24-Hour Movement Behaviors and Impulsivity

Michelle D. Guerrero, PhD,[a] Joel D. Barnes, MSc,[a] Jeremy J. Walsh, PhD,[a,b] Jean-Philippe Chaput, PhD,[a,c,d] Mark S. Tremblay, PhD,[a,c] Gary S. Goldfield, PhD[a,c,d,e]

abstract

BACKGROUND: The objective of this study was to examine individual and concurrent associations between meeting the Canadian 24-Hour Movement Guidelines for Children and Youth (9–11 hours of sleep per night, ≤2 hours of recreational screen time (ST) per day, and at least 60 minutes of moderate to vigorous physical activity per day) and dimensions of impulsivity.

METHODS: Data from this cross-sectional observational study were part of the first annual curated release of the Adolescent Brain Cognitive Development Study. Participants included 4524 children between the ages of 8 and 11 years.

RESULTS: In analyses, it was shown that adherence to individual movement behavior recommendations as well as combinations of adherence to movement behavior recommendations were associated with each dimension of impulsivity. Meeting all 3 movement behavior recommendations was associated with lower positive urgency (95% confidence interval [CI]: −0.12 to −0.05), negative urgency (95% CI: −0.04 to −0.08), Behavioral Inhibition System (95% CI: −0.08 to −0.01), greater perseverance (95% CI: 0.09 to 0.15), and better scores on delay-discounting (95% CI: 0.57 to 0.94). Meeting the ST and sleep recommendations was associated with less impulsive behaviors on all dimensions of impulsivity: negative urgency (95% CI: −0.20 to −0.10), positive urgency (95% CI: −0.16 to −0.08), perseverance (95% CI: 0.06 to 0.15), Behavioral Inhibition System (95% CI: −0.15 to −0.03), Behavioral Activation System (BAS) reward responsiveness (95% CI: −0.04 to −0.05), BAS drive (95% CI: −0.14 to −0.06), BAS fun-seeking (95% CI: −0.15 to −0.17), and delay-discounting task (95% CI: 0.68 to 0.97).

CONCLUSIONS: Findings support efforts to determine if limiting recreational ST while promoting adequate sleep enhances the treatment and prevention of impulsivity-related disorders.

[a]*Healthy Active Living and Obesity Research Group, Children's Hospital of Eastern Ontario Research Institute, Ottawa, Ontario, Canada;* [b]*Exercise, Metabolism, and Inflammation Laboratory, University of British Columbia Okanagan, Kelowna, British Columbia, Canada; and* [c]*Department of Pediatrics and* [d]*School of Human Kinetics, Faculty of Health Sciences, and* [e]*School of Psychology, Faculty of Social Sciences, University of Ottawa, Ottawa, Ontario, Canada*

Dr Guerrero conceived the analytical approach, conducted all analyses, and assisted with drafting the initial manuscript; Mr Barnes and Drs Walsh, Chaput, and Tremblay assisted with data analysis and interpretation and critically reviewed the manuscript for important intellectual content; Dr Goldfield conceptualized the study, assisted with drafting the initial manuscript, and critically reviewed the manuscript for important intellectual content; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

DOI: https://doi.org/10.1542/peds.2019-0187

Accepted for publication Jun 10, 2019

Address correspondence to Dr Michelle D. Guerrero, PhD, Healthy Active Living and Obesity Research Group, Children's Hospital of Eastern Ontario Research Institute, 401 Smyth Rd, Ottawa, ON K1H 8L1, Canada. E-mail: mguerrero@cheo.on.ca

WHAT'S KNOWN ON THIS SUBJECT: Impulsivity has been implicated in the development and maintenance of psychiatric conditions. Sleep, screen time (ST), and physical activity have been independently associated with impulsivity among children; however, how these modifiable factors concurrently relate to children's impulse control is unknown.

WHAT THIS STUDY ADDS: This study is the first to show that adequate sleep and reduced ST are linked with less impulsive behavior among children. Efforts to determine if promoting adequate sleep and limiting ST enhances the prevention of impulsivity-related disorders are needed.

To cite: Guerrero MD, Barnes JD, Walsh JJ, et al. 24-Hour Movement Behaviors and Impulsivity. *Pediatrics*. 2019; 144(3):e20190187

Impulsivity is often characterized as a tendency to act without forethought or to make decisions that reflect an inability to delay gratification; it is a multidimensional construct that encompasses cognitive, emotional, personality, and behavioral elements.[1] Impulsivity is a core characteristic in attention-deficit/hyperactivity disorder[2] but has also been implicated in the development and maintenance of many other psychiatric conditions, such as substance abuse disorders,[3,4] behavioral addictions,[5] eating disorders,[6] and other externalizing behavioral disorders.[7,8] Impulsivity has also been linked to emotion dysregulation leading to self-harm[9] and suicidal attempts among youth.[10] Thus, identifying modifiable determinants of impulsivity can inform targets to enhance the treatment and prevention of impulse control–related psychiatric disorders.

The average amount of sleep (in hours) that youth are achieving per night has decreased in recent decades, in part because of increased use of electronics.[11] Lack of sleep is related to greater impulsivity,[12] with mechanistic evidence suggesting that poor sleep negatively affects prefrontal cortical functioning, resulting in impairments in behavioral inhibition.[13] However, little data exist on the relationship between sleep duration and measures of impulsive personality traits and behavioral inhibition in preadolescent children.

It has been postulated that engaging with electronic devices during development (eg, smartphones), which often necessitates immediate responding to maintain communication or gaming, stimulates powerful behavioral and neurobiological (ie, dopamine release) reinforcement that promotes greater use, resulting in impaired inhibitory control, perseverance, emotion regulation, and other self-regulatory cognitive processes.[14] General support of these hypotheses has been found in several studies; weak impulse control has been associated with heavy engagement with mobile devices,[15] heavy media multitasking,[16] and excessive television watching (>3 hours per day).[13] However, most of this research has been conducted with older adolescents, and therefore relations among screen use and impulsivity in prepubertal children (8–11 years) are unclear.

Physical activity (PA) has been shown to improve domains of cognition,[17] including sustained attention, emotion regulation, and working memory, which are intricately associated with impulse control.[18] Thus, PA may be a viable method for promoting better inhibitory control and reducing impulsivity. Low levels of PA have been linked to impulsive behavior,[13] and it has been shown in several experimental studies that PA reduces behavioral inhibition among youth from clinical populations.[19,20] However, associations with other measures of impulsivity, such as delay-discounting (choosing smaller immediate rewards over larger more-delayed rewards) or self-reported impulsivity traits, have not been well studied in community samples of preadolescent children.

The Canadian 24-Hour Movement Guidelines for Children and Youth[21] are the first evidence-based movement guidelines that address an entire day. These guidelines recommend that children ages 5 to 13 years accumulate a minimum of 60 minutes per day in moderate to vigorous PA, spend no more than 2 hours per day in recreational screen time (ST), and obtain 9 to 11 hours of sleep per night. Children who meet all 3 movement behavior recommendations have better cognitive function,[22] lower odds of obesity,[23] better dietary patterns,[24] and enhanced quality of life[25] than children who do not meet any of the recommendations. Although individual 24-hour movement behaviors are important to consider in relation to impulsivity, what remains unknown is how these behaviors may concurrently relate to impulsivity in children. Therefore, the purpose of the current study was to examine if meeting the 24-hour movement behaviors individually and/or concurrently relate to a broad scope of dimensions of impulsivity in a large and diverse community sample of US children. We hypothesized that children who meet the movement behavior recommendations would exhibit lower scores on multiple indicators of impulsivity than those who do not meet recommendations and that meeting all recommendations would have the strongest relationship with impulsivity dimensions.

METHODS

Study Population

Participants were part of the Adolescent Brain Cognitive Development (ABCD) Study, an ongoing longitudinal, observational study on children's brain development and health.[26] Data for this study are collected on a biennial to annual basis over a 10-year period across 21 sites throughout the United States, using probabilistic sampling to obtain a large, diverse, and geographically stratified population-based sample. We used the first (baseline) cross-sectional curated release of the ABCD Study data set, which comprised 4524 children aged 8 to 11 years. Approval from all relevant institutional research ethics boards were obtained, along with signed informed consent from parents or guardians and assent from participating children in accordance with the principles of Helsinki. Information on the sample, recruitment, measure selection, and compensation are outlined elsewhere.[27,28]

Exposures

Sleep, ST, and PA served as the independent variables. Sleep was assessed by using one question from the Parent Sleep Disturbance Scale for Children.[29] Parents were asked to record the number of hours of sleep their child accumulated most nights. Recreational ST was measured by using the Youth Screen Time Survey (12 items),[30] wherein children were asked to report the number of hours spent engaged in screen-based activities (eg, watching shows and movies, texting) on a typical weekday and weekend day. Daily recreational ST was calculated by taking a weighted average of the weekday and weekend ST items: (sum of weekday ST in decimal hours × 5) + (sum of weekend day ST in decimal hours × 2)/7. PA was assessed by using one item from the Youth Risk Behavior Survey,[31] wherein children were asked to indicate on how many days they were active for at least 60 minutes per day in the last 7 days. Single-item measures of sleep and PA have moderate to strong criterion validity with accelerometry-assessed sleep and PA.[32,33]

Outcomes

Dimensions of impulsivity served as the outcome variables and were measured by using 3 child-reported assessments: UPPS-P Impulsive Behavior Scale[34] (D. Lynam, PhD, unpublished observations), Behavioral Inhibition System (BIS)/Behavioral Activation System (BAS) Scale,[35] and cash choice delay-discounting task.[36] The UPPS-P scale comprises 5 dimensions: negative urgency (eg, "When I am upset, I often act without thinking"), positive urgency (eg, "When I get really happy about something, I tend to do things that can lead to trouble"), (lack of) premeditation (eg, "I like to stop and think things over before I do them"), (lack of) perseverance ("I finish what I start"), and sensation seeking (eg, "I like new, thrilling things, even if they are a little scary"). All items were scored on a 4-point Likert scale, anchored at 1 (not at all like me) and 4 (very much like me). Items assessing (lack of) premeditation and one item assessing (lack of) perseverance were reverse coded. High scores on negative and positive urgency indicate high impulsivity, whereas a high score on perseverance indicates low impulsivity. The BIS/BAS Scale comprises 4 dimensions assessing BIS (eg, "I feel worried when I have done poorly at something"), BAS drive (eg, "I do everything to get the things that I want"), BAS reward responsiveness (eg, "I feel excited and full of energy when I get something that I want"), and BAS fun-seeking (eg, "I crave excitement and new sensations"). Items are scored on a 4-point Likert scale anchored at 0 (not true) and 3 (very true). For the delay-discounting task, children were asked to respond to a hypothetical question, indicating whether they would rather obtain $75 in 3 days (smaller, sooner reward) or $115 in 3 months (larger, later reward). They were also given a third "can't decide" option. Scores on the UPPS-P and BIS/BAS scales have been shown to have adequate reliability coefficients,[27] and the delay-discounting task has correlated well with real monetary rewards.[37]

Statistical Analyses

All analyses were conducted by using Mplus 8.2.[38] Missing data (<1%) were replaced by using multiple imputation. Robust full-information maximum likelihood estimation was used to account for possible nonnormality in responses. Confirmatory factor analyses (measurement models) were first conducted to examine the factorial structure of the UPPS-P and BIS/BAS scales. Intraclass correlations were calculated to determine if meaningful between-level (ie, data collection sites) differences affected the within-

TABLE 1 Means, SDs, and Composite Reliabilities of Study Variables

Variable	Mean	SD	CR
UPPS-P and BIS/BAS dimensions			
Negative urgency	2.10	0.65	0.63
Positive urgency	1.96	0.73	0.68
Perseverance	3.27	0.54	0.70
BIS	2.21	0.60	0.63
BAS drive	2.04	0.76	0.78
BAS reward responsiveness	3.22	0.57	0.74
BAS fun-seeking	2.44	0.65	0.65
Descriptives			
Age, y	10.00	0.61	NA
BMI, kg/m^2	18.63	3.94	NA
Family income[a]	7.41	2.28	NA
Parental education[b]	4.74	1.59	NA

CR, composite reliability; NA, not applicable.

[a] Combined income in past 12 mo from all sources before taxes and deductions on a scale of 1 to 10. 1 = ≤ $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 (all in US dollars).

[b] Highest score on a scale of 1 to 7. 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; and 7 = professional or doctorate degree.

level dependent variables. The intraclass correlations from the unconditional models were low (ranged from 0.003 to 0.03), suggesting that there was little variability between data collection sites. Therefore, although the data were treated as nonnested, potential nonindependence was accounted for by using the TYPE = COMPLEX function in Mplus. Measurement (ie, configural, metric, and scalar) and structural (ie, factor variance and factor mean) invariance across sex were tested and assessed on the basis of Chen et al's guidelines.[39] Structural equation modeling was used to evaluate both the measurement models and the hypothesized structural model. In the hypothesized structural model, impulsivity dimensions were modeled as latent variables, and movement behavior combinations and the delay-discounting task were modeled as observed variables. Covariates (ie, sex, BMI, family income, parental education, and race and ethnicity) were included in the model to account for their potential effect on dimensions of impulsivity. Information regarding how the covariates were categorized is described in Table 1. Various fit indices were used to assess the measurement models, including the comparative fit index (CFI), standardized root square mean residual (SRMR), and root mean square error of approximation (RMSEA). Model fit was deemed acceptable if CFI values were >0.90 and if SRMR and RMSEA values were <0.08.[40] Composite reliability estimates[41] of latent variables were also computed. Statistical inferences were based on *P* values <.05 and confidence intervals (CIs).

Participants were classified into 1 of 8 possible movement behavior recommendation combinations: only PA, only ST, only sleep, PA + ST, PA + sleep, ST + sleep, PA + ST + sleep, and none (no recommendation met).

TABLE 2 Proportions of Study Variables

Descriptives	*N*	%
Sex		
Male	2152	47.6
Female	2372	52.4
Race and ethnicity		
Asian American	115	2.5
African American	452	10.0
White	2660	58.8
Hispanic	740	16.4
Multiracial	557	12.3
Movement behavior combinations		
Only PA	251	5.5
Only ST	522	11.5
Only sleep	1073	23.7
PA + ST	115	2.5
PA + sleep	212	4.7
ST + sleep	802	17.7
PA + ST + sleep	216	4.8
None	1333	29.4
Cash choice task		
Smaller, sooner	1841	40.7
Larger, later	2617	57.8
"Can't decide"	66	1.5

Participants were coded as 0 if they did not meet the behavior recommendation and as 1 if they did meet the behavior recommendation. The cash choice task was also dummy coded, wherein children who selected the larger, later reward or the "can't decide" option were coded as 0 and those who selected the smaller, sooner reward were coded as 1.

RESULTS

Descriptive Statistics and Measurement Models

Descriptive statistics are presented in Tables 1 and 2. Approximately 30% of the sample did not meet any of the recommendations, whereas only 4.8% of the sample met all movement behavior recommendations. Slight modifications were made to both measurement models (ie, deletion of negative factor loadings). The final UPPS-P solution comprised a 3-factor model (positive urgency, negative urgency, and perseverance), which showed excellent model fit (χ^2[51] = 329.58, $P < .001$, CFI = 0.97; SRMR = 0.03; RMSEA = 0.04 [90% CI: 0.031 to 0.038]). The 4-factor solution for the BIS/BAS Scale also revealed excellent model fit (χ^2[146] = 1415.86, $P < .001$, CFI = 0.92; SRMR = 0.04; RMSEA = 0.04 [90% CI: 0.042 to 0.046]). Model fit for the measurement and structural invariance testing indicated acceptable model fit, and all changes in fit indices fell within acceptable ranges, as suggested by Chen et al[39] (see Supplemental Table 6).

Structural Model

UPPS-P

Meeting all movement behavior combinations (versus meeting none of the recommendations) was negatively related to positive and negative urgency and positively related to perseverance. Meeting the ST + sleep recommendations (versus meeting no recommendation) was most strongly associated with negative urgency (β = −.15), and meeting all movement behavior recommendations was most strongly associated with perseverance (β = .12). Compared with meeting no recommendation, meeting only the ST recommendation (β = −.08), the PA + ST recommendations

(β = −.06), the ST + sleep recommendations (β = −.12), and all recommendations (β = −.09) were negatively associated with positive urgency. Meeting the ST + sleep ecommendations had the strongest association with positive urgency. Standardized β coefficients, SEs, *P* values, and CIs are presented in Table 3.

BIS/BAS

Apart from 3 exceptions (meeting only the sleep recommendation, only the PA recommendation, and the PA + ST recommendations), meeting all movement behavior combinations (versus meeting no recommendation) was negatively related to the BIS. Meeting the ST + sleep recommendations had the strongest relationship with the BIS (β = −.09). Meeting only the ST recommendation (β = −.08) and the ST + sleep recommendations (β = −.10) (versus meeting no recommendation) were negatively associated with BAS drive, with the latter combination having the strongest association with BAS drive. Meeting only the ST recommendation (β = −.07) and the ST + sleep recommendations (β = −.11) (versus meeting no recommendation) were negatively related to BAS fun, with the later combination having the strongest association. Meeting only the ST recommendation (β = −.04) and the ST + sleep recommendations (β = −.09) (versus meeting no recommendation) were negatively associated with BAS reward responsiveness. Meeting the PA + sleep recommendations (versus meeting no recommendation) was positively associated with BAS reward responsiveness (β = .05), and meeting only the PA recommendation (versus meeting no recommendation) was positively associated with BAS drive (β = .08), BAS fun (β = .09), and BAS reward responsiveness (β = .06). Standardized β coefficients, SEs, *P* values, and CIs are presented in Table 4.

Delay-Discounting Task

Compared with meeting no recommendation, participants meeting the sleep + PA recommendations (odds ratio [OR] = 0.74), the sleep + ST recommendations (OR = 0.81), and all recommendations (OR = 0.74) were less likely to select the smaller, sooner reward than the larger, later reward or the "can't decide" option. ORs, SEs, *P* values, and CIs are presented in Table 5.

DISCUSSION

The purpose of the current study was to determine if meeting the 24-hour movement behavior recommendations was associated with dimensions of impulsivity. In our results, it was shown that adherence to individual movement behavior recommendations as well as combinations of adherence to movement behavior recommendations were associated with each dimension of impulsivity. More specifically, children who met the sleep and ST recommendations scored favorably on all 8 dimensions of impulsivity (negative urgency, positive urgency, [lack of] perseverance, BIS, BAS drive, BAS reward, BAS fun-seeking, and delay-discounting) than children who did not meet any recommendation. In most cases, meeting the sleep + ST recommendations had the strongest association with the impulsivity dimensions. Although meeting all 24-hour movement behavior recommendations was associated with reduced impulsivity on 5 of the 8 domains (positive urgency, negative urgency, perseverance, BIS, delay-discounting), this movement behavior combination emerged as having the strongest association with only 1 of the impulsivity domains. Thus, with our results, it is suggested that meeting the PA recommendation provided no incremental predictive value beyond meeting the sleep + ST guidelines. The models explained 3.4% to 9.7% of the variance of impulsivity scores.

The sleep + ST movement behavior combination had the strongest association with most of the impulsivity measures (7 out of 8 dimensions), whereas the sleep + ST + PA behavior combination had the strongest association with perseverance. The former finding is not surprising, given that increased ST and reduced sleep have been independently associated with domains reflecting higher impulsivity among university students.[12,15] Moreover, more ST (eg, television, computers, video games, and mobile devices) is adversely associated with various sleep outcomes in school-aged children and adolescents, such as delayed bedtimes and shorter sleep duration.[42,43] Reduced ST has also been associated with greater sleep duration.[44] Our findings highlight that sleep and ST interact in a fashion that provides unique benefits compared with meeting either movement behavior alone and may be especially clinically relevant to target concurrently in interventions, given a small percentage of children meet these movement behavior guidelines.

Some possible mechanisms linking poor sleep and high amounts of ST with greater impulsivity are provided, with insights from basic science research. Reduced sleep duration may negatively impact impulsivity via its adverse biological effects on brain function and structure[45] and often leads to daytime sleepiness, which is associated with diminished inhibitory control and executive function processes and also predisposes youth to substance abuse and suicidality.[46] Modern forms of digital media (eg, excessive social media, video gaming) are highly reinforcing and have been shown to elicit responses in brain reward pathways that are similar to palatable foods[47] and drugs of abuse,[14] with associated decrements

TABLE 3 Standardized Path Coefficients Between Movement Behavior Recommendation Combinations and UPPS-P Dimensions

Path	β	SE	*P*	95% CI	R^2, %
Positive urgency					6.7
24-h movement combinations					
Only PA	.01	0.02	.638	−0.03 to 0.04	
Only ST[a]	−.08	0.02	<.001	−0.12 to −0.04	
Only sleep	−.01	0.02	.543	−0.05 to 0.03	
PA + ST[a]	−.06	0.01	<.001	−0.09 to −0.03	
PA + sleep	−.00	0.01	.944	−0.03 to 0.03	
ST + sleep[a]	−.12	0.02	<.001	−0.16 to −0.08	
PA + ST + sleep[a]	−.09	0.02	<.001	−0.12 to −0.05	
Covariates					
Female (reference: male)[a]	.07	0.02	.001	0.03 to 0.11	
BMI	.01	0.02	.559	−0.02 to 0.04	
Family income[a]	−.06	0.02	.002	−0.10 to −0.02	
Parent education[a]	−.07	0.02	.001	−0.12 to −0.03	
Ethnicity (reference: Asian American)					
White[a]	−.12	0.04	.003	−0.20 to −0.04	
African American	−.01	0.03	.668	−0.07 to 0.04	
Hispanic[a]	−.10	0.03	.001	−0.17 to −0.05	
Multiracial	−.04	0.03	.224	−0.11 to 0.03	
Negative urgency					4.0
24-h movement combinations[a]					
Only PA	−.04	0.02	.029	−0.08 to −0.00	
Only ST	−.13	0.02	<.001	−0.17 to −0.08	
Only sleep	−.06	0.02	.010	−0.11 to −0.01	
PA + ST	−.05	0.02	.002	−0.08 to −0.02	
PA + sleep	−.04	0.02	.033	−0.08 to −0.00	
ST + sleep	−.15	0.02	<.001	−0.20 to −0.10	
PA + ST + sleep	−.11	0.02	<.001	−0.14 to −0.08	
Covariate					
Female (reference: male)[a]	.09	0.02	<.001	0.05 to 0.12	
BMI	−.03	0.02	.093	−0.06 to 0.00	
Family income	.00	0.03	.958	−0.07 to 0.07	
Parent education	−.03	0.02	.304	−0.07 to 0.02	
Ethnicity (reference: Asian American)					
White	−.02	0.05	.649	−0.13 to 0.08	
African American	−.02	0.05	.705	−0.11 to 0.07	
Hispanic	−.05	0.05	.282	−0.15 to 0.04	
Multiracial	−.01	0.04	.763	−0.09 to 0.07	
Perseverance					4.0
24-h movement combinations[a]					
Only PA	.05	0.02	.001	0.02 to 0.08	
Only ST	.10	0.02	<.001	0.06 to 0.14	
Only sleep	.04	0.02	.023	0.01 to 0.07	
PA + ST	.09	0.01	<.001	0.06 to 0.12	
PA + sleep	.07	0.01	<.001	0.04 to 0.09	
ST + sleep	.10	0.02	<.001	0.06 to 0.15	
PA + ST + sleep	.12	0.02	<.001	0.09 to 0.15	
Covariates					
Female (reference: male)[a]	−.07	0.02	<.001	−0.11 to −0.04	
BMI	.01	0.02	.657	−0.03 to 0.05	
Family income[a]	.08	0.04	.030	0.01 to 0.15	
Parent education	−.03	0.02	.234	−0.07 to 0.02	
Ethnicity (reference: Asian American)					
White	.05	0.05	.370	−0.06 to 0.15	
African American[a]	.12	0.04	.002	0.04 to 0.19	
Hispanic[a]	.11	0.04	.004	0.03 to 0.19	
Multiracial	.06	0.04	.111	−0.01 to 0.14	

CIs are standardized.

[a] Indicates a significant path coefficient.

TABLE 4 Standardized Path Coefficients Between Movement Behavior Recommendation Combinations and BIS/BAS Dimensions

Path	β	SE	*P*	95% CI	R^2, %
BIS					
24-h movement combinations					3.4
Only PA	.00	0.02	.892	−0.04 to 0.04	
Only ST[a]	−.05	0.03	.045	−0.10 to −0.00	
Only sleep	−.00	0.03	.882	−0.06 to 0.05	
PA + ST	−.03	0.02	.076	−0.06 to 0.01	
PA + sleep[a]	−.04	0.02	.029	−0.07 to −0.00	
ST + sleep[a]	−.09	0.03	.002	−0.15 to −0.03	
PA + ST + sleep[a]	−.05	0.02	.006	−0.08 to −0.01	
Covariates					
Female (reference: male)[a]	−.01	0.02	<.001	−0.13 to −0.06	
BMI[a]	.04	0.02	.028	0.00 to 0.08	
Family income	.01	0.02	.714	−0.04 to 0.06	
Parent education[a]	−.06	0.02	.014	−0.10 to −0.01	
Ethnicity (reference: Asian American)					
White[a]	−.17	0.05	.002	−0.27 to −0.06	
African American[a]	−.09	0.04	.013	−0.16 to −0.02	
Hispanic	−.08	0.06	.156	−0.19 to 0.03	
Multiracial[a]	−.09	0.04	.030	−0.16 to −0.01	
BAS reward responsiveness					5.0
24-h movement combinations					
Only PA[a]	.06	0.02	.001	0.02 to 0.09	
Only ST[a]	−.04	0.02	.036	−0.08 to −0.00	
Only sleep	.00	0.02	.938	−0.04 to 0.04	
PA + ST	−.01	0.02	.653	−0.05 to 0.03	
PA + sleep[a]	.05	0.02	.002	0.02 to 0.08	
ST + sleep[a]	−.09	0.02	<.001	−0.04 to −0.05	
PA + ST + sleep	−.02	−0.01	.205	−0.10 to 0.00	
Covariates					
Female (reference: male)[a]	−.05	0.02	.018	0.01 to 0.10	
BMI[a]	.05	0.02	.001	0.02 to 0.09	
Family income[a]	−.05	0.02	.032	−0.02 to −0.00	
Parent education	.01	0.03	.963	−0.05 to 0.05	
Ethnicity (reference: Asian American)					
White	−.01	0.05	.905	−0.12 to 0.10	
African American[a]	.08	0.03	.009	0.02 to 0.14	
Hispanic	.05	0.05	.316	−0.05 to 0.14	
Multiracial	.02	0.04	.583	−0.05 to 0.10	
BAS drive					9.7
24-h movement combinations					
Only PA[a]	.08	0.02	<.001	0.05 to 0.11	
Only ST[a]	−.08	0.02	<.001	−0.11 to −0.05	
Only sleep	−.01	0.02	.338	−0.04 to 0.02	
PA + ST	.00	0.01	.900	−0.02 to 0.03	
PA + sleep	.04	0.02	.060	−0.00 to 0.09	
ST + sleep[a]	−.10	0.02	<.001	−0.14 to −0.06	
PA + ST + sleep	−.02	0.02	.243	−0.05 to 0.02	
Covariates					
Female (reference: male)[a]	−.09	0.01	<.001	0.07 to 0.12	
BMI[a]	.03	0.02	.026	0.00 to 0.06	
Family income[a]	−.08	0.03	.002	−0.14 to −0.03	
Parent education	−.03	0.02	.133	−0.07 to 0.00	
Ethnicity (reference: Asian American)					
White	−.04	0.04	.398	−0.12 to 0.05	
African American[a]	.09	0.03	.011	0.02 to 0.15	
Hispanic	.07	0.04	.102	−0.01 to 0.16	
Multiracial	.01	0.03	.676	−0.05 to 0.07	
BAS fun-seeking					
24-h movement combinations					5.0
Only PA[a]	.09	0.02	<.001	0.05 to 0.13	
Only ST[a]	−.07	0.02	.002	−0.11 to −0.02	

TABLE 4 Continued

Path	β	SE	*P*	95% CI	R^2, %
Only sleep	−.01	0.02	.578	−0.05 to 0.03	
PA + ST	.01	0.02	.753	−0.03 to 0.04	
PA + sleep	.04	0.02	.118	−0.00 to 0.08	
ST + sleep[a]	−.11	0.02	<.001	−0.15 to −0.07	
PA + ST + sleep	.01	0.02	.533	−0.03 to 0.05	
Covariates					
Female (reference: male)[a]	−.05	0.02	.014	0.01 to 0.10	
BMI	.03	0.02	.213	−0.02 to 0.07	
Family income	−.02	0.03	.363	−0.07 to 0.03	
Parent education	−.02	0.03	.366	−0.07 to 0.03	
Ethnicity (reference: Asian American)					
White	.11	0.06	.068	−0.01 to 0.23	
African American[a]	.12	0.05	.014	0.02 to 0.21	
Hispanic[a]	.11	0.05	.026	0.01 to 0.20	
Multiracial[a]	.09	0.04	.022	0.01 to 0.16	

CIs are standardized.

[a] Indicates a significant path coefficient.

in attention, cognitive control, and impulsivity.[14] These neurobiological correlates of excessive ST, combined with a prominent dynamic inherent in many screen-based technologies that necessitate immediate responding while punishing delayed responses, may serve to reinforce impulsivity and undermine the development of self-regulatory abilities.

Meeting the PA recommendation (either alone or in combination with meeting the sleep recommendation) was positively related to BAS reward responsiveness and BAS drive. This finding is somewhat consistent with previous research, indicating that greater levels of PA are linked with higher scores on BAS drive[48] and that greater PA enjoyment is positively associated with BAS reward responsiveness.[49] We also found that PA was associated with lower negative urgency and positively associated with perseverance. These novel findings are generally consistent with a recent systematic review in which it was shown that PA is associated with improved executive functioning in youth.[17] The inconsistent associations observed may reflect differences in PA dose, measurement, and sample characteristics across studies. Clearly, more research is needed to determine how PA alone or combined with other movement behavior recommendations is associated with children's impulsive traits. The prospective, longitudinal measures from the ABCD Study will be

TABLE 5 Relationships Between Movement Behavior Recommendation Combinations and Delay-Discounting Task

Path	OR	SE	*P*	95% CI
Smaller, sooner (reference: larger, later and "can't decide" option)				
24-h movement combinations				
Only PA	1.00	0.12	.972	0.79 to 1.26
Only ST	1.00	0.13	.971	0.79 to 1.29
Only sleep	0.96	0.07	.557	0.83 to 1.11
PA + ST	0.84	0.16	.274	0.58 to 1.23
PA + sleep[a]	0.74	0.08	.001	0.60 to 0.92
ST + sleep[a]	0.81	0.07	.005	0.68 to 0.97
PA + ST + sleep[a]	0.74	0.09	.003	0.57 to 0.94
Covariates				
Female (reference: male)[a]	1.16	0.07	.027	1.03 to 1.31
BMI	0.97	0.02	.211	0.93 to 1.02
Family income[a]	1.06	0.03	.012	1.02 to 1.11
Parent education[a]	0.92	0.03	.001	0.87 to 0.97
Ethnicity (reference: Asian)				
White	0.81	0.14	.185	0.57 to 1.15
African American	0.87	0.17	.456	0.60 to 1.28
Hispanic	1.16	0.26	.536	0.75 to 1.81
Multiracial	0.77	0.12	.063	0.56 to 1.06

[a] Indicates a significant path coefficient.

important to better dissect these relationships.

There are limitations and strengths to our study. First, with respect to limitations, our results are based on cross-sectional data, preventing us from drawing any causal inferences regarding associations. Future researchers should not only conduct longitudinal studies but also explore the bidirectional link between the movement behaviors and impulse control. That is, children with impulse control problems may spend more time on rewarding screens, may be more likely to procrastinate bedtime, and may engage in low levels of PA (because the health benefit in future is delayed), which in turn may exacerbate impulsivity, creating a vicious cycle. Second, a single item was used to measure PA, which may have played a role in the lack of observed findings between PA and dimensions of impulsivity. Using other measures of PA (eg, wearable devices) would help to improve the internal validity of our findings. Third, the screen-based questions in our study only assessed the amount of time spent in separate ST behaviors. Other characteristics of ST that can potentially affect young people's behaviors should also be considered. Such characteristics include screen content, timing exposure, size of screen, frequency of phone-checking, and simultaneous use of multiple screens.[43] The act of simultaneously using electronic devices (eg, mobile device, computer or tablet) while watching television is referred to as "screen-stacking" (also known as media multitasking) and is a trend expected to grow as screen-based technologies continue to rapidly evolve. In fact, in recent evidence, it has been shown that nearly half of evening television watchers engage in "screen-stacking."[50] Despite the acknowledged limitations, our study has notable strengths. In this study, we were the first to examine the concurrent associations between sleep, ST, and PA on impulsivity among children. Furthermore, our research is the first to include the UPPS-P and BIS/BAS in one model. By modeling different dimensions of impulsivity simultaneously, we were able to account for the interplay between these dimensions (via variance).

CONCLUSIONS

In the results of the current study, we showed that children who met the sleep + ST recommendations consistently reported lower levels of impulsivity compared with not meeting any movement behavior guidelines. Meeting all movement behavior recommendations was associated with reduced impulsivity on most but not all measures, suggesting that meeting the PA recommendation provided no incremental benefit in terms of reduced impulsivity, although PA is well documented to be important for physical and mental health in youth and should still be encouraged.[51] Our findings have important implications for pediatricians, psychiatrists, educators, parents, and policy makers as they suggest that strategies to limit recreational ST while simultaneously promoting early, routine bedtimes and more sleep may enhance the treatment and prevention of impulsivity-related psychiatric disorders.

ACKNOWLEDGMENTS

Data used in the preparation of this article were obtained from the ABCD Study (https://abcdstudy.org), held in the National Institute of Mental Health Data Archive. This is a multisite, longitudinal study designed to recruit more than 10 000 children aged 9 to 10 years and manage them over 10 years into early adulthood. A listing of participating sites and a complete listing of the study investigators can be found at https://abcdstudy.org/principal-investigators.html. ABCD Study consortium investigators designed and implemented the study and/or provided data but did not necessarily participate in the analysis or writing of this report. This article reflects the views of the authors and may not reflect the opinions or views of the National Institutes of Health or ABCD Study consortium investigators. The ABCD Study data repository grows and changes over time. The ABCD Study data used in this report came from National Institute of Mental Health data (DOI: 10·15154/1412097).

ABBREVIATIONS

ABCD: Adolescent Brain Cognitive Development
BAS: Behavioral Activation System
BIS: Behavioral Inhibition System
CFI: comparative fit index
CI: confidence interval
OR: odds ratio
PA: physical activity
RMSEA: root mean square error of approximation
SRMR: standardized root square mean residual
ST: screen time

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: The Adolescent Brain Cognitive Development 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. Funded by the National Institutes of Health (NIH).

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

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DOI: 10.1542/peds.2019-0187 originally published online August 14, 2019;

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