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Journal search and commentary

Does a modest loss of sleep affect neurocognitive functioning of children?☆

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Objective(s): To (a) assess effects of modest sleep restriction and extension on children's neurobehavioral functioning (NBF); and (b) test the hypothesis that sleep restriction improves sleep efficiency compared to sleep extension.

Study population: Children (39 boys, 38 girls) from grades 4 ($n = 42$, mean age 9.8 years) and 6 ($n = 35$, mean age = 11.6 years). Children were excluded if they had acute or chronic physical illness, used medication or reported developmental or psychiatric disorder.

Study design: Between-groups comparison using random assignment to groups for analyses of instructions on sleep status and an added criteria of success in meeting randomly assigned sleep-behavior goals defining the groups for evaluation of effects of sleep changes on neurobehavioral functioning.

Methods: All subjects slept at home, kept sleep–wake diaries and wore wrist activity monitors during their sleep period for 5 consecutive days. On days 1 and 2 they slept following their regular patterns. After the second night, on day 1 or 2 they were tested for neurobehavioral functioning (NBF) using the neuropsychological evaluation system (NES) developed by one of the authors of this paper. On day 3 the child's parents were called with instructions on whether to have the child go to bed an hour earlier or an hour later for the next 3 nights. A repeat NBF assessment was obtained on the morning after night 5. All NBF testing occurred between 08:00 and 10:00 h. The neuropsychological evaluation included six tests yielding nine different measures: finger taping speed, simple reaction time, continuous performance (CPT) (omission errors, commission errors and reaction time), symbol-digit substitution, visual digit span (forward and backward), and serial digit learning. Sleep–wake diaries were completed for the child's subjective report of sleep characteristics. An activity meter worn on the non-dominant wrist during the sleep times documented the decreased activity usually associated with sleep. The activity was used as a surrogate measure for sleep state using a scoring routine developed by one of the authors. This surrogate measure becomes important for defining the groups used in the evaluation of the effects of sleep changes on neurobehavioral functioning (NBF). Three hypotheses were tested: (1) most children would restrict or expand sleep at home on demand; (2) restricting sleep for children improved 'quality' compared to extending sleep; and (3) sleep restriction compared to extension increased subjective daytime fatigue and compromised NBF. The test for the first two hypotheses used the groups as defined by random assignment to restricted or extended sleep. The last used the same groups, but were further refined by the success criterion for the restricted or extended goal. For this analysis, a third group of those failing to reach the criterion for desired sleep change, was included as a 'no change' group.

Results: All subjective measures of sleep and objective measures of activity showed the expected differences with strong statistical significance (usually <0.005) between the restricted and extended sleep groups. There were two exceptions to this. Morning rise time did not vary; rather, as was expected, the sleep times were changed by earlier or later bed times. The change in percentage of sleep, defined as quiet or inactive by the activity meter, showed only a small and unimpressive difference favoring the restricted sleep group; about the same as an initial difference between the randomly assigned groups. The sleep time, defined by the activity meter as a percent of time in bed, showed a more significant increase for the restricted than extended sleep groups (increase by 3.5% vs. decrease by 0.8%, $P < 0.005$), but again, the change in the restricted group only increased the percentage of sleep to the value observed at baseline for

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the extended group. The changes in these measures, while statistically significant, were in the range of the variation observed between the groups. The sleep time changes were more impressive, amounting to over an hour difference in time in bed (8 h for restricted sleep group compared to 9.2 for the extended) and activity measures indicating periods of inactivity associated with sleep similarly differing by about an hour (7.6 vs. 8.6 h). Similarly, subjective reports indicated shorter sleep latency but increased fatigue for restricted compared to extended sleep. The arbitrary criterion set for successful compliance was an average change of 30 min sleep time in the requested direction over the 3 days. Sleep time was presumably defined by the surrogate measure based on decreased wrist activity. About 63% of the children (65% for extension and 62% for restriction) made this goal. Since nearly half of the children in each experimental group failed to achieve the criterion for successful sleep change, they were analyzed as a 'no-change' group for the evaluation of the effects of sleep changes on NBF. The NBF effects on the nine measures showed significant differences ($P < 0.05$) for simple reaction time (getting worse for both the restricted and 'no change' group, but not changing for the extension group) and digit span forward (increasing for the extension group by 0.28, decreasing for the restriction group by 0.36, with little change (0.05 increase) for the 'no change' group). The continuous performance test reaction time (CPT-RT) showed highly significant ($P < 0.005$) differences, with an average decrease of 0.28 ms for the sleep-extension group, compared to 0.17 increase for the 'no change' and 1.0 decrease for sleep-restriction groups.

Conclusion: The authors reached three basic conclusions. First, that most children can increase or decrease sleep times on demand over a short period of time, and can do this by changing their bed times. Second, that decreasing sleep time improves sleep efficiency and quality, but also increases daytime fatigue. Third, that even this small change—of about a half-hour from baseline sleep, and an hour difference between groups—leads to significant impairment with restriction compared to extension of NBF. The authors note that the effects involve not only reaction time measures related to ability to maintain attention but also to memory for digits, commonly seen as relating to other cognitive features including reading skills. They also note that the magnitudes of the significant NBF differences were about the same as those associated with a 2-year difference in age. Thus the authors comment that the hour difference in sleep, considered a modest difference, is associated with clinically significant differences in NBF, with improvements associated with longer sleep times.

1. Commentary

Most of our information about the developmental significance of sleep comes from animal studies and from natural history studies of children. This is one of a very few actual, experimental studies with children, and it asks the most fundamental question; Does sleep time alter NBF in children in a way that could have cognitive, developmental and learning consequences? The contribution of this article is really twofold. It shows that these studies can be done with children in their homes and that some significant findings can be obtained.

The report demonstrates well that such studies are possible and establishes a methodology both for combining activity measures and subjective reports of sleep and also for demonstrating the utility of subjective scales on which pre-pubescent children can be evaluated for fatigue. The increase in evening fatigue and subjective report of sleep latency with sleep restriction, compared to extension, in one sense validates these scales and supports continued use of these and similar techniques. Remember, finding words that communicate with children's perception of their experiences is hardly trivial. The subjective measures had been previously validated [1] and this study provides further strong support for their use. It also indicates a lower limit of about 4th grade children for this type of study, since there was a failure to complete with 2nd graders.

The results of the study regarding changes in sleep time are impressive, particularly the success of the children in changing their bedtimes. The sleep extension group went to bed earlier and went to sleep at earlier times. It has sometimes been said that a sleep phase delay occurring in some younger children, and certainly in adolescents, makes earlier bed times difficult, but this does not seem to have been the case for most of the 4th and 6th grade students studied. Advancing sleep was not a particular problem for these children, given appropriate support. Perhaps adolescents, with training for an earlier bedtime, could similarly achieve earlier sleep onset. The success in advancing sleep times for younger children might impact the discussion about school starting times. But it should be noted that a substantial minority of over one-third of the children were not successful in meeting the request for sleep changes.

The impact of sleep restriction on sleep efficiency is less clear. The results, while statistically significant, produced changes in the range of the differences between the groups. They hardly seem convincing, particularly since so many measures were evaluated and the level of significance was only 0.05. The change in subjective report of sleep latency was more impressive and more conclusively demonstrates that, for children as for adults, sleep restriction increases sleep drive and reduces waking during sleep.

The impact of sleep times on NCF is even less clear. The group assignment is no longer random, but depends on the ability of the child to reach the sleep goals. This clearly introduces a bias. Children who tend towards less sleep may find it easier to extend, and those who sleep more to restrict sleep. Despite this problem, the statistics fail to adjust for the number of different analyses. A Bonferonni adjustment for nine tests would change alpha to slightly more than

0.005, making the CPT reaction time the only significant result; it is noteworthy that the primary effect for this result is an improvement with sleep extension and virtually no change with sleep restriction.

As the authors note, prior studies of children have failed to show significant cognitive deficits, even after 1 night with sleep restriction of 4 h [2,3]. Cognitive functioning in children appears to be resilient in the face of significant, acute sleep loss. Some differences were found for more complex cognitive tasks and in a control group with significant sleep extension [4]. Contrary to the claims of the authors, the results of this study do not show statistically significant deficits with modest sleep restriction. An appropriately conservative statistical evaluation leaves only one significant finding, involving mostly an improvement in CPT-RT with sleep extension and little effect for sleep restriction. The changes here were modest, but sustained over 3 days, and in the end the effects on NCF are minimal. It would have been interesting to evaluate the effects with increased duration of the sleep changes or slightly greater amount of sleep change.

It is interesting to note that NCF effects are seen primarily when comparing data involving sleep extension, both in this study and in that of Randazzo [4]. Could it be that children already have some chronic sleep restriction affecting their performance, and that further restriction is less likely to show effects than correction of sleep deficit with a sleep extension? We do not like to think that our younger children have chronic, mild sleep deprivation, but these studies may indicate that the question deserves more consideration than it has been given. Contrary to the suggestion made by the authors, the data in this article do not indicate cognitive impairment with about a half-hour less sleep over 3 days, but possibly some improved maintained attention with a half-hour more sleep over 3 days. Clearly, the significance of sleep times for development and learning remains a fundamental question for sleep medicine. This study provides a useful experimental approach, but unfortunately the results are not very conclusive. Answers regarding concerns about our children's development and the need for ensuring adequate sleep await further study.

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