition, group did not moderate the effect of sleep problems on either dependent variable. We conducted simplified OLS regressions as a result. The findings from the simplified OLS regressions revealed that the overall models were not significant for target actions or pairs of actions completed in the correct temporal order. Moreover, neither sleep problems nor group predicted delayed recall performance for either dependent variable.

When considering delayed recall memory relative to performance on novel control sequences presented at the same session, the results of the moderation analyses revealed that sleep problems and group were not independently associated with the recall of target actions. Sleep problems were also unassociated with memory for temporal order information, although group was significantly related to this outcome ($b = -.70$, $SE = .25$, $t = -2.82$, $p = .01$, 95% CI = −1.24 to −.17). In particular, a decrease of .70 pairs of actions were expected for participants with DS at delayed recall in comparison to TD children. Group did not moderate the effect of sleep problems on either dependent variable, however. We conducted simplified OLS regressions as a result. The findings from the simplified OLS regressions revealed that the overall model was not significant for target actions or pairs of actions completed in the correct temporal order. Whereas sleep problems did not predict the delayed recall of target actions or temporal order information, group was associated with memory for pairs of actions ($b = -.67$, $SE = .26$, $t = -2.64$, $p = .02$) but not memory for individual target actions, such that a decrease of .67 pairs of actions were expected for participants with DS at delayed recall in comparison to TD children.

3.3.3 Forgetting.

—The results of the moderation analyses revealed that sleep problems and group were not independently associated with the forgetting of target actions and their order. Contrary to what was reported for the previous analyses, however, group reliably moderated the effect of sleep problems on the forgetting of target actions ($b = 1.42$, $SE = .60$, $t = 2.36$, $p = .03$, 95% CI = .14 to 2.69) and their order ($b = 1.28$, $SE = .44$, $t = 2.92$, $p = .01$, 95% CI = .35 to 2.22). When considering TD participants, sleep problems did not predict the forgetting of individual target actions ($b = -.43$, $SE = .47$, $t = -.92$, $p = .37$, 95% CI = −1.43 to .57) temporal order information ($b = -.38$, $SE = .35$, $t = -1.09$, $p = .29$, 95% CI = −1.11 to .36). When considering children with DS, however, sleep problems were associated with the forgetting of individual target actions ($b = .98$, $SE = .37$, $t = 2.66$, $p = .02$, 95% CI = .20 to 1.77) and temporal order information ($b = .91$, $SE = .27$, $t = 3.35$, $p = .004$, 95% CI = .33 to 1.48). Taken together, these findings indicate that as the centered sleep problems composite score increases by 1 unit, the forgetting of target actions increases by .98 and the forgetting of temporal order information increases by .91 for children with DS. As shown in Figures 2 (individual target actions) and 3 (pairs of actions completed in the correct temporal order), children with DS demonstrated increased forgetting at higher levels of parent-reported sleep problems.

4.0 Discussion

Relations between sleep and cognition are well-established in TD infants and children, with results indicating that both habitual sleep (Lukowski & Milojevich, 2013) and sleep after learning (Kurdziel et al., 2013; Seehagen, Konrad, Herbert, & Schneider, 2015) and are associated with recall memory. The body of work examining relations between sleep and cognition in children with DS is much more limited, however, despite research indicating that these children oftentimes experience sleep problems (Ashworth et al., 2013; Austeng et al., 2014; Breslin et al., 2011; Churchill et al., 2012; Cotton & Richdale, 2006; Levanon et al., 1999; Maris et al., 2016) and have difficulty recalling temporal order information over the long term (Milojevich & Lukowski, 2016). The present study was conducted to determine (1) whether parents reported greater sleep problems for children with DS relative to those who were TD and (2) whether parent-reported sleep problems were differentially related to recall performance in TD children and children with DS when considering the encoding, delayed recall, and forgetting of individual elements of events and their temporal order.

Based on previous research (Ashworth et al., 2013; Cotton & Richdale, 2006; Fernandez et al., 2017; Lukowski & Milojevich, 2017), our first hypothesis was that children with DS would experience more parent-reported sleep problems relative to TD children. This prediction was not supported. We suspect that this finding was not statistically significant due to the relatively small sample of children included in the present study. Two lines of evidence support this assertion. First, the 20 participants included in this report are a subsample of the 40 children described in Lukowski & Milojevich (2017), and the data from this larger study on sleep-temperament associations revealed a significant group difference in the predicted direction on the sleep composite score. Second, the reported effect sizes for the sleep analyses in this report were in the medium to large range (Rosenthal & Rosnow, 1984), suggesting that statistical significance would have been evident with increased power. For these reasons, we expect that a significant group difference in parent-reported sleep problems would have been realized if a larger sample was tested. We also expect that significant findings would have been obtained if we had included a sample of TD children matched to the children with DS on chronological age. We did not include such a group in the present research because TD children matched to the children with DS on chronological age would have scored at ceiling on the elicited imitation assessment. Future research should include this comparison sample, however, as the younger sample of TD children included in the present study likely experienced age-appropriate sleep problems that elevated their parent-reported sleep problems score relative to what would have been observed for older TD children.

Our second hypothesis was that parent-reported sleep problems would be differentially associated with recall memory for children with DS and TD children matched to those with DS on DA. In particular, we predicted that more problematic sleep would be associated with increased forgetting by children with DS relative to TD children. This expectation was based on an extensive literature documenting associations between sleep and the consolidation and/or storage of learned information in TD individuals (for reviews, see Stickgold, 2005; Stickgold & Walker, 2007; Walker & Stickgold, 2004) and a more limited body of work indicating that sleep after learning did not facilitate recall over time in children with DS as was observed for TD children (Ashworth et al., 2013; Spanò et al., 2018). This prediction was also based on previous work indicating that children with DS and TD encoded target actions and temporal order information relative to baseline, but only TD children demonstrated recall of temporal order information after a 1-month delay (Milojevich & Lukowski, 2016). The children included in this latter report are the same as those included herein. The results from this study indicate that sleep problems moderate the effect of group on measures of forgetting when considering both individual target actions and pairs of actions completed in the correct temporal order; significant interactions were not found when considering difference scores indicative of encoding or delayed recall. These findings suggest that children with DS forget information more quickly relative to TD children. It remains to be determined whether this loss of information results from consolidation and/or storage failure due to sleep problems, retrieval failure, or some combination thereof. Although it can be difficult to differentiate forgetting due to consolidation/storage failure or retrieval failure, previous researchers have done so in TD samples both behaviorally (Brainerd, Howe, Kingma, & Brainerd, 1984; Howe & Courage, 1997) and through the use of electrophysiological techniques (particularly when attempting to examine variability in consolidation/storage; Bauer, Wiebe, Carver, Waters, & Nelson, 2003).

Although significant group differences were not obtained when considering parent-reported sleep problems, previous research suggests that sleep may differentially impact cognitive processing in children with DS and TD children. As indicated previously, recent reports have indicated that children with DS do not experience cognitive benefits from daytime naps or overnight sleep comparable to TD children, but that these children may instead benefit from learning and testing over periods of wake (Ashworth et al., 2017; Spanò et al., 2018). One possibility is that the sleep problems experienced by children with DS result in altered sleep architecture relative to what is observed for TD children, and that this variability negatively impacts the consolidation/storage and/or retrieval of learned information. Indeed, data presented in Spanò et al. (2018) indicate that children with DS experienced less REM sleep during the nap relative to TD children. A second possibility is that children with DS may be particularly susceptible to the negative impact of sleep problems on cognitive functioning due to the neuroanatomical alterations that oftentimes accompany the DS diagnosis. For example, a number of studies have reported that children with DS have altered hippocampal and prefrontal morphology relative to those who are TD (Jernigan, Bellugi, Sowell, Doherty, & Hesselink, 1993; Pinter et al., 2001). These neuroanatomical alterations may limit the consolidation/storage and/or retrieval of learned information even when optimal nighttime sleep is obtained. Perhaps most likely, however, is that sleep-cognition associations result from the interaction of altered sleep architecture and atypical neuroanatomical features of children with DS. Research supports this possibility: in one study, the left dentate gyrus of the hippocampus was of reduced diffusivity in children with OSA relative to controls. Moreover, although children with OSA did not perform less well on measures of cognitive functioning relative to controls, the volume of the dentate gyrus was negatively associated with verbal learning across both groups of participants (Cha et al., 2017). Future research is needed, however, to further explore this possibility in relation to recall memory in particular.

Additional work is also needed to confirm causal relations between sleep problems and cognitive functioning. Although it is unlikely that variability in memory processes retroactively impacted parent-reported sleep problems in the present study, some as-of-yet unidentified third variable could have influenced both sleep problems and recall memory. As such, a rigorous experimental design should be used in future research to determine whether reducing the sleep problems experienced by children with DS improves recall performance. Using a procedure similar to the one published in Ashworth et al. (2017), future research should examine whether the timing of learning is associated with reduced forgetting over the long term by children with DS, as this non-invasive behavioral modification could have significant implications for intervention and education.

Finally, subsequent studies on this topic should account for the limitations in the present research. For example, future research should include objective indicators of sleep in addition to the parent-reported questionnaires used herein. Whereas parent informants are valued due to their close relationships with their children, parent-report measures of sleep have been shown to underestimate certain measures of child sleep problems. Because parents only become aware of child night wakings when children signal for attention, parents are unaware of times when children are awake but quiet (Sadeh, 1996). Future research should account for this limitation by recording sleep data using actigraphy or polysomnography (PSG), both of which have been used successfully in previous research on children with DS (actigraphy: Ashworth et al., 2013; PSG: Breslin et al., 2014). Work conducted with PSG in particular would yield important insights into whether the neural signature of sleep in children with DS predicts aspects of recall memory differently from what is observed in TD controls (for an example, see Brooks et al., 2015). These future studies should also include a larger sample of participants than the one reported on herein.

In conclusion, developmental psychologists are only beginning to understand how sleep is associated with cognitive functioning in children with developmental disabilities. The present research adds to this emerging literature by indicating that the sleep problems experienced by children with DS have functional implications for recall memory. Specifically, relative to TD children, children with DS experienced greater forgetting of individual target actions and temporal order information as their sleep problems increased. In addition, sleep problems were not associated with encoding or delayed recall for children in either group. Future research is needed to examine objective indicators of sleep in relation to cognitive functioning in these children as well as to determine whether improving sleep problems in children with DS results in less forgetting and better memory over the long term. Taken together, these findings highlight the need for experimental research on this topic, with the long-term goal of developing and implementing interventions that result in better sleep, cognitive performance, and daytime functioning for children with DS.

References

Antonarakis SE, Avramopoulos D, Blouin JL, Talbot CC, & Schinzel AA (1993). Mitotic errors in somatic cells cause Trisomy 21 in about 4.5% of cases and are not associated with advanced maternal age. Nature Genetics, 3, 146–150. [PubMed: 8499948]

Ashworth A, Hill CM, & Karmiloff-Smith A (2013). Cross syndrome comparison of sleep problems in children with Down syndrome and Williams syndrome. Research in Developmental Disabilities, 34, 1572–1580. [PubMed: 23475007]

Ashworth A, Hill CM, Karmiloff-Smith A, & Dimitriou D (2017). A cross-syndrome study of the differential effects of sleep on declarative memory consolidation in children with neurodevelopmental disorders. Developmental Science, 20, 1–13.

Austeng ME, Øverland B, Kværner KJ, Andersson EM, Axelsson S, Abdelnoor M, & Akre H (2014). Obstructive sleep apnea in younger school children with Down syndrome. International Journal of Pediatric Otorhinolaryngology, 78, 1026–1029. [PubMed: 24809771]

Bauer PJ, DeBoer T, & Lukowski AF (2007). In the language of multiple memory systems: Defining and describing developments in long-term declarative memory In Oakes LM and Bauer PJ (Eds.), Short- and long-term memory in infancy and early childhood (pp. 240–270). New York: Oxford University Press.

Bauer PJ, Güler OE, Starr RM, & Pathman T (2011). Equal learning does not result in equal remembering: The importance of post-encoding processes. Infancy, 16, 557–586. [PubMed: 26207100]

Bauer PJ, & Lukowski AF (2010). The memory is in the details: Relations between memory for the specific features of events and long-term recall during infancy. Journal of Experimental Child Psychology, 107, 1–14. [PubMed: 20493498]

Bauer PJ, Wenner JA, Dropik PL, & Wewerka SS (2000). Parameters of remembering and forgetting in the transition from infancy to early childhood. Monographs of the Society for Research in Child Development, 65, 1–213.

Bauer PJ, Wiebe SA, Carver LJ, Waters JM, & Nelson CA (2003). Developments in long-term explicit memory late in the first year of life: Behavioral and electrophysiological indices. Psychological Science, 14, 629–635. [PubMed: 14629697]

Bayley N (2006). Bayley Scales of Infant and Toddler Development-III. San Antonio, TX: Harcourt Assessment.

Beebe D, & Gozal D (2002). Obstructive sleep apnea and the prefrontal cortex: Towards a comprehensive model linking nocturnal upper airway obstruction to daytime cognitive and behavioral deficits. Journal of Sleep Research, 11, 1–16.

Beebe DW (2011). Cognitive, behavioral, and functional consequences of inadequate sleep in children and adolescents. Pediatric Clinics of North America, 58, 649–665. [PubMed: 21600347]

Brainerd CJ, Howe ML, Kingma J, & Brainerd SH (1984). On the measurement of storage and retrieval contributions to memory development. Journal of Experimental Child Psychology, 37, 478–499.

Breslin JH, Edgin JO, Bootzin RR, Goodwin JL, & Nadel L (2011). Parental report of sleep problems in Down syndrome. Journal of Intellectual Disability Research, 55, 1086–1091. [PubMed: 21726315]

Breslin J, Spanò G, Bootzin R, Anand P, Nadel L, & Edgin J (2014). Obstructive sleep apnea syndrome and cognition in Down syndrome. Developmental Medicine and Child Neurology, 56, 657–664. [PubMed: 24471822]

Brooks LJ, Olsen MN, Bacevice AM, Beebe A, Konstantinopoulou S, & Taylor HG (2015). Relationship between sleep, sleep apnea, and neuropsychological function in children with Down syndrome. Sleep and Breathing, 19, 197–204. [PubMed: 24801138]

Cha J, Zea-Hernandez JA, Sin S, Graw-Panzer K, Shifteh K, Isasi CR, … Arens R (2017). The effects of obstructive sleep apnea syndrome on the dentate gyrus and learning and memory in children. The Journal of Neuroscience, 37, 4280–4288. [PubMed: 28320844]

Charleton PM, Dennis J, & Marder E (2014). Medical management of children with Down syndrome. Paediatrics and Child Health, 24, 362–369.

Chen CC, Spanò G, & Edgin JO (2013). The impact of sleep disruption on executive function in Down syndrome. Research in Developmental Disabilities, 34, 2033–2039. [PubMed: 23584183]

Churchill SS, Kieckhefer GM, Landis CA, & Ward TM (2012). Sleep measurement and monitoring in children with Down syndrome: A review of the literature, 1960–2010. Sleep Medicine Reviews, 16, 477–488. [PubMed: 22410159]

Cotton S, & Richdale A (2006). Parental descriptions of sleep problems in children with autism, Down syndrome, and Prader-Willi syndrome. Research in Developmental Disabilities, 27, 151–161. [PubMed: 15975763]

Curcio G, Ferrara M, & De Gennaro L (2006). Sleep loss, learning capacity and academic performance. Sleep Medicine Reviews, 10, 323–337. [PubMed: 16564189]

de Miguel-Díez J, Villa-Asensi JR, & Álvarez-Sala JL (2003). Prevalence of sleep-disordered breathing in children with down syndrome: Polygraphic findings in 108 children. Sleep, 26, 1006–1009. [PubMed: 14746382]

Dyken ME, Lin-Dyken DC, Poulton S, Zimmerman MB, & Sedars E (2003). Prospective polysomnographic analysis of obstructive sleep apnea in Down syndrome. Archives of Pediatrics & Adolescent Medicine, 157, 655–660.

Fernandez F, Nyhuis CC, Anand P, Demara BI, Ruby NF, Spanò G, … Edgin JO (2017). Young children with Down syndrome show normal development of circadian rhythms, but poor sleep efficiency: A cross-sectional study across the first 60 months of life. Sleep Medicine, 33, 134–144. [PubMed: 28449894]

Gais S, & Born J (2004). Declarative memory consolidation: Mechanisms acting during human sleep. Learning and Memory, 11, 679–685. [PubMed: 15576885]

Goodlin-Jones BL, Sitnick SL, Tang K, Liu J, & Anders TF (2008). The Children's Sleep Habits Questionnaires in toddlers and preschool children. Journal of Developmental and Behavioral Pediatrics, 29, 82–88. [PubMed: 18478627]

Hayes AF (2018). Introduction to mediation, moderation, and conditional process analysis: A regression-based approach (2nd ed.). New York: The Guilford Press.

Hoffmire CA, Magyar CI, Connolly HV, Fernandez ID, & Van Wijngaarden E (2014). High prevalence of sleep disorders and associated comorbidities in a community sample of children with Down syndrome. Journal of Clinical Sleep Medicine, 10, 411–419. [PubMed: 24733987]

Howe ML, & Courage ML (1997). Independent paths in the development of infant learning and forgetting. Journal of Experimental Child Psychology, 67, 131–163. [PubMed: 9388803]

Jernigan TL, Bellugi U, Sowell E, Doherty S, & Hesselink JR (1993). Cerebral morphologic distinctions between Williams and Down syndromes. Archives of Neurology, 50, 186–191. [PubMed: 8431138]

Kopasz M, Loessl B, Hornyak M, Riemann D, Nissen C, Piosczyk H, & Voderholzer U (2010). Sleep and memory in healthy children and adolescents: A critical review. Sleep Medicine Reviews, 14, 167–177. [PubMed: 20093053]

Kurdziel L, Duclos K, & Spencer RMC (2013). Sleep spindles in midday naps enhance learning in preschool children. Proceedings of the National Academy of Sciences, 110, 17267–17272.

Lal C, White DR, Joseph JE, Van Bakergem K, & LaRosa A (2015). Sleep-disordered breathing in Down syndrome. CHEST, 147, 570–579. [PubMed: 25644910]

Levanon A, Tarasiuk A, & Tal A (1999). Sleep characteristics in children with Down syndrome. The Journal of Pediatrics, 134, 755–760. [PubMed: 10356146]

Lukowski AF, & Milojevich HM (2013). Sleeping like a baby: Examining relations between habitual infant sleep, recall memory, and generalization across cues at 10 months. Infant Behavior and Development, 36, 369–376. [PubMed: 23578887]

Lukowski AF, & Milojevich HM (2016). Examining recall memory in infancy and early childhood using the elicited imitation paradigm. Journal of Visualized Experiments, 110, 1–9.

Lukowski AF, Milojevich HM, Eales L (2019). Cognitive functioning in children with Down syndrome: Current knowledge and future directions In Benson J (Ed)., Advances in child development and behavior, Vol. 56 (pp. 257–289). New York: Elsevier. [PubMed: 30846049]

Lukowski AF, Phung JN, & Milojevich HM (2014). Language facilitates event memory in early childhood: Child comprehension, adult-provided linguistic support and delayed recall at 16 months. Memory, 5-6, 1–16.

Lukowski AF, Phung JN, & Milojevich HM (2015). Language facilitates event memory in early childhood: Child comprehension, adult-provided linguistic support and delayed recall at 16 months. Memory, 23, 848–863. [PubMed: 24999740]

Lukowski AF, Wiebe SA, Haight JC, Deboer T, Nelson CA, & Bauer PJ (2005). Forming a stable memory representation in the first year of life: Why imitation is more than child's play. Developmental Science, 8, 279–298. [PubMed: 15819758]

MacTurk RH, Hunter FT, McCarthy ME, Vietze PM, & McQuiston S (1985). Social mastery motivation in Down syndrome and nondelayed infants. Topics in Early Childhood Special Education, 4, 93–109.

Maris M, Verhulst S, Wojciechowski M, Van De Heyning P, & Boudewyns A (2016). Prevalence of obstructive sleep apnea in children with Down Syndrome. Sleep, 39, 699–704. [PubMed: 26612391]

Owens JA, Spirito A, & McGuinn M (2000). The Children's Sleep Habits Questionnaire (CSHQ): Psychometric properties of a survey instrument for school-aged children. Sleep, 23, 1043–1051. [PubMed: 11145319]

Phung JN, Milojevich HM, & Lukowski AF (2014). Adult language use and infant comprehension of English: Associations with encoding and generalization across cues at 20 months. Infant Behavior and Development, 37, 465–479. [PubMed: 24983506]

Pinter JD, Brown WE, Eliez S, Schmitt JE, Capone GT, & Reiss AL (2001). Amygdala and hippocampal volumes in children with Down syndrome: A high-resolution MRI study. Neurology, 56, 972–974. [PubMed: 11294940]

Rast M, & Meltzoff AN (1995). Memory and representation in young children with Down syndrome: Exploring deferred imitation and object permanence. Development and Psychopathology, 7, 393–407. [PubMed: 25530676]

Rosenthal R, & Rosnow RL (1984). Essentials of behavioral research: Methods and data analysis. New York: McGraw Hill.

Sadeh A (1996). Evaluating night wakings in sleep-disturbed infants: A methodological study of parental reports and actigraphy. Sleep, 19, 757–762. [PubMed: 9085482]

Sadeh A (2004). A brief screening questionnaire for infant sleep problems: Validation and findings for an internet sample. Pediatrics, 113, e570–e577. [PubMed: 15173539]

Seehagen S, Konrad C, Herbert JS, & Schneider S (2015). Timely sleep facilitates declarative memory consolidation in infants. Proceedings of the National Academy of Sciences, 112, 1625–1629.

Seifer R, Sameroff AJ, Dickstein S, & Hayden LC (1996). Parental psychopathology and sleep variation in children. Child and Adolescent Psychiatric Clinics of North America, 5, 715–727.

Sherman SL, Allen EG, Bean LH, & Freeman SB (2007). Epidemiology of Down syndrome. Mental Retardation and Developmental Disabilities, 13, 221–227.

Sherman SL, Petersen MB, Freeman SB, Hersey J, Pettay D, Taft L, … Hassold TJ (1994). Non-disjunction of chromosome 21 in maternal meiosis I: Evidence for a maternal age-dependent mechanism involving reduced recombination. Human Molecular Genetics, 3, 1529–1535. [PubMed: 7833907]

Shott SR, Amin R, Chini B, Heubi C, Hotze S, & Akers R (2006). Obstructive sleep apnea. Archives of Otolaryngology: Head and Neck Surgery, 132, 432–436. [PubMed: 16618913]

Spanò G, Gómez RL, Demara BI, Alt M, Cowen SL, & Edgin JO (2018). REM sleep in naps differentially relates to memory consolidation in typical preschoolers and children with Down syndrome. Proceedings of the National Academy of Sciences, 115, 11844–11849.

Stein MB, Belik S-L, Jacobi F, & Sareen J (2008). Impairment associated with sleep problems in the community: Relationship to physical and mental health comorbidity. Psychosomatic Medicine, 70, 913–919. [PubMed: 18842741]

Stickgold R (2005). Sleep-dependent memory consolidation. Nature, 437, 1272–1278. [PubMed: 16251952]

Stickgold R, & Walker MP (2007). Sleep-dependent memory consolidation and reconsolidation. Sleep Medicine, 8, 331–343. [PubMed: 17470412]

Vanvuchelen M, Feys H, & De Weerdt W (2011). Is the good-imitator-poor-talker profile syndrome-specific in Down syndrome? Evidence from standardised imitation and language measures. Research in Developmental Disabilities, 32, 148–157. [PubMed: 20926249]

Venuti P, de Falco S, Esposito G, & Bornstein MH (2009). Mother-child play: Children with Down syndrome and typical development. American Journal on Intellectual and Developmental Disabilities, 114, 274–288. [PubMed: 19642713]

Walker MP, & Stickgold R (2004). Sleep-dependent learning and memory consolidation. Neuron, 44, 121–133. [PubMed: 15450165]

Wenner JA, & Bauer PJ (1999). Bringing order to the arbitrary: One- to two-year-olds' recall of event sequences. Infant Behavior and Development, 22, 585–590.

World Health Organization (2018). Genes and chromosomal diseases: Down syndrome. Retrieved from http://www.who.int/genomics/public/geneticdiseases/en/index1.html

Yoon PW, Freeman SB, Sherman SL, Taft LF, Gu Y, Pettay D, … Hassold TJ (1996). Advanced maternal age and the risk of Down syndrome characterized by the meiotic stage of the chromosomal error: A population-based study. American Journal of Human Genetics, 58, 628–633. [PubMed: 8644722]

What This Paper Adds

Relative to typically developing (TD) children, children with Down syndrome (DS) more commonly experience sleep problems (Ashworth, Hill, & Karmiloff-Smith, 2013; Austeng et al., 2014; Breslin, Edgin, Bootzin, Goodwin, & Nadel, 2011; Churchill, Kieckhefer, Landis, & Ward, 2012; Cotton & Richdale, 2006; Levanon, Tarasiuk, & Tal, 1999; Maris, Verhulst, Wojciechowski, Van De Heyning, & Boudewyns, 2016) and have difficulty recalling temporal order information over the long term (Milojevich & Lukowski, 2016). Despite these findings, minimal research has been conducted documenting associations between sleep and recall memory in children with DS. The present research examines associations between parent-reported sleep problems in children with DS and TD children matched on developmental age. The results revealed that sleep problems are preferentially associated with the forgetting of information by children with DS. That is, at higher levels of parent-reported sleep problems, children with DS demonstrated increased forgetting relative to TD children. These findings highlight the need for additional experimental work demonstrating causality, with the long-term goal of developing and implementing interventions that improve sleep and cognitive functioning in children with DS.

Figure 1.
Example of the three-step event sequence Make a Shaker. The left panel shows the first step of putting the block into one of the nesting cups; the middle panel shows the second step of assembling the nesting cups; the right panel shows the third step of shaking the assembled apparatus. The figure and caption are reproduced from Phung, Milojevich, & Lukowski (2014) and Milojevich & Lukowski (2016); the figure was also previously featured in Lukowski, Phung, & Milojevich (2015).

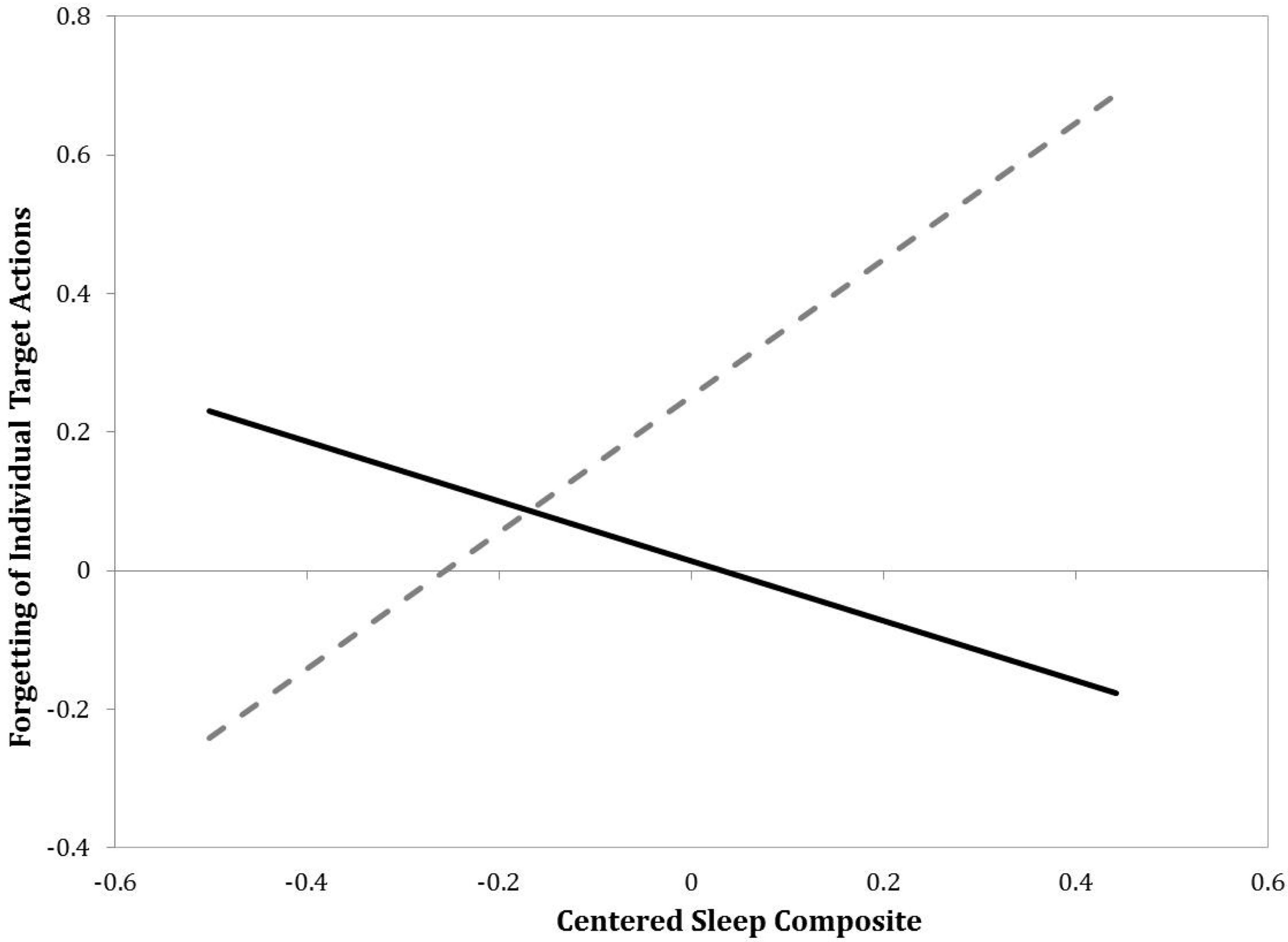

Figure 2.

Significant interaction between parent-reported sleep problems and the forgetting of individual target actions (data from the DS group is shown in gray and data from the TD group is shown in black). The findings indicate that children with DS experience more forgetting at higher levels of parent-reported sleep problems relative to TD children.

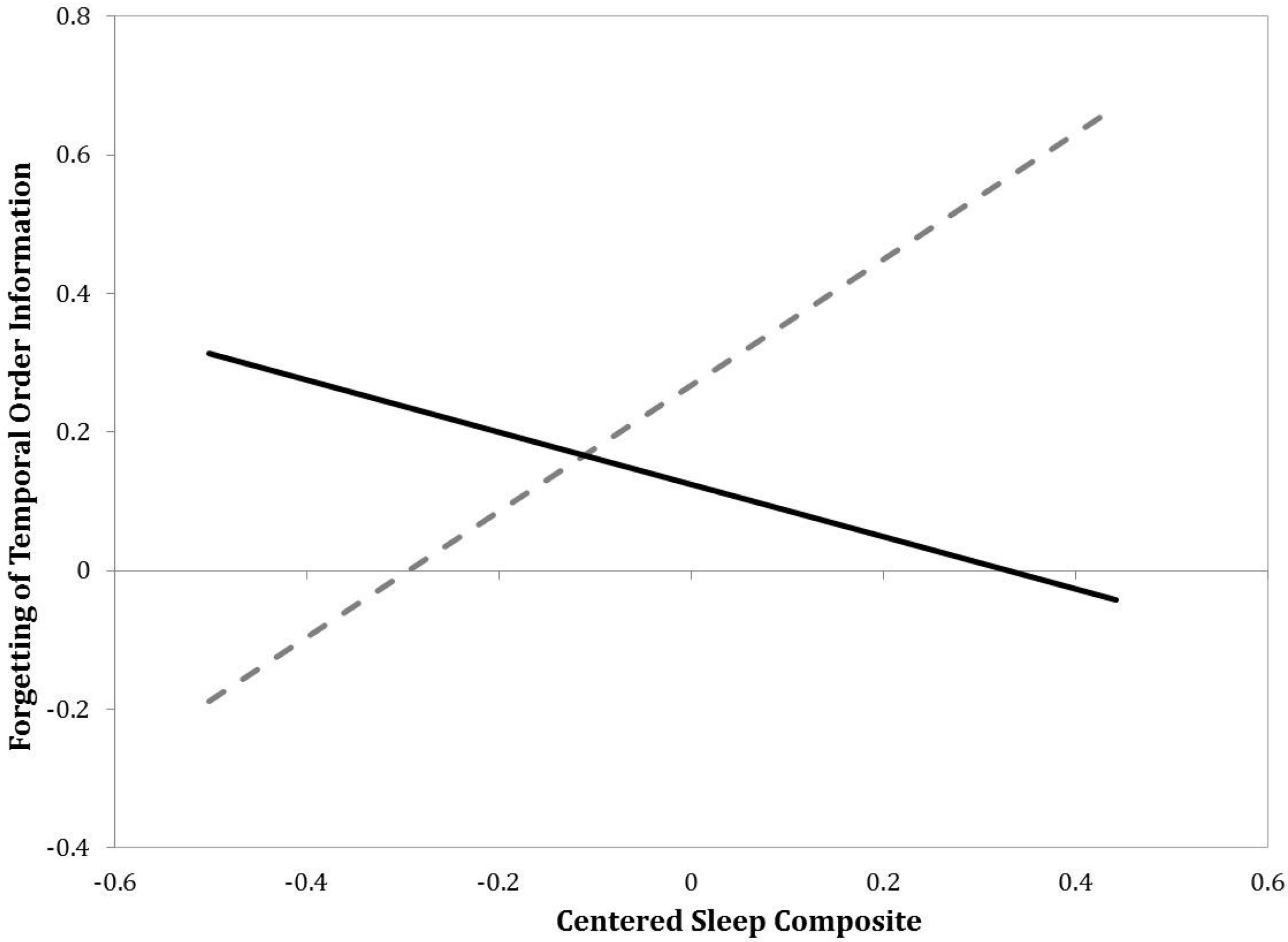

Figure 3.
Significant interaction between parent-reported sleep problems and the forgetting of pairs of actions completed in the correct temporal order (data from the DS group is shown in gray and data from the TD group is shown in black). The findings indicate that children with DS experience more forgetting at higher levels of parent-reported sleep problems relative to TD children.

Table 1

Demographic Information by Group

	DS	TD	Statistic	*p*-value
Chronological age (months)	32.82 ± 9.40	21.69 ± 4.16	$F = 11.73$	.003
Developmental age (months)	21.50 ± 4.55	23.20 ± 4.69	$F = .68$	.42
Infant sex (% girls)	50%	30%	$\chi^2 = .83$	.36
Infant ethnicity (% Hispanic)	50%	10%	$\chi^2 = 3.81$	.05
Maternal education (% with ≥ 4-year college degree)	90%	80%	$\chi^2 = .39$	.53

Note: This table was reproduced from Table 1 in Milojevich & Lukowski (2016).

Table 2

Correlations between Demographic Characteristics and the Primary Variables of Interest

	Sleep Problems	Encoding		Delayed Recall Relative to Baseline		Delayed Recall Relative to Novel Events		Forgetting	
		Actions	Pairs	Actions	Pairs	Actions	Pairs	Actions	Pairs
Chronological age	.23	.27	.21	−.06	−.06	−.25	−.33	−.10	−.34
Developmental age	.02	.61*	.70*	.16	.32	−.10	.18	−.08	.01
Infant sex	.17	.23	.23	.23	.20	−.03	.02	−.06	−.09
Infant ethnicity	−.09	−.05	−.17	−.11	−.18	−.32	.01	−.25	−.05
Maternal education	.08	.06	.27	−.07	.09	−.01	.07	.12	.21