Bidirectional Relationships Between Sleep Duration and Screen Time in Early Childhood

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Screen time and sleep duration have important implications for the health and well-being of children. For instance, excessive screen time and shorter sleep durations are predictive of behavioral and social problems, poorer academic performance, and health conditions such as obesity. These findings are concerning because the level of media use (ie, computer use and television viewing) among children is increasing. For example, the average amount of screen time among US children 8 to 18 years of age increased from 6:21 to 7:38 hours per day from 1999 to 2009. In contrast, sleep durations appear to be decreasing, with children in 2011 estimated to sleep 1 hour less per night, on average, compared with children in the early 20th century.

There are well-documented associations between sleep duration and screen time. Increased screen time among children is associated with an elevated risk of subsequent sleep problems, including shorter sleep durations, disturbed sleep, and frequent night wakings. Increased screen time could limit sleep duration by reducing the time available for sleep (consistent with the displacement hypothesis) and/or by interfering with circadian rhythms and promoting physiological arousal. Although most research has focused on the potential influence of screen time on sleep duration, the relationships may be reciprocal. This is because a lack of sleep promotes greater daytime sleepiness and tiredness, which could translate into more sedentary behaviors as children feel less motivated to engage in active play.

IMPORTANCE Sleep duration and media use (ie, computer use and television viewing) have important implications for the health and well-being of children. Population data suggest that shorter sleep duration and excessive screen time are growing problems among children and could be interacting issues.

OBJECTIVE To examine whether bidirectional relationships exist between sleep duration and media use among children, and whether these associations are moderated by child- and household-related factors.

DESIGN, SETTING, AND PARTICIPANTS Cohort study of a representative sample of 3427 Australian children (4-5 years of age at baseline [51.2% male children]), obtained from the Longitudinal Study of Australian Children. Data were available from 3 waves (2004, 2006, and 2008) when children were 4, 6, and 8 years of age, respectively.

MAIN OUTCOMES AND MEASURES Sleep duration and media use.

RESULTS Bidirectional relationships were observed between sleep duration and media use; for instance, total media use at 4 years of age was significantly associated with sleep duration at 6 years of age (β = −0.06 [95% CI, −0.10 to −0.02]), with media use at 6 years of age predicting sleep duration at 8 years of age (β = −0.06 [95% CI, −0.11 to −0.02]). Sleep duration at 4 years of age was associated with media use at 6 years of age (β = −0.10 [95% CI, −0.14 to −0.05]), with sleep duration at 6 years of age predicting media use at 8 years of age (β = −0.08 [95% CI, −0.13 to −0.03]). Several of these bidirectional relationships varied by socioeconomic status.

CONCLUSIONS AND RELEVANCE The results supported the hypotheses that bidirectional relationships exist between sleep duration and media use among children. These findings are important given recent population trends for increased media use and shorter sleep durations among children.

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studies have examined the potential bidirectional associations between screen-time behaviors and sleep. In a longitudinal study of adolescents, Johnson et al\(^ {17} \) found that the amount of screen time predicted sleep duration, but this association did not hold in the opposite direction. However, Bartlett et al\(^ {18} \) found that sleep duration was inversely associated with subsequent television viewing, which provides some support for a reciprocal relationship.

The present study investigates whether bidirectional relationships exist between screen time and sleep duration among children. It was hypothesized that screen time would be inversely associated with subsequent sleep duration among children and that sleep duration would be inversely associated with subsequent television viewing and computer use. Because sleep duration and screen-time behaviors are influenced by factors such as sex, obesity, and socioeconomic status,\(^ {18,19} \) we also hypothesized that the bidirectional relationships would be moderated by these factors.

**Method**

This study used data from the Longitudinal Study of Australian Children, which tracks a cohort of infants from birth (cohort B) and a cohort of children from 4 to 5 years of age (cohort K). Participants were randomly selected from the Medicare Australia database (the most comprehensive database of the Australian population), with each sample intended to be representative of the Australian population. Follow-up data are collected every 2 years from children and their parents through self-report questionnaires, interviews, and time use diaries.

The present study focused on children from cohort K, using data from waves 1 through 3 when the children were 4 to 5 years of age, 6 to 7 years of age, and 8 to 9 years of age, respectively. This included a total of 4983 children at baseline (ie, 4-5 years of age); the response rate was 50%, and the sample was broadly representative of Australian children 4 to 5 years of age.\(^ {20} \) Follow-up data were collected from 4464 children 6 to 7 years of age and 4331 children 8 to 9 years of age, representing an attrition rate of 13.1% across the 3 time points. Written informed consent was provided by a parent for each child participant, and the Longitudinal Study of Australian Children received ethical approval from the human research ethics committee of the University of Melbourne.

**Measures**

**Time Use Diaries**

Information on sleep duration and media use was collected using 24-hour time use diaries completed by one of the child’s parents (the parent deemed most knowledgeable about the child, usually the child’s mother). At each wave, parents completed 2 time use diaries: one assessed a 24-hour period on a weekday, while the other assessed a 24-hour period on a weekend day. Each time use diary was split into 15-minute intervals, with parents instructed to indicate what the child was doing in each 15-minute interval by selecting from a list of 26 activities.

By using the time use diaries, parents collected information on sleep duration (ie, the amount of time their child spent “sleeping and napping”); a weighted average of weekday and weekend sleep duration was taken to calculate weekly sleep duration. Parents reported the amount of time their child watched television, videos, and movies (“television viewing”) and used a computer or played computer games (“computer use”). Weekday and weekend values were weighted to provide weekly estimates of television viewing, computer use, and total media use (ie, television viewing and computer use).

**Covariates**

Each child’s body mass index (BMI; calculated as weight in kilograms divided by height in meters squared) was calculated from measurements of each child’s weight (digital BMI bathroom scales [HoMedics]) and height (Invicta stadiometer [Modern Teaching Aids]) taken by a trained investigator. The BMI values were calculated and converted to International Task Force on Obesity categories of body weight status (lean vs overweight/obese).\(^ {21} \) Parents indicated whether or not their child had problems sleeping (eg, difficulty falling asleep or waking during the night), and this information was used to create a binary indicator of the presence of sleep problems.

Weekly household income was standardized according to the number of people residing in the household\(^ {22} \) and was split into approximate quartiles. The education level of the mother (hereafter referred to as maternal education and based on questions relating to the highest level of education completed) was coded as “some high school,” “completed year 12 (final year of high school),” and “tertiary qualification” (eg, university degree or trade certificate).

**Statistical Analysis**

The bidirectional relationship between sleep duration and media use was tested using cross-lagged panel models performed with Mplus version 6.11.\(^ {23} \) Cross-lagged models provide an ideal approach to simultaneously examining the bidirectional relationships between variables over time. This is because they test stability paths (eg, sleep duration at 4 years of age → sleep duration at 6 years of age), concurrent paths (eg, sleep duration at 4 years of age with television viewing at 4 years of age), and cross-lagged paths (eg, sleep duration at 4 years of age → television viewing at 6 years of age; television viewing at 4 years of age → sleep duration at 6 years of age). The structure of the cross-lagged model for total media use is shown in our Figure and included the child’s sex and baseline obesity status, with sleep problems, household income, and maternal education as covariates. This modeling approach was conducted separately for total media use, television viewing, and computer use.

The multiple group function in Mplus was used to test whether the cross-lagged associations varied by the covariates identified; this approach is comparable to testing multiple interaction effects.\(^ {24} \) For instance, to examine sex differences, the lagged paths were constrained to be equal across boys and girls (fully constrained model). The model was then retested with one path unconstrained, and the χ² difference relative to the fully constrained model was derived. If statistically significant, the unconstrained path differed signifi-
cantly between boys and girls. If not significant, the path was constrained, and the model was retested with another path unconstrained. Sequential testing of each path provided an indication of whether they varied by the particular covariate.

A total of 1117 children had missing sleep or screen-time data across all 3 time points and were excluded from the analyses. An additional 429 children had missing data for the covariates and were excluded, resulting in a final sample size of 3427 children. For the remaining children, missing sleep duration or screen-time data were handled using full information maximum likelihood. Techniques such as full information maximum likelihood provide unbiased estimates of missing parameters in large samples while retaining natural variability in the missing data and avoiding uncertainty caused by estimating data.24

Results

Descriptive Statistics
The sample included 3427 children 4 to 5 years of age at baseline (51.2% male children); 19.8% of children were overweight or obese, and 50.0% had at least 1 sleep problem (Table 1). Average sleep durations and television viewing decreased over time, whereas computer use increased. Children who were excluded owing to missing data were more likely to have a sleep problem (P < .001) at baseline, lower household incomes (P < .001), and lower maternal education (P < .001) (Table 1) than those included in our study. There were no significant differences by sex or BMI.

Cross-Lagged Results

Total Media Use
There were significant bidirectional associations between sleep duration and total media use (Figure and Table 2). Media use at 4 years of age was significantly associated with sleep duration at 6 years of age (β = −0.06 [95% CI, −0.10 to −0.02]), with media use at 6 years of age predicting sleep duration at 8 years of age (β = −0.06 [95% CI, −0.11 to −0.02]). Thus, a 1-hour mean change in media use was associated with a 3.6-minute mean change in sleep duration between each lag, while holding all other variables in the model constant. Sleep duration at 4 years of age was associated with media use at 6 years of age (β = −0.10 [95% CI, −0.14 to −0.05]), with sleep duration at 6 years of age predicting media use at 8 years of age (β = −0.08 [95% CI, −0.13 to −0.03]). Thus, a 1-hour mean change in sleep duration was associated with a 4.8-to-6-minute mean change in media use.

These associations did not vary significantly by child sex, obesity, or sleep quality. The relationship between media use at 4 years of age and sleep duration at 6 years of age did vary by maternal education (χ² = 12.36 for difference, P < .001); significant inverse associations were observed when mothers had completed high school (β = −0.14 [95% CI, −0.24 to −0.04]) or a tertiary qualification (β = −0.08 [95% CI, −0.12 to −0.04]), but not when mothers had not completed high school (β = 0.07 [95% CI, −0.01 to 0.16]). The relationship between media use at 6 years of age and sleep duration at 8 years of age varied by income (χ² = 4.73 for difference, P = .03) and was evident in quartiles 1 (β = −0.14 [95% CI, −0.26 to −0.02]) and 2 (β = −0.10 [95% CI, −0.20 to −0.01]), but not in quartile 3 (β = 0.00 [95% CI, −0.08 to 0.08]) or quartile 4 (β = −0.08 [95% CI, −0.16 to 0.00]). The relationship between sleep duration at 6 years of age and media use at 8 years of age differed by income (χ² = 17.29 for difference, P < .001); a significant inverse association was observed in quartiles 1 (β = −0.16 [95% CI, −0.29 to −0.03]) and 3 (β = −0.19 [95% CI, −0.28 to −0.11]), but not in quartile 2 (β = −0.07 [95% CI, −0.17 to 0.03]) or quartile 4 (β = 0.06 [95% CI, −0.03 to 0.15]).

Television Viewing
There were significant bidirectional associations between sleep duration and television viewing (Table 2). These associations did not vary significantly by sex or sleep quality. The relationship between television viewing at 6 years of age and sleep duration at 8 years of age differed by child obesity status (χ² = 6.45 for difference, P = .011) and was significant in obese (β = −0.24 [95% CI, −0.38 to −0.10]) but not lean children (β = −0.04 [95% CI, −0.09 to 0.02]).

Several associations varied by maternal education. The link between television viewing at 4 years of age and sleep duration at 6 years of age (χ² = 9.13 for difference, P = .003) was significant when mothers had a tertiary qualification (β = −0.08 [95% CI, −0.12 to −0.03]) but not when mothers had (β = −0.11 [95% CI, −0.22 to 0.00]) or had not (β = 0.08 [95% CI, −0.02 to 0.18]) completed high school. The association between television viewing at 6 years of age and sleep duration at 8 years of age (χ² = 5.05 for difference, P = .03) was observed when mothers had not completed high school (β = −0.19 [95% CI, −0.31 to −0.07]) but not when mothers had completed high school (β = −0.10 [95% CI, −0.23 to 0.03]) or a tertiary qualification (β = −0.03 [95% CI, −0.10 to 0.03]). Finally, the relationship between sleep duration at 6 years of age and television viewing at 8 years of age (χ² for difference = 4.21, P = .04) was significant when mothers had completed high school (β = −0.16 [95% CI, −0.27 to −0.05]) but not when mothers had not completed high school (β = −0.02 [95% CI, −0.13 to 0.10]) or when mothers had completed a tertiary qualification (β = −0.03 [95% CI, −0.08 to 0.01]).

The relationship between television viewing at 6 years of age and sleep duration at 8 years of age varied by income (χ² = 5.16 for difference, P = .03) and was significant in quartiles 2 (β = −0.21 [95% CI, −0.42 to 0.00]) and 3 (β = −0.10 [95% CI, −0.19 to −0.01]), but not in quartile 1 (β = −0.13 [95% CI, −0.27 to 0.01]) or quartile 4 (β = 0.01 [95% CI, −0.08 to 0.10]). The relationship between sleep duration at 6 years of age and tele-

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vision viewing at 8 years of age ($\chi^2 = 19.46$ for difference, $P < .001$) was significant in income quartile 3 ($\beta = −0.17$ [95% CI, −0.24 to −0.10]) but not in quartile 1 ($\beta = −0.11$ [95% CI, −0.22 to 0.01]), quartile 2 ($\beta = −0.04$ [95% CI, −0.13 to 0.05]), or quartile 4 ($\beta = 0.06$ [95% CI, −0.01 to 0.14]).

Computer Use

Computer use did not predict subsequent sleep duration in either interval (Table 2), but sleep duration was a predictor of subsequent computer use. These associations did not vary significantly by sex, obesity status, sleep problems, or maternal education. However, income moderated the relationship between computer use at 4 years of age and sleep duration at 6 years of age ($\chi^2 = 4.23$ for difference, $P = .04$); this relationship was evident in quartile 1 ($\beta = −0.25$ [95% CI, −0.49 to −0.02]) but not in quartile 2 ($\beta = 0.05$ [95% CI, −0.18 to 0.28]), quartile 3 ($\beta = −0.20$ [95% CI, −0.41 to 0.01]), or quartile 4 ($\beta = −0.07$ [95% CI, −0.28 to 0.14]).

Discussion

Consistent with previous research,7,8,12,25 the present results indicate that longer screen time (especially television viewing) predicted shorter sleep duration in children. There are several explanations for these findings. For example, according to the displacement hypothesis,13,16 longer screen time could displace sleep duration directly26 or indirectly by displacing time spent in other behaviors that benefit sleep (eg, physical activity).27 In addition, because screen time involves exposure to artificial light, it may contribute to shorter sleep duration by affecting circadian rhythms.26,28

The most novel finding is that sleep duration was inversely associated with subsequent screen time. Although several researchers have suggested that sleep duration could influence subsequent media use,14,15,17 few studies have examined this proposition.16 Less sleep could promote tiredness and fatigue, which could reduce the motivation to engage in more active behaviors, and, over time, could lead to sedentary activities such as television viewing and computer use.14,13,14 For children with a short sleep duration that reflects an underlying sleep problem, there may be a tendency to engage in behaviors such as television viewing or computer use as a way to cope with sleepiness and tiredness, or as a way to improve their sleep.

Therefore, our results suggest a bidirectional association between sleep duration and screen time. Several associations were most evident for children whose mothers had a lower education level (ie, year 12 completion vs higher qualification) and whose family income was low or high. Previous
studies\(^{29,30}\) have demonstrated that lower socioeconomic status among children is linked with increased television viewing and poorer sleep quality, possibly because of lower parental awareness of recommendations regarding health behaviors, fewer rules regarding media use and limit setting, and a reduced emphasis on routines. Lower socioeconomic status could also result in fewer opportunities for children to engage in more active play because of limited space, less safe environments, and fewer opportunities to participate in active after-school pursuits.\(^{34}\) Children in these environments may therefore be more likely to engage in sedentary behaviors such as television viewing and computer use.

The finding that several associations were more pronounced in children from higher-income households was unexpected. However, higher income is correlated with a greater number of media devices in a household,\(^6\) which could contribute to shorter sleep duration and increased screen time for some children. Obesity also moderated the relationship between television viewing at 6 years of age and sleep duration at 8 years of age, and the effect was only evident among obese children. It is possible that obesity jointly influences sleep duration and television viewing. This is plausible because obesity can contribute to shorter sleep duration,\(^{21}\) via conditions such as sleep apnea. In addition, obesity may contribute to television viewing because of an underlying predisposition to engage in more sedentary behaviors.\(^{22}\)

The effect sizes observed in the total sample were relatively small; however, this is not surprising because numerous factors influence screen-time behavior and sleep duration. However, substantially larger effects were observed in some subgroups. Among children from lower-income households, a 1-hour increase in media use at 6 years of age was associated with an 8.4- to 9.6-minute reduction in sleep duration at 8 years of age (adjusted for covariates). Among overweight/obese children, a 1-hour increase in television viewing at 6 years of age predicted a 14.4-minute reduction in sleep duration. Thus, the bidirectional relationships were more pronounced for some children, which could have important implications for their health and well-being.

Our study has several strengths, including the analytic approach and the large, longitudinal sample. As in any longitudinal study, however, the period of the time lag between each wave warrants discussion. According to the displacement hypothesis, the effects of media use on sleep duration would be expected to take time to emerge,\(^{13}\) and this has received some support.\(^{16}\) Similarly, the effects of shorter sleep durations (eg, fatigue) would likely take time to translate into behavior change (eg, television viewing). Therefore, although the optimal lag is not known, the present lag of 2 years allowed us to observe how the reciprocal relationships unfolded gradually over time under free-living conditions.

The present results could be biased by the exclusion of participants due to missing data; this could limit the representativeness of the present results. A further limitation is that sleep duration and screen time were assessed via parent-completed time use diaries; these data generally correspond well with more objective measures,\(^5,33\) but there is potential for inaccuracies and biases. The measures of screen time were also broad and did not assess mobile devices (eg, mobile phones and tablet devices), which are increasingly common and could also be linked to a child’s sleep duration. Furthermore, we included a range of covariates but cannot rule out residual confounding due to factors such as medical conditions, behavior problems, or parental monitoring. Parental monitoring and rules may be especially important for young children\(^26\) because households with less strict rules regarding media use and/or the timing of sleep may contribute to the joint expression of these behaviors.\(^{28}\)

### Conclusion

Our study provides a novel and timely insight into the temporal relationships between sleep duration and screen-time behaviors among children. Using data from a relatively large sample across multiple time points, we observed bidirectional relationships between sleep duration and screen time. These findings suggest that sleep duration and media use could be interacting problems for children, particularly for children from lower socioeconomic households. These are important issues, given that shorter sleep durations and excessive media use predict a range of adverse social and health-related outcomes for children.
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