Associations between 24 hour movement behaviours and global cognition in US children: a cross-sectional observational study

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Summary

Background Childhood and adolescence are crucial periods for brain development, and the behaviours during a typical 24 h period contribute to cognitive performance. The Canadian 24-Hour Movement Guidelines for Children and Youth recommend at least 60 min physical activity per day, 2 h or less recreational screen time per day, and 9–11 h sleep per night in children aged 8–11 years. We investigated the relationship between adherence to these recommendations and global cognition.

Methods In this cross-sectional observational study, we obtained data from the first annual curated release of the Adolescent Brain Cognitive Development study, a 10-year longitudinal, observational study. Data were collected from 21 study sites across the USA between Sept 1, 2016, and Sept 15, 2017. The participants were 4524 US children aged 8–11 years from 20 study sites. Exposures of interest were adherence to the physical activity, recreational screen time, and sleep duration guideline recommendations. The primary outcome was global cognition, assessed with the NIH Toolbox (National Institutes of Health, Bethesda, MD, USA), which we analysed with multivariable linear mixed-effects models to examine the relations with movement behaviour variables.

Findings Complete movement behaviour data were available for 4520 participants. The mean number of guideline recommendations met was 1·1 (SD 0·9). Overall, 2303 (51%) participants met the sleep recommendation, 1655 (37%) met screen time, and 793 (18%) met the physical activity recommendation. 3190 (71%) participants met at least one recommendation, whereas 216 (5%) of participants met all three recommendations. Global cognition was positively associated with each additional recommendation met (β=1·44, 95% CI 0·82–2·07, p<0·0001). Compared with meeting none of the recommendations, associations with superior global cognition were found in participants who met all three recommendations (β=3·89, 95% CI 1·43 to 6·34, p=0·0019), the screen time recommendation only (β=4·25, 2·50–6·01, p<0·0001), and both the screen time and the sleep recommendations (β=5·15, 3·56–6·74, p<0·0001).

Interpretation Meeting the 24 h movement recommendations was associated with superior global cognition. These findings highlight the importance of limiting recreational screen time and encouraging healthy sleep to improve cognition in children.

Funding National Institutes of Health.

Lancet Child Adolesc Health 2018

Published Online September 26, 2018 http://dx.doi.org/10.1016/S2352-4642(18)30278-5

See Online/Comment http://dx.doi.org/10.1016/S2352-4642(18)30305-5

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Introduction

Behavioural exposures during a typical day contribute to brain and cognitive development in children. Physical activity, sedentary behaviour, and sleep might independently and collectively affect cognition. Evidence that 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, the effects become more pronounced with increasing physical fitness.[1,3] The influence of physical activity on cognition in children is nuanced, with factors such as context (structured *vs* unstructured, alone *vs* in groups, indoors *vs* outdoors, etc), intensity, and duration of physical activity possibly being important.[1,2] The mechanistic basis for benefits garnered through physical activity are thought to include increased cerebral blood flow and metabolism, better neurotransmitter regulation, enhanced functional coupling between networks of the brain, and the provision of neurotrophins, such as brain-derived neurotrophic factor.[4]

Sleep plays an important part in brain development and plasticity. Good sleep quality and quantity are positively associated with cognition and academic performance in children and adolescents.[5,6] In children aged 6–13 years, a meta-analysis showed that longer sleep duration was associated with superior verbal skills and full intelligence quotient (IQ) measures than shorter sleep duration.[5]

The study of the relationship between sedentary behaviours and cognition in children is in its infancy.

Research in context

Evidence before this study

Childhood is a critical period for cognitive development, and cognition is associated with children's future academic, occupational, and socioeconomic performance, as well as with reduced all-cause mortality. Released in 2016, the Canadian 24-Hour Movement Guidelines for Children and Youth aim to promote optimum health in children aged aged 5–17 years. They recommend at least 60 min moderate to vigorous physical activity per day, 2 h or less recreational screen time per day, and 9–11 h sleep per night in children aged 5–13 years. However, the relationship between meeting these recommendations and cognition is unknown. To identify studies that have investigated the relationships between physical activity, sleep, screen use, and cognition in children, we searched PubMed without date restrictions, with the primary search terms "physical activity", "exercise", "fitness", "physical education", "media use", "screen time", "TV watching", "sleep", "cognition", "executive function", and "academic achievement" in various combinations. A 2016 systematic review showed 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, although the effects are small. Lastly, findings on the effects of screen time on cognition in children are equivocal, and nuanced investigations into the effects of different screen use behaviours on the health of children are needed. We found three studies that had investigated associations between health behaviours and academic performance in children. Children who met the criteria for multiple health behaviours performed better academically than children who met one or none. No investigations assessed the relationship between meeting the Canadian 24 h movement behaviour guidelines and cognition in children.

Added value of this study

We showed a positive relationship between global cognition and the number of 24 h movement behaviour recommendations met in children aged 9–10 years, which suggests that behaviour throughout the day matters for cognitive health. Meeting the screen time recommendation alone or the screen time and sleep recommendations together were associated with superior global cognition compared with not meeting any recommendations. These findings indicate that efforts should be taken to promote adherence to the movement behaviour guidelines, especially the screen time and sleep duration recommendations.

Implications of all the available evidence

Our analysis addresses an important research gap and establishes a platform for longitudinal surveillance of cognitive outcomes in a nationally diverse sample of children in the USA. The findings suggest that further research into the potential effects of physical activity, recreational screen time, and sleep on cognition is warranted, and support clinical consideration of adopting these or developing other comprehensive 24 h movement guidelines for promoting cognitive health in children.

Some early evidence shows negative associations with working memory,[7] but some studies have shown benefits to aspects of attention.[8] These differing results might be due to the diversity in types of sedentary behaviours (eg, screen time *vs* reading a book). With the widespread use of screen-based devices, their use takes up most of children's sedentary time.[9] Children and adolescents in the USA have been reported to spend an average of 7·5 h per day engaged in screen-based activities.[9] The relationship between screen use and cognition in school-aged children is not clear, but evidence suggests that it varies on the basis of the content and type of screen-based activity (eg, playing video games *vs* social media) and a child's age.[9–11] Paediatricians, parents, and educators need to promote daily behaviours that positively influence cognition in children.

The Canadian 24-Hour Movement Guidelines for Children and Youth were published in 2016.[12] They recommend at least 60 min physical activity of moderate to vigorous intensity, no more than 2 h recreational screen time per day, and 9–11 h uninterrupted sleep per night in children aged 5–13 years.[13] The recommendations for physical activity and sleep are consistent with those established by WHO[14] and the National Sleep Foundation,[15] respectively. Neither organisation, however, makes a recommendation for screen time in children aged 5 years and older. We have found that meeting all three movement behaviour recommendations is more important for a child's overall physical and psychosocial health than meeting one recommendation alone.[16] In a study of Canadian children aged 10–11 years, achieving multiple recommended health behaviours was more strongly associated with academic achievement than meeting one or none of the recommendations,[6] which suggests that combinations of health behaviours might interact to produce beneficial effects. Similarly, Spanish girls, but not boys, meeting combinations of health behaviour recommendations showed significantly better academic performance than those who met the recommendation for only one behaviour.[17] However, whether meeting all or combinations of two movement behaviour recommendations is more important to the cognition of children than meeting single recommendations is unknown. This information will be important to inform future interventions and clinical and public health guidelines aimed at promoting children's cognition.

In this study we aimed to investigate whether meeting the recommendations from the Canadian 24 h movement behaviour guidelines was associated with superior cognition in a large diverse sample of US children in the

Adolescent Brain Cognitive Development (ABCD) study.[18] We tested the hypotheses that children who meet the recommendations will have superior cognition outcomes to those who do not meet the recommendations and that the number of recommendations met would have an additive effect on cognition.

Methods

Study design and participants

We used the baseline cross-sectional data from the annual curated release 1.0 of the ABCD study, which began on Sept 1, 2016, and is a longitudinal, observational study that tracks children through adolescence across numerous domains related to brain development and health in 21 research sites across the USA. Data are being collected every 1 or 2 years over a 10-year period. The study is facilitated by the ABCD consortium.

Children aged 9–10 years were recruited by probability sampling of public and private elementary schools within the catchment areas of the 21 study sites, producing a large, diverse, and geographically stratified sample. Those who visited a research site and completed a battery of measures and questionnaires were eligible for inclusion. To maximise diversity in social, biological, and environmental influences, no exclusion criteria were applied other than age and attending a public or private elementary school in the catchment area.

The ABCD biomedical ethics framework was developed to ensure a coherent and consistent mandate, with sufficient flexibility to ensure compliance with state-specific and institution-specific research ethics boards' requirements, and all procedures were approved at the site level by institutional ethics boards.[19] All experimental procedures were compliant with the Declaration of Helsinki and subsequent revisions. Parents or guardians provided written informed consent and children assented before participation in the study. Compensation was offered to parents for travel and incidental costs (eg, child care for siblings) and financial honoraria were provided to parents and children for their participation in the study.

Outcome measures and exposures

Discussion and justification for the measures included in the ABCD study are presented elsewhere.[18,20] The primary outcome of interest was global cognition, which was assessed with the NIH Toolbox (National Institutes of Health, Bethesda, MD, USA) administered on iPads (Apple, Cupertino, CA, USA). The NIH Toolbox consists of seven validated and reliable psychometric tasks that span six cognitive domains: language abilities, episodic memory, executive function, attention, working memory, and processing speed.[20,21] This measure purports to reflect general intelligence[21] as a surrogate for IQ.[20,21] Secondary outcomes were fluid and crystallised intelligence, which are subcomponents of global cognition.[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. Crystallised 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 standardised mean of 100 (SD 15).[21] We assessed global cognition and these subcomponent composites because of the multiplicity of independent, and probably convergent, influences of the behaviours assessed in the ABCD study on multiple domains of cognition.[1,2,5,9,11]

Exposures of interest were physical activity, screen time, and sleep duration. Physical activity was assessed with the exercise questions from the Youth Risk Behaviour Survey,[23] in which participants reported the number of days that they were physically active for at least 60 min per day in the previous 7 days. Recreational

For the **ABCD study** see https://ndar.nih.gov/study.html?id=500

For the **ABCD consortium** see https://abcdstudy.org/principal-investigators.html

	Participants (n=4524)	Missing cases (% of overall sample)
Demographics		
Sex		
Boys	2152 (48%)	NA
Girls	2372 (52%)	NA
Age (years)	10·0 (0·6)	0
School grade	4·3 (0·8)	0
Height (cm)	140·8 (8·0)	1 (<1%)
Weight (kg)	37·3 (10·3)	5 (<1%)
Body-mass index (kg/m²)	18·6 (4·0)	6 (<1%)
Pubertal development scale score*	1·6 (0·5)	4 (<1%)
Highest parental education†	4·7 (1·6)	5 (<1%)
Family income‡	7·5 (2·2)	357 (8%)
Race or ethnicity	..	48 (1%)
Asian	113 (3%)	NA
African American§	440 (10%)	NA
White	2651 (59%)	NA
Hispanic	726 (16%)	NA
Multiracial	546 (12%)	NA
Cognitive function outcomes		
Global cognition	97·3 (16·8)	473 (11%)
Crystallised intelligence	102·4 (17·3)	457 (10%)
Fluid intelligence	107·1 (18·0)	470 (10%)

Data are n (%) or mean (SD). NA=not available.*Shows the average score across five items (growth in height, growth of hair, and skin changes in girls and boys, facial hair growth and deepening of voice in boys only, and breast growth and menarche in girls only), each scored on a scale of 0=no development to 4=complete development. †Highest score on a scale of 1=≤grade 12; 2=high-school graduate or General Educational Development certification; 3=some college; 4=associate degree; 5=bachelor's degree; 6=master's degree; 7=professional or doctorate degree. ‡Combined income in past 12 months from all sources before taxes and deductions on a scale of 1=<US$5000; 2=$5000–11 199; 3=$12 000–15 999; 4=$16 000–24 999; 5=$25 000–34 999; 6=$35 000–49 999; 7=$50 000–74 999; 8=$75 000–99 999; 9=$100 000–199 999; and 10=≥$200 000. §5·4% participants also selected African American with another category, giving a total proportion of 15·2%, which is slightly over-representative of the national proportion but below the ABCD study recruitment target of 16·6%.

Table 1: **Baseline characteristics**

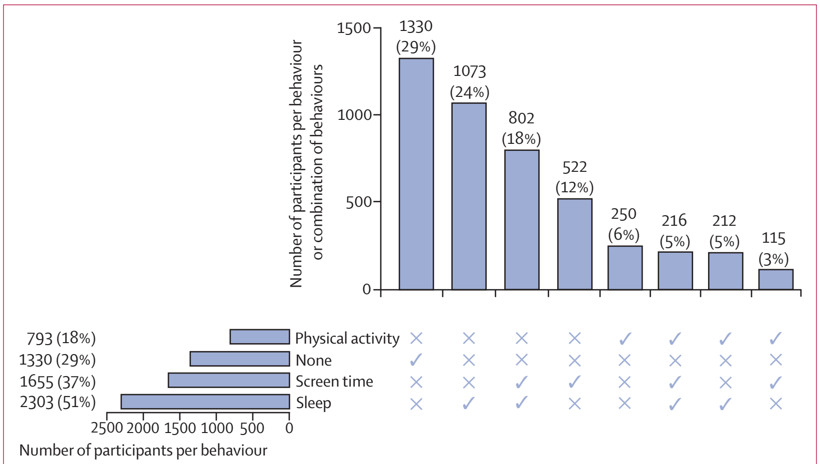

Figure: **Proportions of children meeting movement behaviour recommendations**
Vertical bars represent the numbers of participants meeting recommendations for the individual movement behaviour or combination of behaviours (unique counts; four participants had missing data), and the horizontal bars represent the numbers of participants meeting recommendations for a particular movement behaviour (non-unique counts). Percentage values do not total 100% because of rounding.

screen time was measured with the Youth Screen Time Survey,[24] which asks participants to report the number of hours spent per typical weekday and weekend day performing various recreational screen-based activities (eg, social media, watching television). Daily recreational screen time was calculated by taking a weighted average of weekday and weekend screen time: ([sum of week day screen time in decimal hours × 5] + [sum of weekend day screen time in decimal hours × 2]) / 7. Sleep duration was reported by parents with the Parent Sleep Disturbance Scale for Children[25] and was defined as the number of hours of sleep a child gets on most nights. We coded the questionnaire response ranges as single values: 9–11 h=10·0 h; 8–9 h=8·5 h; 7–8 h=7·5 h; 5–7 h=6·0 h; and less than 5 h=2·5 h. Children who reported being physically active 7 days per week, accumulating 2 h or less of daily recreational screen time, and sleeping 9–11 h per night were classified as meeting the recommendations of the 24 h movement behaviour guidelines.[13]

Statistical analysis

We assessed covariates that have established associations with global cognition. High household income, parental and child education, being of Asian or white descent, and advanced stage of pubertal development are associated positively with global cognition,[16,21] whereas high body-mass index (BMI) and incidence of traumatic brain injury are associated negatively.[19] We measured household income as combined income in past 12 months from all sources before taxes and deductions, on a scale of 1=<US$5000; 2=$5000–11 199; 3=$12 000–15 999; 4=$16 000–24 999; 5=$25 000–34 999; 6=$35 000–49 999; 7=$50 000–74 999; 8=$75 000–99 999; 9=$100 000–199 999; and 10=≥$200 000. Parental and child education were defined as highest level reached and current grade, respectively. Race or ethnic background (African American, Asian, White, Hispanic, or multiracial) were reported by parents via questionnaires.[26] Pubertal status was assessed with the Youth Pubertal Development Scale.[27] For BMI we calculated age-specific and sex-specific Z scores from objectively measured height and weight, and WHO reference data.[28] History of traumatic brain injury was reported by parents with the Modified Ohio State University TBI Screen—Short Version.[29] For ordinal and continuous variables (family income, parental education, and pubertal development), refusals and "don't know" responses were converted to missing cases.

Participant-level associations between behaviour variables and cognition scores were fitted with multivariable linear mixed-effects (random intercepts) models. Given the hierarchical nature of the dataset we nested individual participants' outcomes within study sites. We ran random intercept and random slopes models, but some of these models failed to converge and, therefore, we only present results from the random intercept models in this Article. For the primary and secondary outcomes, we ran a null model with a simple random intercept model that included only the dependent variable and the cluster variable (site) to enable comparison and calculation of within-class correlations and pseudo R^2 coefficients. We ran two full models that differed only by the movement behaviour variables included: model 1 included the number of movement behaviour recommendations met as a continuous variable and model 2 included adherence to movement behaviour recommendations as a categorical variable. In all models, parameter estimates were calculated with a maximum likelihood algorithm to compare them with meaningful Akaike information criterion values. Models were also run with a restricted maximum likelihood algorithm and parameter estimates remained unchanged. We used Bonferroni correction to account for multiple comparisons and β coefficients, in which p values less than 0·016 were significant. All analyses were done with RStudio 1.1.422.

Role of the funding source

The funder had no role in the study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

The first annual curated release of the ABCD dataset included 4524 children aged 8–11 years (table 1). Across sites, a range of 836–853 participants had incomplete observations and were excluded from regression analysis due to missing data.

Participants reported being physically active for at least 60 min on a mean of 3·7 (SD 2·3) days per week. The mean recreational screen time was 3·6 (SD 2·9) h per day and the mean sleep duration was 9·1 (1·1) h per night. A mean of 1·1 (SD 0·9) guideline recommendations

	Adherence to recommendation as continuous variable (model 1)		Adherence to recommendation as categorical variable (model 2)	
	β coefficient (95% CI)	p value*	β coefficient (95% CI)	p value*
Intercept	108·04 (95% CI 104·22 to 111·86)	<0·0001	106·20 (95% CI 102·33 to 110·07)	<0·0001
Race or ethnicity (reference: Asian)				
African American	−13·45 (−17·33 to −9·57)	<0·0001	−13·04 (−16·90 to −9·18)	<0·0001
White	−4·04 (−7·49 to −0·58)	0·022	−3·78 (−7·22 to −0·35)	0·031
Hispanic	−7·33 (−11·03 to −3·62)	0·0001	−7·20 (−10·89 to −3·52)	0·0001
Multiracial	−3·72 (−7·39 to −0·05)	0·047	−3·43 (−7·08 to 0·22)	0·066
Sex (reference: male)	0·55 (−0·53 to 1·63)	0·32	0·15 (−0·93 to 1·24)	0·78
School grade	3·11 (2·43 to 3·79)	<0·0001	3·14 (2·46 to 3·82)	<0·0001
Multilingual (reference: no)	1·20 (0·08 to 2·32)	0·035	1·20 (0·09 to 2·31)	0·035
Pubertal development (scale)	−1·02 (−2·29 to 0·24)	0·11	−0·90 (−2·16 to 0·36)	0·16
Body-mass index *Z* score	−0·15 (−0·53 to 0·23)	0·44	−0·12 (−0·50 to 0·26)	0·53
Highest parent education (ordinal scale)	2·47 (2·02 to 2·91)	<0·0001	2·40 (1·96 to 2·85)	<0·0001
Family income (ordinal scale)	0·64 (0·33 to 0·96)	0·0001	0·65 (0·33 to 0·96)	0·0001
Traumatic brain injury† (reference: yes)	−0·85 (−2·34 to 0·64)	0·26	−0·78 (−2·27 to 0·70)	0·29
Number of guidelines met	1·44 (0·82 to 2·07)	<0·0001	..	..
Guidelines met (reference: none)				
All met	..	..	3·89 (1·43 to 6·34)	0·0019
Physical activity only	..	..	0·20 (−2·12 to 2·53)	0·86
Physical activity + screen time	..	..	0·31 (−2·93 to 3·54)	0·85
Physical activity + sleep	..	..	−1·77 (−4·27 to 0·72)	0·16
Screen time only	..	..	4·25 (2·50 to 6·01)	<0·0001
Screen time + sleep	..	..	5·15 (3·56 to 6·74)	<0·0001
Sleep only	..	..	0·76 (−0·63 to 2·16)	0·28
R^2	0·218	..	0·228	..

In both two-level mixed-effects models, the intercept for the dependent variable was free to vary by site. *p<0·016 significant after Bonferroni correction. †Included for participants whose 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 "Has your child ever lost consciousness due to their head/neck injury?".

Table 2: **Associations between meeting movement behaviour recommendations and global cognition**

were met. After excluding four participants with missing movement behaviour data, overall 2303 (51%), 1655 (37%), and 793 (18%) participants met the sleep, screen time, and physical activity recommendations, respectively (figure). 3190 (71%) participants met at least one recommendation and 216 (5%) met all three recommendations. 792 (18%) children were obese.[28] Global cognition was positively associated with each additional recommendation met (β=1·44, 95% CI 0·82–2·07, p<0·0001). Global cognition was also superior if all three recommendations were met compared with if no recommendations were met (β=3·89, 95% CI 1·43–6·34, p=0·0019; table 2). Meeting only the screen time recommendation or both the screen time and the sleep recommendations also had positive associations with global cognition compared with no recommendations being met (β=4·25, 95% CI 2·50–6·01, p<0·0001 and β=5·15, 3·56–6·74, p<0·0001, respectively; table 2). These models accounted for 21·8–22·8% of the overall variance in global cognition. Meeting other combinations of recommendations was not associated with global cognition (table 2).

The number of recommendations met was associated with superior crystallised and fluid intelligence scores (tables 3, 4), although the association with fluid intelligence was no longer significant after Bonferroni adjustment for multiple comparisons. We found positive associations between meeting only the screen time recommendation or both the screen time and the sleep recommendations and crystallised and fluid intelligence scores (tables 3, 4). Overall, these models accounted for 22·1–22·9% of the variability in crystallised intelligence and 9·7–10·4% of the variability in fluid intelligence. Meeting other combinations of recommendations was not associated with crystallised or fluid intelligence (tables 3, 4).

Discussion

We found that meeting all three movement behaviour recommendations in the Canadian 24 h movement behaviour guidelines was associated with superior global cognition compared with meeting no recommendations, with meeting the screen time recommendation alone or the screen time plus sleep recommendations

	Adherence to recommendations as continuous variable (model 1)		Adherence to recommendations as categorical variable (model 2)	
	β coefficient (95% CI)	p value*	β coefficient (95% CI)	p value*
Intercept	111·06 (106·99 to 115·13)	<0·0001	109·26 (105·13 to 113·39)	<0·0001
Race or ethnicity (reference: Asian)				
African American	–10·43 (–14·49 to –6·38)	<0·0001	–10·12 (–14·16 to –6·08)	<0·0001
White	–1·61 (–5·21 to 2·00)	0·38	–1·43 (–5·03 to 2·16)	0·43
Hispanic	–7·05 (–10·93 to –3·18)	0·0004	–6·94 (–10·80 to –3·08)	0·0004
Multiracial	–1·95 (–5·78 to 1·88)	0·32	–1·72 (–5·54 to 2·09)	0·38
Sex (reference: male)	–0·39 (–1·52 to 0·74)	0·49	–0·74 (–1·87 to 0·40)	0·20
School grade	3·03 (2·32 to 3·74)	<0·0001	3·08 (2·37 to 3·79)	<0·0001
Multilingual (reference: no)	1·59 (0·42 to 2·76)	0·0079	1·58 (0·41 to 2·75)	0·0079
Pubertal development (scale)	–1·16 (–2·48 to 0·16)	0·086	–1·05 (–2·37 to 0·27)	0·12
Body-mass index *Z* score	0·20 (–0·20 to 0·60)	0·33	0·23 (–0·17 to 0·63)	0·26
Highest parent education (ordinal scale)	2·64 (2·17 to 3·11)	<0·0001	2·57 (2·10 to 3·03)	<0·0001
Family income (ordinal scale)	0·69 (0·35 to 1·02)	0·0001	0·69 (0·36 to 1·02)	<0·0001
Traumatic brain injury (reference: yes)†	–0·64 (–2·19 to 0·92)	0·42	–0·56 (–2·11 to 0·99)	0·48
Number of guidelines met	1·51 (0·86 to 2·16)	<0·0001	..	..
Guidelines met (reference: none)				
All met			3·72 (1·15 to 6·29)	0·0045
Physical activity only	..	..	–0·22 (–2·65 to 2·22)	0·86
Physical activity + screen time	..	..	–0·72 (–4·12 to 2·67)	0·68
Physical activity + sleep	..	..	–0·55 (–3·16 to 2·05)	0·68
Screen time only	..	..	3·79 (1·95 to 5·63)	0·0001
Screen time + sleep	..	..	5·37 (3·70 to 7·04)	<0·0001
Sleep only	..	..	0·81 (–0·65 to 2·27)	0·28
R^2	0·221	..	0·229	..

In both two-level mixed-effects models, the intercept for the dependent variable was free to vary by site. *p<0·016 significant after Bonferroni correction. †Included for participants whose 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 "Has your child ever lost consciousness due to their head/neck injury?".

***Table 3:* Associations between meeting movement behaviour recommendations and crystallised intelligence**

having the strongest associations. Meeting the physical activity recommendations—alone or in combination with one other recommendation—showed no association with global cognition. Similar findings were seen for the secondary measures of crystallised and fluid intelligence.

A child's cognitive development is influenced by experience-dependent cultural and environmental factors, including diet, education, environmental exposures (eg, family dynamics or pollution), and daily movement behaviours.[22] Accordingly, the shift in the lifestyle behaviours of children towards low physical activity levels,[30] reduced sleep times,[31] and high levels of screen use[11] might pose a threat to cognitive development. The independent and combined associations between these behaviours and cognition in children continue to be revealed, but to our knowledge no previous studies have assessed outcomes from the perspective of behaviours throughout the whole day. The relationships between cognition and recreational screen use and screen time in school-aged children are also not well researched.[11] The available evidence from a range of age groups suggests that recreational screen use affects cognition differently depending on the screen type (video games *vs* mobile devices), content (educational *vs* entertainment), and task requirements (focused attention *vs* multitasking).[10,11] For instance, video game playing might benefit information processing and visuospatial abilities[11] and educational television programmes might enhance cognitive development.[11] However, emerging evidence suggests that mobile device and social media uses have an unfavourable relationship with attention, memory, impulse control, and academic performance.[10] Possible reasons for these negative relationships are the interfering effects of social media multitasking,[9] reduced sleep time, or both.[32] Regardless of the mechanism, we found that, independent of screen content considerations, exceeding the screen time recommendation was negatively associated with global cognition in children aged 8–11 years. This finding raises important considerations regarding the use of screen-based educational tools and warrants prompt, nuanced research 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 is known to affect brain health negatively.[5,15,32] In a meta-analysis, longer sleep duration was favourably

	Adherence to recommendations as continuous variable (model 1)		Adherence to recommendations as categorical variable (model 2)	
	β coefficient (95% CI)	p value*	β coefficient (95% CI)	p value*
Intercept	102·67 (98·81 to 106·53)	<0·0001	101·41 (97·47 to 105·34)	<0·0001
Race or ethnicity (reference: Asian)				
African American	−11·71 (−15·67 to −7·75)	<0·0001	−11·32 (−15·27 to −7·36)	<0·0001
White	−4·86 (−8·38 to −1·34)	0·0068	−4·58 (−8·10 to −1·07)	0·011
Hispanic	−5·20 (−8·98 to −1·43)	0·0069	−5·08 (−8·84 to −1·31)	0·0082
multiracial	−4·19 (−7·96 to −0·43)	0·029	−3·92 (−7·68 to −0·17)	0·041
Sex (reference: male)	1·39 (0·27 to 2·52)	0·015	1·07 (−0·06 to 2·20)	0·062
School grade	2·25 (1·55 to 2·95)	<0·0001	2·27 (1·57 to 2·97)	<0·0001
Multilingual (reference: no)	0·31 (−0·84 to 1·46)	0·59	0·32 (−0·83 to 1·47)	0·59
Pubertal development (scale)	−0·67 (−1·98 to 0·64)	0·31	−0·58 (−1·89 to 0·73)	0·38
Body-mass index *Z* score	−0·42 (−0·82 to −0·02)	0·037	−0·41 (−0·80 to −0·01)	0·045
Highest parent education (ordinal scale)	1·46 (1·00 to 1·91)	<0·0001	1·41 (0·95 to 1·87)	<0·0001
Family income (ordinal scale)	0·46 (0·13 to 0·78)	0·0063	0·46 (0·13 to 0·78)	0·0062
Traumatic brain injury (reference: yes)†	−0·70 (−2·25 to 0·85)	0·37	−0·67 (−2·22 to 0·87)	0·39
Number of guidelines met	0·89 (0·24 to 1·53)	0·0070	..	..
Guidelines met (reference: none)				
All met	..	..	2·69 (0·13 to 5·24)	0·039
Physical activity only	..	..	0·51 (−1·92 to 2·94)	0·68
Physical activity + screen time	..	..	1·17 (−2·20 to 4·54)	0·49
Physical activity + sleep	..	..	−2·31 (−4·91 to 0·29)	0·082
Screen time only	..	..	3·27 (1·44 to 5·10)	0·0005
Screen time + sleep	..	..	3·21 (1·55 to 4·86)	0·0001
Sleep only	..	..	0·41 (−1·04 to 1·87)	0·58
R^2	0·097	..	0·104	..

In both two-level mixed-effects models, the intercept for the dependent variable was free to vary by site. *p<0·016 significant after Bonferroni correction. †Included for participants whose 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 “Has your child ever lost consciousness due to their head/neck injury?”.

Table 4: **Associations between meeting movement behaviour recommendations and fluid intelligence**

associated with verbal and full IQ in children.[5] Only half of the participants in the current study met the sleep duration recommendations, although meeting this recommendation alone was not associated with improved cognition. Rather, it needed to be combined with meeting the screen time recommendation to have a positive effect. This finding raises the possibility that daily recreational screen use in excess of 2 h attenuates the benefits of sleep for cognition.[32] Factors related to familial influence and household structure might also affect the relationship between sleep and cognition. Limits on screen time imposed by parents might not only attenuate the interfering effects of screen use before bed but could also replace them with cognitively engaging activities, including reading. Unfortunately, we were unable to establish directionality of effects or their underlying mechanisms in this 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] In the FITKids randomised controlled trial,[3] attention, inhibition, cognitive flexibility, and the neurophysiological processes that underlie these functions improved following a 9-month structured physical activity intervention in children aged 8–9 years. A possible explanation for our results is the use of one self-reported measure of physical activity in the ABCD study, which might have lacked the resolution needed to show variability in context, intensity, and duration of physical activity. Cognition is positively affected by more intense physical activity,[1,3] which is why the 24 h movement behaviour guidelines recommend at least 60 min of moderate to vigorous activity per day. Irrespective of our findings, physical activity remains the most important behaviour for physical health outcomes,[16] and there is no indication in the literature that it negatively affects cognition.[1]

The positive relationships between childhood global cognition and future academic success[33] and reduced all-cause mortality risk[34] provides a rationale for encouraging behavioural practices that promote healthy cognitive development in children. WHO and the National Sleep Foundation have physical activity[14] and sleep guidelines[15] for school-aged children, but these and the American Academy of Pediatrics guidelines do

See Online for appendix

not have screen time recommendations for children older than 5 years. Based on the positive relationship between meeting the recommendations and global cognition and on the positive outcome with meeting screen time recommendations alone, paediatricians, family doctors, and WHO should encourage adherence to the 24 h movement guidelines for promoting cognitive and physical health in children.

Our findings are preliminary, and future research is required to fully elucidate the independent and combined effects of the recommended movement 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 optimising cognitive development. The ABCD dataset is scheduled to be released on an annual basis until the year 2028, which will enable such research to be done.

This study has some limitations. First, the cross-sectional nature of the dataset does not allow for tracking the durability and consistency of movement behaviour adherence over time and precludes causal inferences to be made. Second, the self-reported exposures and outcomes, despite being psychometrically valid,[18] might have been prone to inaccurate reporting because the questionnaires were administered only once, and responses could have been subject to potential recall bias, social bias, or both. A combination of objective and subjective measures of movement behaviours, such as accelerometers and self-report measures, would be preferable in future studies to characterise context, intensity, and duration of behaviours. Furthermore, assessment of cardiorespiratory fitness as a covariate would be an important addition. For this analysis, data on participants' fitness was not available. For sleep behaviour, use of the Parent Sleep Disturbance Scale for Children might have led to unintentional mis-classifications of sleep duration because categories overlap (eg, 8–9 h and 9–11 h). The screen time survey was developed by the ABCD consortium, based on the widely used Visual Media Use Survey,[18,24] but reliability and validity measures are not available. Third, due to the failure of some of our random intercept and slope models to converge, the results presented in this study are from random intercept models. These results might contain bias and loss of efficiency compared with a model including random intercepts and random slopes. In model 2, the categorical variables were unbalanced due to small numbers of participants in some categories (eg, only 212 [5%] met the physical activity and sleep recommendations), which might affect the parameter estimates. Diagnostic plots revealed some hetero-scedasticity in our models. We used several techniques (eg, log transformation of the outcome variables, weighted variance structures) to treat heteroscedasticity, and log transformation resulted in some improvement (appendix), but we opted to retain the original models with heteroscedasticity in favour of preserving the interpretation of our findings. Fourth, the extent to which missing data might have affected the results in this analysis is unknown. Finally, residual confounding by unmeasured variables is always a possibility in observational studies.

Our study had some notable strengths. The size and sociodemographic diversity of the ABCD sample are important features. The proportion of obese children (18%) in our study was similar to that in the US population of children aged 6–11 years (18·4%).[35] Although not nationally representative, extensive measures were taken to obtain a proportionate, geographically stratified, and near-representative sample of US children to maximise the generalisability of the findings. The assessment of global cognition and its subcomponents, crystallised and fluid intelligence, with the NIH Toolbox allows direct comparison of our findings with those of other studies that have used this method. The availability of many potentially important covariates strengthened the analysis. Finally, investigating cognition in relation to the 24 h movement behaviour guidelines is an integrative perspective across the whole day that has yet to be considered in the literature. This approach provides a holistic understanding of how daily movement behaviours affect the cognitive health of children. Our findings provide a platform for future investigations aimed at improving understanding of the relationships between daily behaviours and cognition in children and youth.

To conclude, meeting the recommendations of the Canadian 24 h movement behaviour guidelines was associated with improved global cognition in US children. The greatest benefit was seen with meeting all three recommendations, followed by the screen time and sleep recommendation then the screen time recommendation alone, and significant positive effects were seen in children who met all three recommendations or the screen time and sleep recommendations. Paediatricians, parents, educators, and policy-makers should promote limiting recreational screen time and prioritising healthy sleep routines throughout childhood and adolescence.

Contributors

JJW, JDB, J-PC, and MST conceived the study. All authors submitted the application to access the Adolescent Brain Cognitive Development study dataset. JJW and JDB conceived the analytical approach with the support of all other authors. JDB did all analyses with the support of JJW, J-PC, KEG, and RLZ. JJW, JDB, and MST interpreted the results and all authors provided critical feedback. JJW, JDB, and MST wrote the first draft. All authors critically reviewed and provided feedback on drafts and approved of the final version.

Declaration of interests

We declare no competing interests.

Acknowledgments

Data used in the preparation of this article were obtained from the Adolescent Brain Cognitive Development (ABCD) study, held in the US National Institute of Mental Health Data Archive. The ABCD study is supported by the US National Institutes of Health and federal partners (U01DA041022, U01DA041028, U01DA041048, U01DA041089, U01DA041106, U01DA041117, U01DA041120, U01DA041134, U01DA041148, U01DA041156, U01DA041174, U24DA041123, and U24DA041147). ABCD consortium investigators designed and implemented this analysis, provided data, or both, but did not all participate in this analysis or writing of this report. This Article reflects the views of the authors and might not reflect the opinions or views of the US National Institutes of Health or ABCD consortium investigators.

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