International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878
SJIF (2025): 8.036

Non-Linear Effects of Sleep Duration on Cognitive Alertness in Adolescents: An Observational Study

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Abstract: ***This study investigates the relationship between sleep duration and cognitive alertness in male adolescents using naturalistic daily measurements. Participants completed online Corsi Block-Tapping and Stroop tasks, with performance aggregated into a composite cognitive coefficient. Spearman correlation and regression analyses indicated a moderate overall association between sleep duration and cognitive performance, with stronger correlations observed when excessive sleep durations were excluded. Binned analysis suggested an optimal performance range around 9–10 hours of sleep. The findings support a non-linear relationship between sleep duration and alertness, highlighting diminishing returns beyond an optimal threshold and demonstrating the feasibility of scalable online cognitive assessment methods.***

Keywords: Adolescent sleep, cognitive performance, working memory, executive function, sleep duration optimisation, behavioural analytics

1. Introduction

Sleep plays a vital role in cognitive development, particularly during adolescence, a period of profound neural restructuring. While the detrimental effects of sleep deprivation on alertness and memory are well-established, the influence of smaller, naturalistic fluctuations in sleep duration is less clearly defined. This study investigates the cognitive impact of such variations, aiming to determine whether increased sleep consistently improves cognitive performance, or whether an optimal range exists beyond which additional rest provides diminishing returns. By leveraging accessible online tools and naturalistic testing environments, this study also explores a scalable framework for adolescent cognitive research. It is hypothesised that sleep duration will show a positive correlation with cognitive performance up to a threshold. This relationship will exhibit diminishing returns beyond an optimal range. Extremely short sleep durations will be associated with significantly lower performance.

2. Existing Literature

Adolescent sleep is closely linked to cognitive performance, with insufficient rest associated with poorer attention, working memory, and overall mental functioning.[1,2] Sleep deprivation can result in slower responses and reduced accuracy in complex tasks.[3,4] Recent research using device-based sleep tracking in adolescents has demonstrated that even small differences in natural sleep duration and timing correlate with measurable changes in cognitive test performance, brain structure, and physiological indicators.[5]

Working memory and executive control are commonly measured using the Corsi Block-Tapping Task and the Stroop Task, both of which have been validated for reliable, repeated assessment, including in online formats.[6,7]

Based on existing literature, it is reasonable to expect that alertness will be significantly lower for sleep durations below 7 hours, and that as sleep duration increases, so will alertness and cognitive function.

3. Methodology

Pilot Phase

A one-week pilot trial was conducted using a selection of cognitive assessments to determine test suitability. The Corsi Block-Tapping Test and the Stroop Task were selected for their cognitive breadth, consistency, and practical feasibility in daily use. These were deemed to effectively assess working memory and executive control, respectively.

Participants

Over 50 male adolescents (aged 14–18) voluntarily participated. This sample size allowed for sufficient data to be collected to reach conclusions. Inclusion was restricted to this demographic to minimise biological variation associated with sex and age. Exclusion criteria included diagnosed sleep disorders, stimulant consumption (e.g., caffeine), and any days involving illness or events likely to disrupt normal sleep patterns.

Ethical Considerations

This study was conducted in accordance with standard ethical guidelines for human participant research. Informed consent was obtained from all participants prior to data collection. Participation was voluntary and data were anonymised at the point of collection. No personally identifiable information was recorded. The study involved minimal risk, consisting solely of non-invasive cognitive tasks and self-reported sleep data.

Data Collection

Each morning, participants completed a Google Form reporting their sleep onset and wake times. Immediately after waking, they completed the Corsi Block-Tapping Test, to assess spatial working memory, and the Stroop Task, to assess response inhibition and cognitive flexibility. Scores were automatically recorded in a central Google Sheet for processing. Daily reminders were sent to ensure consistent responses.

Participants were instructed to complete all cognitive tests under consistent conditions, including immediately after waking, in a quiet environment, and using the same device where possible. While adherence could not be strictly controlled, these guidelines were implemented to reduce variability arising from external factors. No objective verification of environmental or device consistency was implemented. As such, uncontrolled variables including screen size, input latency, ambient noise, and participant compliance may introduce measurement variability. These uncontrolled variables introduce potential confounding effects, as variation in testing conditions may systematically influence cognitive performance independently of sleep duration. As no covariate adjustment or stratification was applied, these factors represent unmodelled sources of variance within the dataset.

4. Data Processing

Sleep Data

Using the reported sleep onset and wake times, a sleep duration was calculated in decimal hours and then in minutes for each data entry. Obvious data errors, such as using a 12 hour clock instead of the requested 24 hour clock, were manually corrected (for example, if a participant records going to sleep at "11:00" and waking up at "08:00", it can be assumed that they mean 11PM and 8AM, therefore the "11:00" is changed to "23:00", making the entry compatible with the spreadsheet formulae).

Entries with incomplete or missing values for either sleep duration or cognitive test results were excluded from analysis. No imputation methods were applied. All analyses were therefore conducted on complete-case data only.

Test Scoring and Normalisation

Participants recorded their results for the Stroop Task via two separate entries - percentage accuracy and answer rate (seconds per question). Therefore, it was necessary to create a composite Stroop score which rewarded high values of accuracy and punished high values of answer rate.

Z-Scores were calculated for both test types to create a comparable scale.

A Cognitive Coefficient (CC) was calculated by averaging Z-scores from the two tests, giving equal weight to working memory and executive function.

Binned Analysis

Sleep durations were sorted into six bins: <6h, 6–7h, 7–8h, 8–9h, 9–10h, >10h. These bins were selected so that each bin would contain approximately the same number of data points.

Mean CC was calculated within each bin to observe cognitive performance trends while reducing data noise. Binning was implemented to reduce high-frequency noise and mitigate the influence of outliers. Equal-frequency binning ensured comparable statistical weight across intervals, improving stability of mean estimates while preserving overall distribution structure.

Correlation Analysis

In order to calculate Spearman's Rank Correlation Coefficient (SRCC), each data entry was given two rankings - one for sleep duration, and the other for CC. This was then repeated using only data with a sleep duration under 10h, in order to test the hypothesis that excessive sleep does not lead to improved alertness.

SRCC was used to assess correlation between sleep duration and CC.

Two regression models were set up; one assuming a linear correlation (Fig. 1), and the other assuming a non-linear relationship (Fig. 2). R^2 from the two scatter graphs was used to evaluate how well sleep duration could predict cognitive performance, by assessing the suitability of the regression models.

A priori power analysis indicates that, at $\alpha = 0.05$, approximately 85–100 independent observations are required to detect a moderate correlation ($\rho \approx 0.3$) with 80% power. The dataset comprised approximately 90 observations; however, as repeated measures were obtained from the same participants, observations are not fully independent. Assuming an average of 2–3 observations per participant, the effective sample size is likely reduced to approximately 30–45 independent units. Consequently, the study is adequately powered to detect large effects but underpowered for moderate or small effect sizes. Findings should therefore be interpreted as exploratory.

5. Results

Correlation Measures

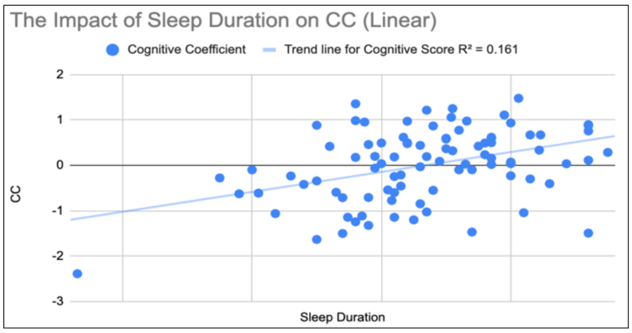

Figure 1: Scatter plot of sleep duration against cognitive coefficient (CC), with linear regression model

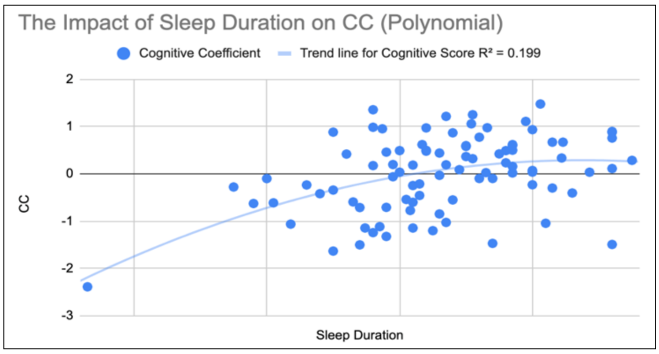

Figure 2: Scatter plot of sleep duration against cognitive coefficient (CC), with second-degree polynomial regression model.

R^2 (Assuming a linear relationship): 0.161 - indicating that approximately 16% of variance in CC is accounted for by sleep duration under a linear model (Fig. 1).

R^2 (From 2nd-degree polynomial): 0.199 - indicating that approximately 19% of variance in CC is accounted for under a second-degree polynomial model (Fig. 2).
SRCC (Full dataset): 0.370- a moderate positive correlation.
SRCC (Excluding >10h sleep): 0.699- a stronger correlation.

Binned Analysis

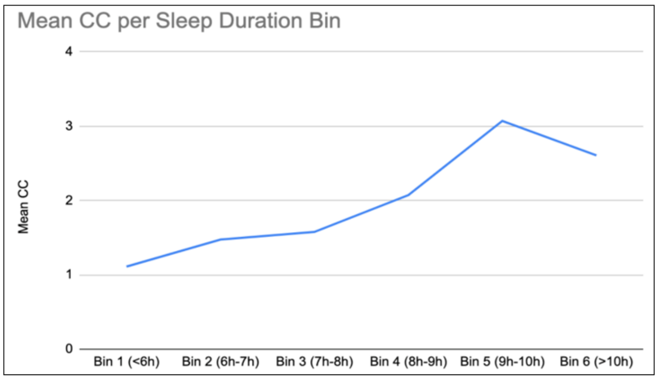

Figure 3: Mean cognitive coefficient (CC) across sleep duration bins, illustrating a non-linear relationship.

The use of binned analysis reduced noise from individual data entries. This improved stability of central tendency estimates by reducing the influence of high-variance observations (Fig. 3).

6. Discussion

This study is distinct in its methodological scalability, relying on repeated, participant-driven data collection rather than controlled laboratory intervention. While prior studies emphasise physiological precision or large-scale passive tracking, this approach demonstrates that meaningful behavioural patterns can be extracted from low-cost, high-frequency observational datasets. This represents a trade-off favouring ecological validity and accessibility over experimental control.

The primary aim of this study was to explore whether the established association between longer sleep and improved cognitive performance persists at higher sleep durations, or if performance plateaus or even declines beyond a certain point. Identifying a possible "optimal sleep range" was therefore a key objective.

Initial correlation analysis, using Spearman's Rank Correlation Coefficient (SRCC) - which gave a result of 0.370 - showed a moderate positive relationship between sleep duration and cognitive score. However, when entries with sleep durations exceeding 10 hours were removed, the SRCC rose significantly to 0.699. This substantial increase suggests that excessive sleep may be associated with diminished marginal gains and that the benefits of additional sleep diminish beyond a certain point, while supporting the hypothesis that shorter sleep durations will have a negative impact on alertness.

Attempts to fit parametric regression models using a polynomial regression yielded an R^2 value of 0.199 (Fig. 2), indicating a poor fit. The limited explanatory power of the regression model meant that deriving a peak sleep duration using calculus returned the unrealistic result of an optimal sleep duration at 11.5 hours, contradicting both existing literature and common expectations.

Instead, a binned analysis provided greater interpretive clarity. By calculating average performance for six sleep duration bins, analysis indicated that cognitive scores peaked in the 9–10 hour range (Fig. 3). Performance was significantly lower in shorter sleep ranges and began to level off or slightly fall beyond 10 hours. This suggests that while additional sleep is generally beneficial up to a point, there are diminishing returns once a certain threshold is crossed.

The finding that shorter sleep durations were associated with significantly lower scores reinforces the well-established link between insufficient sleep and reduced alertness. However, the observation that scores also declined beyond 10 hours is statistically relevant, as it challenges the assumption that more sleep is always better.

Together, these results suggest that sleep duration does influence cognitive performance, but in a non-linear way- with benefits increasing up to an optimal range, and then flattening or reversing. The shift in SRCC values, the limited regression fit, and the shape of the binned curve all support this theory.

7. Conclusion

The study identified a moderate association between sleep duration and cognitive performance among adolescents, with performance peaking within an estimated 9–10 hour range. Evidence supports a non-linear relationship, though explanatory power remains limited due to observational design and self-reported sleep measures. Future research incorporating objective sleep tracking, controlled testing conditions, and broader cognitive metrics is required to validate and generalise these findings.

References

[1] Beebe, Dean W. 2011. "Cognitive, Behavioral, and Functional Consequences of Inadequate Sleep in Children and Adolescents." *Pediatric Clinics of North America* 58 (3): 649–65. https://doi.org/10.1016/j.pcl.2011.03.002.
[2] Wolfson, Amy R., and Mary A. Carskadon. 1998. "Sleep Schedules and Daytime Functioning in Adolescents." *Child Development* 69 (4): 875–87. https://doi.org/10.1111/j.1467-8624.1998.tb06149.x
[3] Lim, Julian, and David F. Dinges. 2010. "A Meta-Analysis of the Impact of Short-Term Sleep Deprivation on Cognitive Variables." *Psychological Bulletin* 136 (3): 375–89. https://doi.org/10.1037/a0018883
[4] Pilcher, June J., and Allen I. Huffcutt. 1996. "Effects of Short-Term Sleep Deprivation on Performance: A Meta-Analysis." *Sleep* 19 (4): 318–26. https://doi.org/10.1093/sleep/19.4.318
[5] Ma, Qing, Barbara J. Sahakian, Bei Zhang, Zeyu Li, Jin-Tai Yu, Fei Li, Jianfeng Feng, and Wei Cheng. 2025. "Neural Correlates of Device-Based Sleep Characteristics in Adolescents." *Cell Reports* 44 (5): 115565. https://doi.org/10.1016/j.celrep.2025.115565.

[6] Kessels, Roy P. C., Martine J. E. van Zandvoort, Albert Postma, L. Jaap Kappelle, and Edward H. F. de Haan. 2000. "The Corsi Block-Tapping Task: Standardization and Normative Data." *Applied Neuropsychology* 7 (4): 252–58. https://doi.org/10.1207/S15324826AN0704_8
[7] Stroop, J. Ridley. 1935. "Studies of Interference in Serial Verbal Reactions." *Journal of Experimental Psychology* 18 (6): 643–62. https://doi.org/10.1037/h0054651