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Associations between 24-hour movement behaviours and global cognition in a cross-sectional sample of US children

Jeremy J. Walsh, PhD¹, Joel D. Barnes, MSc¹, Jameason D. Cameron, PhD¹, Gary S. Goldfield, PhD^{1,2,3,4}, Jean-Philippe Chaput, PhD^{1,2,3}, Katie E. Gunnell, PhD⁵, Andrée-Anne Ledoux, PhD⁶, Roger L. Zemek, MD^{3,6}, and Mark S. Tremblay, PhD^{1,3}

¹Healthy Active Living and Obesity Research Group, Children's Hospital of Eastern Ontario Research Institute, Ottawa, ON, K1H 8L1, Canada

²School of Human Kinetics, University of Ottawa, Ottawa, ON, K1N 6N5, Canada

³Department of Pediatrics, University of Ottawa, Ottawa, ON, K1N 6N5, Canada

⁴School of Psychology, University of Ottawa, Ottawa, ON K1N 6N5, Canada

⁵Department of Psychology, Carleton University, Ottawa, ON, K1S 5B6, Canada

⁶Emergency Department Research, Children's Hospital of Eastern Ontario Research Institute, Ottawa, ON, K1H 8L1, Canada

Abstract

Background: Childhood is a critical period for brain development, and the behaviours that comprise a typical 24-hour day contribute to cognitive performance in children. This study investigated the relationship between cognition and meeting the 24-hour movement behaviour guidelines of 60 minutes of physical activity, 2 hours of recreational screen time, and 9–11 hours of sleep per day in 9–10 year-olds.

Methods: This study presents cross-sectional data from the first annual curated release of the Adolescent Brain Cognitive Development Study (ABCD) – a 10-year longitudinal, observational study investigating brain development in US children. Data were collected from 21 study sites across the United States between September 2016 and 2017. Participants were 4,524 US children aged 9–10 years. Exposures were combinations of adherence to physical activity, recreational

Address Correspondence to: Jeremy J. Walsh, PhD, Healthy Active Living and Obesity Research Group, Children's Hospital of Eastern Ontario Research Institute, 401 Smyth Road, Ottawa, ON, Canada, K1H 8L1, Phone: +1 613 737 7600 ext. 4158, Fax: +1 613 738 4800, jeremywalsh16@gmail.com.

Contributors

All authors collectively submitted an application to the ABCD Study to gain access to the ABCD dataset, led by JW, JW, JB, J-PC, and MT conceived of the study. JB and JW conceived the analytical approach with the support of all authors. JB performed all analyses with the support of JW, KG, J-PC, and RZ. JW, JB, and MT interpreted the results and all authors provided critical feedback on interpretation of results. JW, JB, and MT drafted the initial manuscript. All authors critically reviewed and provided feedback on multiple iterations of the manuscript, and all authors approved of the final version of the manuscript.

Declaration of Interests

The other authors declared no conflicts of interest.

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screen time, and sleep duration recommendations and number of recommendations met. The primary outcome was global cognition and secondary outcomes were crystallized and fluid intelligence.

Findings: The mean (SD) number of guideline recommendations met was 1.1 (0.9). Overall, 51.0% of participants met the sleep recommendation, 36.6% met screen time, and 17.5% met the physical activity recommendation. 70.6% of participants met at least 1, whereas 4.8% of participants met all 3 recommendations. Multi-level regression analysis revealed a statistically significant positive association between global cognition and each additional recommendation met [$\beta=1.44$ (95% CI: 0.82 – 2.07), $p<0.001$]. There was a statistically significant positive association between global cognition and meeting sleep + screen recommendations [$\beta=5.15$ (95% CI: 3.56 – 6.74), $p<0.001$] or meeting the screen-only recommendation [$\beta=4.25$ (95% CI: 2.50 – 6.01, $p<0.001$) compared to not meeting any recommendations.

Interpretation: Meeting the recommendations of the 24-hour movement guidelines was associated with superior global cognition in this sample of US children. These findings highlight the importance of limiting recreational screen time and encouraging healthy sleep for promoting better cognition in children.

INTRODUCTION

Behavioural exposures that comprise a typical day contribute to brain and cognitive development in children. Of these, the three behaviours along the 24-hour movement continuum (physical activity, sedentary behaviour, and sleep) may independently and collectively influence cognition in children. Evidence suggests that both a single bout of physical activity and regular participation in structured physical activity benefit aspects of cognition in children, including reaction time, attention, memory, inhibition, and multiple domains of academic performance.^{1–3} Moreover, children with higher physical fitness tend to perform better on these measures compared to their less fit peers.^{1,3} The influence of physical activity on cognition in children is nuanced, as factors like context (structured versus unstructured, alone versus in groups, indoors versus outdoors), intensity, and duration of physical activity may be important.^{1,2} The mechanistic basis for benefits garnered through physical activity may include increased cerebral blood flow and metabolism, better neurotransmitter regulation, enhanced functional coupling between networks of the brain, and the provision of neurotrophins like brain-derived neurotrophic factor (BDNF).⁴ Sleep plays an important role in brain development and plasticity, and greater sleep quality and quantity are positively associated with cognition and academic performance in children and youth.^{5,6} A recent meta-analysis found that longer sleep duration was associated with superior verbal and full intelligence quotient (IQ) measures in children aged 6–13 years. The study of the relationship between sedentary behaviours and cognition in children is in its infancy, with some early evidence showing negative associations with working memory,⁷ whereas others show benefits to aspects of attention,⁸ possibly owing to the diversity of types and contents of sedentary behaviours (e.g., screen-time vs. reading a book). With the omnipresence of screen-based devices in modern society, the majority of sedentary behaviour in children is now spent engaged with screens.⁹ Recent reports suggest that youth in the US spend an average of 7.5 hours per day engaged in screen-based activities.⁹

Currently, the relationship between screen use and cognition in school-aged children lacks strong evidence; however, the available evidence suggests a disparate relationship between screen time and cognition, based on the content and type of screen-based activity and the age of the child.^{9–11} It is incumbent upon pediatricians, parents, and educators to promote daily behaviours that positively influence cognition in children.

We recently published the Canadian 24-Hour Movement Guidelines for Children and Youth,¹² which recommend at least 60 minutes of daily moderate-to vigorous-intensity physical activity (MVPA), no more than 2 hours of daily recreational screen time, and 9–11 hours of uninterrupted sleep per night in 5- to 13-year-olds.¹³ The specific recommendations for MVPA and sleep are consistent with those established by the World Health Organization (WHO)¹⁴ and the National Sleep Foundation,¹⁵ respectively, whereas these organizations do not currently recommend screen time limits for children 5 years old. We have found that meeting all three movement behaviour recommendations is more important for a child's overall physical and psychosocial health than meeting the recommendation for a single behaviour.¹⁶ Indeed, the combined contribution of whole day behaviours may be more impactful on a child's health than a single behaviour. In support of this, a recent study of 10–11 year-old Canadian children found that meeting the recommendations for multiple health behaviours was more strongly associated with academic achievement compared to meeting one or none of the recommendations.⁶ Similarly, Spanish girls, but not boys, meeting combinations of health behaviour recommendations have significantly better academic performance compared to those meeting a single behaviour.¹⁷ Currently, however, it is unknown whether meeting all or combinations of the movement behaviour recommendations is more important to the cognition of children than meeting single behaviours. This information is important to inform future interventions and clinical and public health guidelines aimed at promoting children's cognition.

The purpose of this study was to investigate the associations between meeting the recommendations from the 24-hour movement guidelines and cognition in a large, diverse sample of US children from the Adolescent Brain Cognitive Development (ABCD) study.¹⁸ We hypothesized that children who meet the recommendations of the 24-hour movement guidelines would have superior measures of cognition compared to those who fail to meet the recommendations and that the number of recommendations met would demonstrate a positive additive effect with measures of cognition.

METHODS

Study Design

This study presents baseline cross-sectional data from the first annual curated release of the ABCD study (DOI: 10.15154/1412097). The ABCD study is a longitudinal, observational study that tracks children through adolescence across numerous domains related to brain development and health with data collected on a biennial-to-annual basis over a 10-year period, beginning in September 2016. The study is facilitated by the ABCD consortium, which is comprised of a coordinating centre, data analysis centre, and 21 research sites across the USA that are responsible for all data collection. Discussion and justification for the measures included in the ABCD study are presented elsewhere.^{18,19} The ABCD

biomedical ethics framework was developed to ensure a coherent and consistent mandate, with sufficient flexibility to ensure compliance with state- and institution-specific research ethics board requirements, and all procedures were approved by site-level institution research ethics boards.²⁰ All experimental procedures were in compliance with the Declaration of Helsinki and subsequent revisions.

Participants

The first annual curated release of the ABCD dataset included 4,524 children aged 9–10 years. Children and their parents/guardians visited a research site and completed a battery of measures and questionnaires. Participants were recruited using probability sampling of public and private elementary schools within the catchment areas of the 21 study sites, producing a large nationally diverse and geographically stratified sample. In an attempt to recruit a diverse sample of children with a broad range of social, biological, and environmental influences, there were no exclusion criteria aside from age and attending a private or public elementary school in the US. All parents/guardians provided written informed consent and child assent was obtained prior to participation in the study. Compensation was offered to parents for travel and incidental costs (e.g., the cost child care for siblings) and financial honorariums were provided to parents and children for their participation in the study.

Outcome Measures, Exposures, and Covariates

The primary outcome of interest was global cognition, assessed using the Youth NIH Toolbox[®] administered on iPads. The Toolbox[®] consists of seven validated and reliable, psychometrically sound tasks that span six cognitive domains including language abilities, episodic memory, executive function, attention, working memory, and processing speed.^{19,21} This measure purports to reflect general intelligence or ‘g factor’²¹ – a surrogate for IQ.^{19,21} Subcomponents of global cognition, crystallized and fluid intelligence, were included as secondary outcomes.^{21,22} Fluid intelligence reflects an individual’s capacity for flexible, goal-directed behaviour in an ever-changing environment and is the conduit through which learning occurs, whereas crystallized intelligence reflects declarative and procedural knowledge gained through past learning and is highly experience-dependent.²² All scores were age-corrected standard scores producing a standardized mean of 100 and SD of 15.²¹ The rationale for assessing global cognition and its subcomponent composites was based on the multiplicity of independent and likely convergent influences of physical activity, screen use, and sleep on multiple domains of cognition.^{1,2,5,9,11}

Exposures of interest were physical activity, screen time, and sleep duration. Physical activity measures were obtained using the exercise questions from the Youth Risk Behaviour Survey.²³ Participants reported the number of days that they were physically active for a total of at least 60 minutes per day in the past 7 days. Recreational screen time was measured using the Youth Screen Time Survey,²⁴ which asked participants to report the number of hours per typical weekday and weekend day spent performing a variety of recreational screen-based activities (e.g., social media, watching television). Sleep duration was defined as the number of hours of sleep a child gets on most nights, reported by parents using the Parent Sleep Disturbance Scale for Children.²⁵ Children who reported being

physically active 7 days per week, accumulating 2 hours of daily recreational screen time, and sleeping 9 – 11 hours per night were considered to be meeting the recommendations of the 24-hour movement guidelines.¹³

Covariates included school grade, body mass index (BMI) z-scores, calculated from objectively-measured height and weight, and age- and sex-specific using reference data from the WHO.²⁶ Parental education, combined household income (treated as continuous variables), and racial/ethnic background were reported by parents via questionnaires.²⁷ Racial/ethnic categories were African-American, Asian, Caucasian, Hispanic, or multiracial in accordance with the categories established by the ABCD study. Pubertal status was assessed using the Youth Pubertal Development Scale.²⁸ History of traumatic brain injury (TBI) was reported by parents using the Modified Ohio State University TBI Screen – Short Version.²⁹ These covariates were chosen based on their association with the outcome and exposure variables, as higher household income, parental and child education, more advanced pubertal development, and being of Asian or Caucasian descent are associated with higher scores of global cognition.^{16,21} Whereas higher BMI and incidence of TBI are associated with lower measures of global cognition.¹⁹

Role of the Funding Source

The funding source sponsors had no role in the design, collection, analysis, or interpretation of the data. Further, the funding source sponsors were not involved in the writing of this report. JW and JB had access to the raw data, provided through the National Institutes of Mental Health Data Archives by the ABCD study consortium. The corresponding author had full access to all of the data and the final responsibility to submit for publication.

Statistical Analysis

For variables treated as ordinal or continuous (pubertal developmental, parental education, family income), refusals and “don’t know” responses were converted to missing cases. Daily recreational screen time was calculated by taking a weighted average of weekday and weekend screen time: $[(\text{the sum of week day screen time in decimal hours} \times 5) + (\text{the sum of weekend day screen time in decimal hours} \times 2)] / 7$. Sleep duration (hours per night) was estimated by recoding response ranges to hours: 9–11 hours = 10 hours; 8–9 hours = 8.5 hours; 7–8 hours = 7.5 hours; 5–7 hours = 6 hours; < 5 hours: 2.5 hours.

Participant-level associations between behaviour variables and cognition scores were fitted using multivariable linear mixed effects (random intercepts) models where participant observations were nested within site given the hierarchical nature of the dataset. (Note: we also ran random slopes models and some models failed to converge; therefore, we present random intercept models herein). For the primary and secondary outcomes, a null model was run using a simple random intercept model that includes only the dependent variable and the cluster variable (site) for comparison against the full models, and to calculate intra-class correlation and pseudo R^2 coefficients. Two full models were also run differing only by the movement behaviour variables included (model 1: the number of movement behaviour recommendations met as a continuous variable; model 2: movement behaviour recommendation adherence patterns as a categorical variable). In all models, parameter

estimates were calculated using a maximum likelihood algorithm in order to compare models using meaningful AIC values. Models were also run using a restricted maximum likelihood algorithm and parameter estimates remained unchanged. A Bonferroni correction was used to account for multiple comparisons and beta coefficients with a $p < 0.016$ were considered statistically significant. A range of 836 – 853 participants with incomplete observations were excluded from regression analysis due to missing data. All analyses were performed using RStudio 1.1.422.

RESULTS

Participant Characteristics and Adherence to Movement Behaviour Recommendations

Participant characteristics and missing cases are displayed in Table 1 (see eTable 1 in the supplement for comparison of participant characteristics for complete vs. missing cases) and Figure 1 displays characteristics of adherence to movement behaviour recommendations. On average (mean $\pm$ SD), participants reported 3.7 ± 2.3 days per week of being physically active for at least 60 minutes. The average recreational screen time was 3.6 ± 2.9 hours per day and average sleep duration was 9.1 ± 1.1 hours per night. The average number of guideline recommendations met was 1.1 ± 0.9 . Overall, 51.0%, 36.6%, and 17.5% of participants met the sleep, screen time, and physical activity recommendations, respectively (Figure 1). 70.6% of participants met at least 1 recommendation, whereas 4.8% of participants met all 3 recommendations. Rates of obesity in the current sample (17.5%) were similar to US national data (18.4%) from 2015–2016 in 6- to 11-year old children (www.cdc.gov/nchs/data/databriefs/db288.pdf).

Associations Between Meeting the 24-Hour Movement Behaviour Recommendations and Cognition

Table 2 shows the associations between the primary outcome (global cognition score), and patterns of meeting various movement behaviour recommendations. Results demonstrate a significant positive association between global cognition with each additional recommendation met (as a continuous variable) [$\beta = 1.44$ (95% CI: 0.82 – 2.07), $p < 0.001$]. Meeting all three recommendations was associated with significantly superior global cognition compared to not meeting any recommendations (as a categorical variable) [$\beta = 3.89$ (95% CI: 1.43 – 6.43, $p = 0.001$)]. Only meeting the screen-only [$\beta = 5.15$ (95% CI: 3.56 – 6.74), $p < 0.001$] or screen + sleep [$\beta = 4.25$ (95% CI: 2.50 – 6.01, $p < 0.001$)] recommendations had statistically detectable associations with superior global cognition compared to not meeting any recommendations. These models account for 21.8 – 22.8% of the overall variance in global cognition.

Tables 3 and 4 show the associations between meeting the movement behaviour recommendations and the secondary outcomes of crystallized and fluid intelligence, respectively. The number of recommendations met was positively associated with superior crystallized [$\beta = 1.51$ (95% CI: 0.86 – 2.16), $p < 0.001$] and fluid intelligence score [$\beta = 0.89$ (95% CI: 0.24 – 1.53), $p < 0.007$]. Compared to not meeting any, meeting all three recommendations was positively associated with superior crystallized intelligence (Table 3) [$\beta = 3.72$ (95% CI: 1.15 – 6.29), $p = 0.004$] and fluid intelligence (Table 4) [$\beta = 2.69$ (95% CI:

0.13 – 5.24), $p=0.039$] scores although the latter was deemed not statistically detectable after adjusting the alpha level for multiple comparisons. Meeting the sleep + screen or screen-only recommendations was also positively associated with superior crystallized [sleep + screen $\beta=5.37$ (95% CI: 3.70 – 7.04), $p<0.001$; screen-only $\beta=3.79$ (95% CI: 1.95 – 5.63), $p<0.001$] and fluid intelligence scores [sleep + screen $\beta=3.21$ (95% CI: 1.55 – 4.86), $p<0.001$; screen-only $\beta=3.27$ (95% CI: 1.44 – 5.10), $p<0.001$]. Overall, these models account for 22.1 – 22.9% of the variability in crystallized intelligence and 9.7 – 10.4% of variability in fluid intelligence.

DISCUSSION

The main findings of this study are: 1) meeting the screen-time only recommendation had the strongest favourable relationship with global cognition, 2) meeting all three movement recommendations was associated with superior global cognition compared to not meeting any recommendations, 3) the combination of meeting screen time + sleep recommendations was associated with better global cognition compared to not meeting these recommendations, and 4) meeting the physical activity recommendations was not associated with measures of global cognition in this sample of 9–10 year-old US children. In general, similar relationships were observed for measures of crystallized and fluid intelligence.

The Whole Day Matters

A child's cognitive development is influenced by experience-dependent cultural and environmental factors including diet, education, environmental exposures (e.g., family dynamics, pollution, etc.), and daily movement behaviours.²² Accordingly, the shift in the lifestyle behaviours of children towards low physical activity levels³⁰ and a reduction in sleep,³¹ and ubiquitous screen use¹¹ may pose a threat to cognitive development. The independent and combined associations between these behaviours and cognition in children continue to be elucidated; however, no previous investigations have examined these outcomes from the perspective of the whole-day. There is a lack of research exploring the relationship between cognition and recreational screen use and screen time in school-aged children.¹¹ The available evidence from a collection of age cohorts suggests that recreational screen use may differentially impact cognition depending on screen type (video games vs. mobile device), content (educational vs. entertainment), and task requirements (focused attention vs. multitasking).^{10,11} For instance, video game playing may benefit information processing and visuospatial abilities,¹¹ and educational television programs can be beneficial for cognitive development in children.¹¹ However, emerging evidence suggests that higher rates of mobile device and social media use has an unfavorable relationship with attention, memory, impulse control, and academic performance,¹⁰ possibly due to interfering effects of social media multi-tasking⁹ and/or the negative impact of excessive screen time on sleep.³² Regardless of the mechanism, our findings show that independent of screen content considerations, not meeting the screen time recommendation was associated with lower measures of cognition in 9–10 year old children. This raises important considerations regarding the utility of screen-based educational tools and warrants timely, nuanced investigations into the relationship between screen content and context, screen time, screen type, and cognition in children.

Adequate sleep is required for healthy cognitive development and function in children, and sleep loss in children can negatively impact brain health.^{5,15,32} Only half of the participants in the current study met the sleep duration recommendations; however, meeting the sleep recommendation alone was not associated with cognition. A recent meta-analysis observed that longer sleep duration was favourably associated with verbal and full IQ in children.⁵ Interestingly, the strongest positive relationship between cognition and any combination of behaviours in this study was observed in children meeting the sleep + screen recommendation. This raises the possibility that daily recreational screen use in excess of 2 hours may attenuate the benefits of sleep for cognition.³² As well, factors related to familial influence and household structure may dually impact this relationship, as limits on screen time imposed by parents may attenuate the interfering effects of screen use before bed and this time may instead be filled with cognitively engaging activities, including reading. Unfortunately, we are unable to establish directionality or mechanisms underlying the observed effects in the current study.

A somewhat surprising finding was that meeting the physical activity recommendation was not associated with cognition, given the substantial evidence supporting the acute and sustained impact of physical activity on aspects of cognition in children.¹ Indeed, the recent FITKids randomized controlled trial observed improvements in attention, inhibition, and cognitive flexibility, and the neurophysiological processes that underlie these functions following a 9-month structured physical activity intervention in children aged 8–9 years.³ The single, self-reported measure of physical activity in the current study may lack the resolution needed to examine variability in the context, intensities, and duration of physical activity. Indeed, the physical activity guidelines recommend at least 60 minutes of MVPA per day, and the best available evidence suggests that physical activity intensity favourably impacts cognition in children.^{1,3} Nonetheless, physical activity is the single most important behaviour for physical health outcomes¹⁶ and there is no indication from previous literature that it negatively affects cognition.¹

Clinical and Research Implications

The positive relationship between childhood global cognition and future academic success³³ and lower all-cause mortality³⁴ provides rationale for encouraging behavioural practices that promote healthy cognitive development in children. Currently, the WHO and National Sleep Foundation have physical activity¹⁴ and sleep guidelines¹⁵ for school-aged children; however, they do not have screen time recommendations for children aged >5 years old. Based on the positive additive relationship between meeting the recommendations and global cognition, and the importance of meeting screen time recommendations alone, pediatricians, family doctors, and the WHO should encourage adherence to the 24-hour movement guidelines for promoting cognitive and physical health in children.

Despite these preliminary findings, future research is required to fully elucidate the independent and combined effects of these behaviours on cognition and brain maturation, the temporal trends in movement behaviour habits and adherence, and whether cognitive development tracks with changes in behaviour over time. This information will be important for establishing intervention targets and informing early intervention approaches for

optimizing cognitive development. The ABCD dataset is scheduled to be released on an annual basis until the year 2028, which will allow for several of these analyses to be undertaken.

Limitations and Strengths

The cross-sectional nature of the current dataset does not allow for tracking the durability and consistency of movement behaviour adherence over time, which precludes any causal inferences. The self-report nature of the exposures and outcomes, despite being psychometrically valid,¹⁸ opens the possibility for inaccurate reporting, as the questionnaires were administered at a single time point and are subject to potential recall and/or social bias. A combination of objective and subjective measures of movement behaviours using accelerometers and self-report measures would be preferable in future studies in order to characterize context, intensity, and duration of behaviours. Further, accounting for cardiorespiratory fitness as a covariate would be an important addition to the current study; however, data on participants' fitness was not available. Sleep categorization may lead to unintentional misclassification as the Parent Sleep Disturbance Scale for Children contains overlapping categories (8–9 hours, 9–11 hours). The screen time survey was developed by the ABCD consortium, based off the widely used Visual Media Use Survey;^{18,24} however, reliability and validity measures are not available for this survey. Due to the failure of some of our random intercept/slope models to converge, the results presented in this study are from random intercept models. These results may contain bias and loss of efficiency compared to a random intercept/slope model. The model 2 exposure variable for our outcomes was unbalanced with small cases for some categories (e.g., only 4.7% of the sample met the physical activity + sleep recommendation), which could affect the parameter estimates in these models. Diagnostic plots revealed some heteroscedasticity was present in our models. Techniques were applied (e.g., log-transformation of the outcome variables, weighted variance structures) to treat the heteroscedasticity with the log-transformation technique resulting in some improvement (see Supplementary Material); however, we have opted to retain the original models with heteroscedasticity in favour of preserving the interpretation of our findings. Also, it is not known to what extent the presence of missing data in this analysis may affect the results. Finally, residual confounding by unmeasured variables is always a possibility in observational studies.

Nonetheless, the size and the sociodemographic diversity of the ABCD sample is an important strength of this study. Although not nationally representative, extensive measures were taken to obtain a proportionate, geographically stratified and near-representative sample of US children, thereby improving the generalizability of these findings. The assessment of global cognition and its subcomponents, crystallized and fluid intelligence, using the standardized NIH Toolbox[®] allows for the direct comparison to other studies that use the Toolbox[®]. Also, the availability of many potentially important covariates strengthens findings from this analysis. Finally, investigating cognition in relation to the 24-hour movement behaviour guidelines is a highly novel and integrative perspective that has yet to be considered in the literature. These findings provide a platform for future investigations aimed at obtaining a better understanding the relationships between daily behaviours and cognition in children and youth.

CONCLUSION

Meeting the recommendations of the 24-hour movement guidelines was associated with superior global cognition in US children. Specifically, the greatest benefits for cognition were seen in children who met the screen time + sleep or the screen-only recommendations, suggesting that pediatricians, parents, educators, and policy-makers limit recreational screen time and prioritize healthy sleep routines throughout childhood and adolescence.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

Data used in the preparation of this article were obtained from the Adolescent Brain Cognitive Development (ABCD) Study (<https://abcdstudy.org>), held in the NIMH Data Archive (NDA). This is a multisite, longitudinal study designed to recruit more than 10,000 children aged 9–10 years and follow them over 10 years into early adulthood. The ABCD Study is supported by the National Institutes of Health and additional federal partners under award numbers U01DA041022, U01DA041028, U01DA041048, U01DA041089, U01DA041106, U01DA041117, U01DA041120, U01DA041134, U01DA041148, U01DA041156, U01DA041174, U24DA041123, and U24DA041147. A full list of supporters is available at <https://abcdstudy.org/nih-collaborators>. A listing of participating sites and a complete listing of the study investigators can be found at <https://abcdstudy.org/principal-investigators.html>. ABCD consortium investigators designed and implemented the study and/or provided data but did not necessarily participate in analysis or writing of this report. This manuscript reflects the views of the authors and may not reflect the opinions or views of the NIH or ABCD consortium investigators. The ABCD data repository grows and changes over time. The ABCD data used in this report came from NIMH Data DOI: 10-15154/1412097.

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RESEARCH IN CONTEXT

Evidence before this study

Childhood is a critical period for cognitive development, and cognition is favourably associated with a child's future academic, occupational and socioeconomic success, and lower all-cause mortality. The Canadian 24-hour movement guidelines for children and youth aged 5–17 years (60 minutes of moderate-to-vigorous physical activity, 2 hours of recreational screen time, and 9–11 hours of sleep) were released in 2016 and created to promote optimal health; however, the relationship between meeting the guideline recommendations and cognition is currently unknown. To identify studies that have investigated the relationships between physical activity, sleep, screen use, and cognition in children, we canvassed PubMed in English using combinations of primary search terms including: “physical activity”, “exercise”, “fitness”, “physical education” “media use”, “screen time”, “TV watching”, “sleep”, “cognition”, “executive function”, and “academic achievement”. We found high quality systematic reviews and meta-analyses related to physical activity and sleep, and a timely special issue in *Pediatrics* in November 2017 focused on the implications of screen-use for children's physical and cognitive health.

A 2016 systemic review found that acute and chronic structured physical activity is beneficial for cognition and academic achievement in children aged 6–13 years. The literature also supports the importance of adequate sleep for cognition and academic performance in children; however, these effects are small. Lastly, the effects of screen-time on cognition in children is currently equivocal and nuanced investigations into the effects of screen behaviours on the health of children are needed. To date, three studies have examined the associations between health behaviours and academic performance in children and found that children who met the criteria for multiple health behaviours performed better academically compared to children who met only one or none behaviour. Despite these findings, there has yet to be an investigation into the relationship between meeting the 24-hour movement guidelines and cognition in children.

Added value of this study

This study shows a positive relationship between global cognition and the number of recommendations met in 9–10 year-old children, suggesting that the whole day matters for cognitive health. As well, meeting the screen-only or screen + sleep recommendations were positively associated with superior global cognition compared to not meeting any recommendations. These findings highlight that efforts should be taken to promote movement behaviour guideline adherence, especially the screen time recommendations, for optimizing the cognition of children.

Implications of all the available evidence

These cross-sectional data are from the February 2018 first annual release of Adolescent Brain Cognitive Development (ABCD) Study. This timely report addresses an important research gap and establishes a platform for longitudinal surveillance of these outcomes in a nationally diverse sample of US children (10-year period, 2018 – 2028). These findings

warrant further research into the potential causal effects of these behaviours on cognition, and from a global perspective, this study provides clinical considerations for adopting and/or developing comprehensive 24-hour movement guidelines for promoting cognitive health in children.

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Figure 1. Proportions of children meeting one, a combination, or all of the movement behaviour recommendations

Vertical bars represent the proportion of participants within each of the eight adherence cases found in this sample. The horizontal bars represent the proportion of participants meeting a given movement behaviour. Abbreviations: PA = physical activity.

Table 1.

Participant characteristics

Variable	No. (SD or %)	No. Missing Cases
Demographics		
Number of children	4,524	NA
Male sex, No.	2,152 (47.6%)	NA
Age, y	10.0 (0.6)	0 (0%)
School grade	4.3 (0.8)	0 (0%)
Height, cm	140.8 (8.0)	1 (<0.1%)
Weight, kg	37.3 (10.3)	5 (0.1%)
Body mass index, kg·m ²	18.6 (4.0)	6 (0.1%)
Pubertal development scale, 0–4 ^a	1.6 (0.5)	4 (<0.1%)
Highest parental education, 1–7 ^d	4.7 (1.6)	5 (0.1%)
Family income, 1–10 ^c	7.5 (2.2)	357 (7.9%)
Race / Ethnicity		48 (1.1%)
Asian, No.	113 (2.5%)	NA
African American, No. ^d	440 (9.8%)	NA
Caucasian, No.	2,651 (59.2%)	NA
Hispanic, No.	726 (16.2%)	NA
Multiracial, No.	546 (12.2%)	NA
Cognitive Function Outcomes		
Global Cognition	97.3 (16.8)	473 (10.5%)
Crystallized Intelligence	102.4 (17.3)	457 (10.1%)
Fluid Intelligence	107.1 (18.0)	470 (10.4%)

Abbreviations: NA = not available, SD = standard deviation. Data are given as mean (SD) or (%). Missing data are presented as number of cases (% of sample).

^a Pubertal development scale represents average score across five items where 0 = no development and 4 = complete 5 development for a given item.

^b Highest parental education represents the highest education score between the parents where 1 = less than high school diploma and 7 = professional school degree (e.g., MD)/doctoral degree.

^c Family income represents combined income in the past 12 months from all sources before taxes and deductions where 0 = less than \$5k and 10 = \$200k.

^d The proportion of individuals who only selected African American was 9.8%; however, the number of individuals who selected African American and an additional category was 5.4%, making the number of African American children in the current sample 15.2%, which is slightly over-representative of the National proportion but below the ABCD recruitment target of 16.6%.

Table 2.

Associations between meeting the physical activity, screen time, and sleep duration recommendations and global cognition.

Independent variables	Dependent variable: global cognition					
	Model 1			Model 2		
	Beta	95% CI	p	Beta	95% CI	p
Fixed effects						
(Intercept)	108.04	104.22 – 111.86	<0.0001	106.20	102.33 – 110.07	<0.0001
Race: African American (reference: Asian)	–13.45	–17.33 – –9.57	<0.0001	–13.04	–16.90 – –9.18	<0.0001
Race: Caucasian	–4.04	–7.49 – –0.58	0.022	–3.78	–7.22 – –0.35	0.031
Race: Hispanic	–7.33	–11.03 – –3.62	0.0001	–7.20	–10.89 – –3.52	0.0001
Race: multiracial	–3.72	–7.39 – –0.05	0.047	–3.43	–7.08 – 0.22	0.066
Gender (reference: male)	0.55	–0.53 – 1.63	0.32	0.15	–0.93 – 1.24	0.78
School grade	3.11	2.43 – 3.79	<0.0001	3.14	2.46 – 3.82	<0.0001
Multilingual (reference: no)	1.20	0.08 – 2.32	0.035	1.20	0.09 – 2.31	0.035
Pubertal development (scale)	–1.02	–2.29 – 0.24	0.11	–0.90	–2.16 – 0.36	0.16
BMIz	–0.15	–0.53 – 0.23	0.44	–0.12	–0.50 – 0.26	0.53
Highest parent education (ordinal scale)	2.47	2.02 – 2.91	<0.0001	2.40	1.96 – 2.85	<0.0001
Family income (ordinal scale)	0.64	0.33 – 0.96	0.0001	0.65	0.33 – 0.96	0.0001
Traumatic brain injury (reference: yes) ^a	–0.85	–2.34 – 0.64	0.26	–0.78	–2.27 – 0.70	0.29
Number of guidelines met	1.44	0.82 – 2.07	<0.0001			
Guidelines met: all (reference: none)				3.89	1.43 – 6.34	0.0019
Guidelines met: pa only				0.20	–2.12 – 2.53	0.86
Guidelines met: pa+screen				0.31	–2.93 – 3.54	0.85
Guidelines met: pa+sleep				–1.77	–4.27 – 0.72	0.16
Guidelines met: screen only				4.25	2.50 – 6.01	<0.0001
Guidelines met: screen+sleep				5.15	3.56 – 6.74	<0.0001
Guidelines met: sleep only				0.76	–0.63 – 2.16	0.28
Random effects						
Within-site variance		233.148			230.156	
Between-site variance		2.153			2.010	
N _{site}		20			20	

Independent variables	Dependent variable: global cognition					
	Model 1			Model 2		
	Beta	95% CI	p	Beta	95% CI	p
ICC _{site}			0.009			0.009
Observations		3675			3671	
R ²		0.218			0.228	
AIC		30515.280			30446.029	
Deviance		30483.280			30402.029	

Two-level mixed-effects models were fit where the intercept for the dependent variable was free to vary by site.

Abbreviations: AIC = Akaike information criterion, BMIz = age- and sex-specific body mass index z scores computed using World Health Organization reference data, 95% CI = 95% confidence interval, ICC_{site} = intra-class correlation coefficient for site, i.e. the proportion of variation in the dependent variable between sites vs. the total variation, PA = physical activity.

^aTraumatic brain injury was included for cases where parents responded YES to the question “Has your child ever been hospitalized or treated in an emergency room following an injury to his/her head or neck?” and YES to the follow-up question, “Has your child ever lost consciousness due to their head/neck injury?”.

Table 3.

Associations between meeting the physical activity, screen time, and sleep duration recommendations and crystallized intelligence.

Independent variables	Dependent variable: crystallized intelligence					
	Model 1			Model 2		
	Beta	95% CI	p	Beta	95% CI	p
Fixed effects						
(Intercept)	111.06	106.99 – 115.13	<0.0001	109.26	105.13 – 113.39	<0.0001
Race: African American (reference: Asian)	–10.43	–14.49 – –6.38	<0.0001	–10.12	–14.16 – –6.08	<0.0001
Race: Caucasian	–1.61	–5.21 – 2.00	0.38	–1.43	–5.03 – 2.16	0.43
Race: Hispanic	–7.05	–10.93 – –3.18	0.0004	–6.94	–10.80 – –3.08	0.0004
Race: multiracial	–1.95	–5.78 – 1.88	0.32	–1.72	–5.54 – 2.09	0.38
Gender (reference: male)	–0.39	–1.52 – 0.74	0.49	–0.74	–1.87 – 0.40	0.20
School grade	3.03	2.32 – 3.74	<0.0001	3.08	2.37 – 3.79	<0.0001
Multilingual (reference: no)	1.59	0.42 – 2.76	0.0079	1.58	0.41 – 2.75	0.0079
Pubertal development (scale)	–1.16	–2.48 – 0.16	0.086	–1.05	–2.37 – 0.27	0.12
BMIz	0.20	–0.20 – 0.60	0.33	0.23	–0.17 – 0.63	0.26
Highest parent education (ordinal scale)	2.64	2.17 – 3.11	<0.0001	2.57	2.10 – 3.03	<0.0001
Family income (ordinal scale)	0.69	0.35 – 1.02	0.0001	0.69	0.36 – 1.02	<0.0001
Traumatic brain injury (reference: yes)	–0.64	–2.19 – 0.92	0.42	–0.56	–2.11 – 0.99	0.48
Number of guidelines met	1.51	0.86 – 2.16	<0.0001			
Guidelines met: all (reference: none)				3.72	1.15 – 6.29	0.0045
Guidelines met: pa only				–0.22	–2.65 – 2.22	0.86
Guidelines met: pa+screen				–0.72	–4.12 – 2.67	0.68
Guidelines met: pa+sleep				–0.55	–3.16 – 2.05	0.68
Guidelines met: screen only				3.79	1.95 – 5.63	0.0001
Guidelines met: screen+sleep				5.37	3.70 – 7.04	<0.0001
Guidelines met: sleep only				0.81	–0.65 – 2.27	0.28
Random effects						
Within-site variance		254.929			252.289	
Between-site variance		6.130			5.958	
N _{site}		20			20	

Independent variables	Dependent variable: crystallized intelligence				
	Model 1		Model 2		
	Beta	95% CI	p	Beta	95% CI
ICC _{site}		0.023			0.023
Observations		3688			3684
R ²		0.221			0.229
AIC		30965.971			30905.804
Deviance		30933.971			30861.804

Two-level mixed-effects models were fit where the intercept for the dependent variable was free to vary by site.

Abbreviations: AIC = Akaike information criterion, BMI_z = age- and sex-specific body mass index z scores computed using World Health Organization reference data, 95% CI = 95% confidence interval, ICC_{site} = intra-class correlation coefficient for site, i.e. the proportion of variation in the dependent variable between sites vs. the total variation, PA = physical activity, N_{site} = number of sites.

Table 4.

Associations between meeting the physical activity, screen time, and sleep duration recommendations and fluid intelligence.

Independent variables		Dependent variable: fluid intelligence				
		Model 1		Model 2		
	Beta	95% CI	p	Beta	95% CI	p
Fixed effects						
(Intercept)	102.67	98.81 – 106.53	<0.0001	101.41	97.47 – 105.34	<0.0001
Race: African American (reference: Asian)	-11.71	-15.67 – -7.75	<0.0001	-11.32	-15.27 – -7.36	<0.0001
Race: Caucasian	-4.86	-8.38 – -1.34	0.0068	-4.58	-8.10 – -1.07	0.011
Race: Hispanic	-5.20	-8.98 – -1.43	0.0069	-5.08	-8.84 – -1.31	0.0082
Race: multiracial	-4.19	-7.96 – -0.43	0.029	-3.92	-7.68 – -0.17	0.041
Gender (reference: male)	1.39	0.27 – 2.52	0.015	1.07	-0.06 – 2.20	0.062
School grade	2.25	1.55 – 2.95	<0.0001	2.27	1.57 – 2.97	<0.0001
Multilingual (reference: no)	0.31	-0.84 – 1.46	0.59	0.32	-0.83 – 1.47	0.59
Pubertal development (scale)	-0.67	-1.98 – 0.64	0.31	-0.58	-1.89 – 0.73	0.38
BMIz	-0.42	-0.82 – -0.02	0.037	-0.41	-0.80 – -0.01	0.045
Highest parent education (ordinal scale)	1.46	1.00 – 1.91	<0.0001	1.41	0.95 – 1.87	<0.0001
Family income (ordinal scale)	0.46	0.13 – 0.78	0.0063	0.46	0.13 – 0.78	0.0062
Traumatic brain injury (reference: yes)	-0.70	-2.25 – 0.85	0.37	-0.67	-2.22 – 0.87	0.39
Number of guidelines met	0.89	0.24 – 1.53	0.0070			
Guidelines met: all (reference: none)				2.69	0.13 – 5.24	0.039
Guidelines met: pa only				0.51	-1.92 – 2.94	0.68
Guidelines met: pa+screen				1.17	-2.20 – 4.54	0.49
Guidelines met: pa+sleep				-2.31	-4.91 – 0.29	0.082
Guidelines met: screen only				3.27	1.44 – 5.10	0.0005
Guidelines met: screen+sleep				3.21	1.55 – 4.86	0.0001
Guidelines met: sleep only				0.41	-1.04 – 1.87	0.58
Random effects						
Within-site variance		252.749			251.084	
Between-site variance		0.159			0.177	
N _{site}		20			20	

Independent variables	Dependent variable: fluid intelligence				
	Model 1		Model 2		
	Beta	95% CI	p	Beta	95% CI
ICC _{site}		0.001			0.001
Observations		3678			3674
R ²		0.097			0.104
AIC		30820.038			30774.510
Deviance		30788.038			30730.510

Two-level mixed-effects models were fit where the intercept for the dependent variable was free to vary by site.

Abbreviations: AIC = Akaike information criterion, BMI_z = age- and sex-specific body mass index z scores computed using World Health Organization reference data, 95% CI = 95% confidence interval, ICC_{site} = intra-class correlation coefficient for site, i.e. the proportion of variation in the dependent variable between sites vs. the total variation, PA = physical activity.