Meeting 24-hour Movement Behavior Guidelines is Linked to Academic Engagement, Psychological Functioning, and Cognitive Difficulties in Youth with Internalizing Problems

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Abstract

*Background***:** This study aimed to investigate associations of meeting 24-hour movement behavior (24-HMB: physical activity [PA], screen time [ST] in the school-aged youth, and sleep) guidelines with indicators of academic engagement, psychological functioning, and cognitive function in a national representative sample of U.S. youth.

*Methods***: I**n this cross-sectional study,1794 participants aged 6 to 17 years old were included for multivariable logistic regression to determine the above-mentioned associations, while adjusting for sociodemographic and health covariates.

Results: The proportion of participants who met 24-HMB guideline(s) varied greatly (PA+ ST+ sleep = 34 [weighted 1.17%], PA+ST = 23 [weighted 1.72%], PA +sleep = 52 [weighted 2.15%], PA = 34 [weighted 2.88%], ST = 142 [weighted 7.5%], ST+ sleep = 209 [weighted 11.86%], sleep = 725 [weighted 35.5%], none = 575 [weighted 37.22%]). Participants who met ST guideline alone and integrated (ST + Sleep and ST + sleep + PA) guidelines demonstrated the consistently beneficial associations with learning interest/curiosity, caring for school performance, completing required homework, resilience, cognitive difficulties, self-regulation (ps < 0.05).

*Conclusion***:** Meeting 24-HMB guidelines in an isolated or integrative manner was associated with improved academic engagement, psychological functioning, and reduced cognitive difficulties. These findings highlight the importance of the promotion of 24-HMB guidelines in youth with internalizing problems. Future longitudinal studies are needed to investigate whether changes or modifications of meeting specific 24-HMB guidelines (especially ST) is beneficial for youth with internalizing problems.

Keywords: Physical activity, sleep, screen time, anxiety, depression

Introduction

Internalizing problems (i.e., anxiety and depression) are associated with serious public health issues (Murray et al., 2012) because of their early onset (Gutman & Codiroli McMaster, 2020; Kessler et al., 2007; Pine et al., 1998) and their high lifetime prevalence rate (Pine et al., 1998; Woodward & Fergusson, 2001). Moreover, internalizing problems, anxiety and depression specifically, are the most commonly diagnosed mental illnesses among youth including children and adolescents worldwide (Merikangas et al., 2010; Racine et al., 2021), and have detrimental effects on both physical and mental health (Gore et al., 2011; Renaud et al., 2008; Van Ameringen et al., 2003; Weinberg et al., 1973). Anxiety is typically characterized by excessive fear and worry, which can lead to a wide range of physiological and behavioral disturbances, such as increased heart rate, muscle tension, and difficulty to concentrate (DSM-5, APA, 2013). Depression is often characterized by persistent feelings of sadness and hopelessness and a loss of interest in previously pleasurable activities, which can lead to impairments in both physical and behavioral functioning (DSM-5, APA, 2013). Depression and anxiety often co-occur, either concurrently or sequentially, contributing to a high level of comorbidity (Garber & Weersing, 2010; Moffitt et al., 2007; Pine et al., 1998). The considerable overlap between these two internalizing problems may arise by a shared domain of negative affectivity (Angst et al., 1990; Axelson & Birmaher, 2001). Of note, children and adolescents with depression and anxiety tend to experience more difficulties with mental, social, and educational outcomes compared to typically developing peers (Saris et al., 2017; Sellers et al., 2019). For example, there is evidence that youth with internalizing problems exhibit lower levels of school-related performance (Awadalla et al., 2020; Bitsko et al., 2018; Castaneda et al., 2008), show decreased resilience in the face of adversity and stress (Min et al., 2013), and demonstrate poorer cognitive performance (Castaneda et al., 2008), which in turn can contribute to a lower quality of life and diminished sense of overall well-being (Rapaport et al., 2005).

To treat health problems associated with internalizing conditions, pharmacotherapy and psychological interventions are commonly used (Aldridge et al., 2022; Cuijpers et al., 2013) . However, the use of pharmacotherapy in youth is a matter of ongoing debate because of potential negative side effects,

while psychotherapy and other non-pharmacological interventions are currently underutilized due to their higher cost and limited personnel resources of the health care system (Cipriani et al., 2016; Cuijpers et al., 2016; Locher et al., 2017; Sharma et al., 2016). Therefore, researchers have recently started to pay more attention to the influence of modifiable lifestyle factors as potential targets for treatment of internalizing problems in youth – namely an increase of regular physical activity (PA) (Cecchini et al., 2023; Chen et al., 2021; Zhang et al., 2022), a reduction of screen time (ST) (Ref), and adherence of adequate sleep patterns(de Lannoy et al., 2023; Gilchrist et al., 2021). In general, these lifestyle factors are known to positively influence a wide range of physical and mental health outcomes in youth with internalizing problems. For example, regular engagement in PA was positively associated with health and well-being of children with internalizing problems (Rocha et al., 2015). In this regard, there is also growing evidence that relatively high levels of PA can improve cognitive performance (Ben et al., 2023; Dale et al., 2019; Luo et al., 2023; Marquez et al., 2020; Murphy et al., 2020; Singh et al., 2023; Zhu et al., 2019), and psychological functioning (Carek et al., 2011; Erickson et al., 2019) in youth. In contrast, it has been observed that unhealthy lifestyle behaviors such as excessive ST are associated with higher levels of depression and anxiety in adolescents (Khouja et al., 2019; Oberle et al., 2020), while too short or too long sleep is associated with a higher severity of internalizing disorders, which in turn negatively influences the well-being of youth with internalizing problems (Bourke & Phillips, 2023; Difrancesco et al., 2019; Siwa et al., 2023; Liye Zou et al., 2023).

Traditionally, studies investigating the associations of PA, ST, and sleep with the overall development and well-being of youth have considered these lifestyle factors in isolation rather than in an integrated manner. In recent years, a more holistic view has emerged that emphasizes the need to consider these three mutually exclusive and time-limited movement behaviors simultaneously. In this context, 24-Hour Movement Behavior (24-HMB) guidelines were developed to recognize the interdependence of PA, sedentary behaviors (referring to ST in school-aged youth), and sleep. For a healthy development of youth, 24-HMB guidelines recommend at least 60 minutes of moderate-to-vigorous PA (MVPA) per day, $\leq$ 2 hours of recreational ST per day, and 9-11 hours of sleep per night (Gunnell et al., 2016; Oberle et al., 2020). Indeed, several studies have provided evidence that neurotypical youth (da Costa et al., 2022; García-Hermoso et al., 2023; Lee et al., 2023; Watson et al., 2022) as well as youth with neurodevelopmental conditions such as autism disorder (Kong et al., 2023), attention

deficit/hyperactive disorder (Taylor et al., 2023) who met 24-HMB guidelines exhibited more positive health outcomes related to overall development and well-being than those who did not adhere to these guidelines.

However, the relationship between meeting 24-HMB guidelines and the well-being of youth with internalizing problems (i.e., depression and anxiety) has to the best of our knowledge not been studied. In particular, the association between 24-HMB guidelines and academic engagement, psychological functioning, and cognitive difficulties (i.e., concentration, memory and decisions making) in youth with comorbid mental health problems remains relatively elusive. Given that meeting one or more components of 24-HMB guidelines may have synergistic effects, it is important to investigate the associations between 24-HMB guidelines and the above-mentioned indicators in this specific population. In addition, certain factors, such as sociodemographic variables (e.g., sex/gender, ethnicity, family income, education of primary caregivers) (Fancourt et al., 2021; Goodwin et al., 2020), overweight status (Cornette, 2011), adverse childhood experiences (Hughes et al., 2021), maternal and paternal mental health status (Westrupp et al., 2023), and mental health care utilization, may influence the overall development and well-being of youth with internalizing problems. Therefore, these factors were assessed and controlled for in the present study.

In summary, the current study investigated the associations between meeting 24-HMB guidelines and selected health indicators in youth with internalizing problems. Specifically, the primary hypotheses of the current study were as follows: (1) meeting one or more 24-HMB guideline(s) is positively associated with academic engagement in youth with internalizing problems, (2) meeting one or more guidelines of 24-HMB guideline(s) is positively associated with psychological functioning in youth with internalizing problems, and (3) meeting one or more guideline(s) of 24-HMB guideline(s) is negatively associated with cognitive difficulties in youth with internalizing problems.

Method

Sample and data source

Data in this cross-sectional study were obtained from the 2021-2021 U.S. National Survey of Children's Health (NSCH). Of note, data were collected at two different periods (June 2020-January 2021 and July 2021-January 2022). Detailed information on the data collection can be found elsewhere

(https://www.childhealthdata.org). The study protocol and procedures for this survey followed the same procedures as described in previous studies (Kong et al., 2023; Taylor et al., 2023) with the exception of the selection criteria for the specific population of youth examined in this study. Briefly, a parent or legal guardian of the selected youth completed the survey. A total of 93,669 households completed the survey in 2 years, with 42,777 completed in 2020 and 50,892 completed in 2021. The present study targets youth (6-17 years) with internalizing problems. The presence of internalizing problems was assessed via two separate questions (as reported by primary caregivers of the children or adolescent), which read as follows: (a) your child has anxiety problems, (b) your child has depression? When these questions both were answered yes, participant was included our study.

Demographic and medical information

Data on age, sex, ethnicity, household poverty level, the highest level of education of primary caregivers, overweight status, adverse childhood experiences, maternal mental health status, paternal mental health status, and mental health care received were used as covariates in this study. Children and adolescents were classified as overweight if the caregivers reported a diagnosis from a physician or health care provider. Adverse childhood experiences refer to 10 negative experiences that children may have experienced in their early years, such as difficulty meeting basic needs due to family income, divorce or separation of parents or guardians, death of parents or guardians, and so on.

Independent variables

In this study, the number of meeting 24-HMB guidelines (i.e., 0 to 3 guidelines) was used as a continuous variable, and combinations of whether or not meeting 24-HMB guidelines (i.e., PA, ST, or sleep, PA + ST, PA + sleep, or ST + sleep, PA + ST + sleep) were used as categorical variables. Three single-item questions were used to measure the three components of 24-HMB (i.e., PA, ST, and sleep duration). Participants were coded as 1 if they met the guidelines, and 0 if they did not. PA level was measured by the question, “During the past week, on how many days did this child exercise, play a sport, or participate in PA for at least 60 minutes?” This response was scored on a 4-point rating scale (1 = 0 days, 2 = 1-3days, 3 = 4-6 days, and 4 = 7 days/every week). The youth of caregivers who chose option 4 (7 days/every week) met PA guideline alone, and the rest were classified as not meeting this guideline. ST was assessed with the question, “On most weekdays, about how much time did this child

spend in front of a TV, computer, cell phone, or other electronic device watching programs, playing games, accessing the internet, or using social media? (Do not include time spent doing schoolwork.)" The responses were scored on a 5-point rating scale (1 = less than 1h, 2 = 1h, 3 = 2h, 4 = 3h, and 5 = 4h or more). Responses from 1 to 3 (no more than 2h) were coded as 1 and the remaining responses were coded as 0. Sleep duration was quantified with the question, "During the past week, how many hours of sleep did this child get on most weeknights?" Responses were scored on a 7-point scale (1 = less than 6h, 2 = 6h, 3 = 7h, 4 = 8h, 5 = 9h, 6 = 10h, and 7 = 11h or more). For children aged 5 to 13 years, responses of 5 to 7 (9h hours or more) were considered to meet sleep guideline alone, and for participants aged 14 to 17 years, responses of 4 to 6 (8 to 10h) were also considered to meet the sleep guideline.

Dependent variables

Academic engagement was operationalized using three indicators: (i) learning interest/curiosity, (ii) caring about school performance, and (iii) completing required homework. These indicators are closely related to academic engagement (Chaput et al., 2014; Ghasemi et al., 2018; Tremblay et al., 2016). The following three single-item questions were used to measure these three indicators: How often does this child (a) show interest and curiosity in learning new things, (b) care about doing well in school, and (c) complete all required homework? There were four response options for each single-item question, with possible responses ranging from 1 (always) to 4 (never). Frequency response scores were reversed, with higher scores indicating greater levels of school engagement.

Psychological functioning refers to the overall mental and emotional well-being and performance of an individual. It encompasses various aspects, including emotional regulation, social interactions, and adaptive behaviors (Burke et al., 2015). In this study, two indicators (resilience and self-regulation indicator) were selected for operationalization. The following two single-item questions were used to measure each indicator: How often does this child (a) work to finish tasks he/she starts, and (b) stay calm and in control when faced with a challenge? Each single-item question is scored on 4 different response levels, with 1 (always) to 4 (never). Frequency response scores were reversed, with higher scores indicating better emotional functioning.

Cognitive difficulties were collected from parents using the following single-item question (Taylor et al., 2023), using this term to explore cognitive function: Does this child have serious difficulty concentrating, remembering, or making decisions because of a physical, mental, or emotional condition? A binary response is provided and coded as 0 = no or 1 = yes.

Statistical analysis

Statistical analyses in this study were performed using Stata (StataCorp., College Station, TX, USA). A new variable, STRATACROSS, was created by combining the state of residence variance (FIPSST), the identification for households marked with children (STRATUM), and the individual household identifier to enable the application of sampling weights. Subpopulations were identified using the survey data option in Stata for youth diagnosed with internalizing problems. Descriptive statistics were computed for all variables. Continuous variables were described by means and standard deviations. Categorical variables were described using unweighted sample counts and weighted (wt) percentages. Multivariable logistic regressions were used to estimate the odds ratios (OR), with 95% confidence intervals (95% CI), between meeting24-HMB guidelines (in both categorical and continuous analyses) and school engagement (e.g., learning interest/curiosity, caring about school performance, completing required homework), psychological functioning (resilience and self-regulation), and cognitive difficulties. The number of meeting 24-HMB guidelines (continuous variables) and the combinations of meeting specific 24-HMB guidelines (categorical variables) were treated separately as independent variables in the models. Age, sex, ethnicity, household poverty level, the highest level of education of primary caregivers, overweight status, adverse childhood experiences, mental health status of mother, mental health status of father, and received mental health care status were used as covariates. For all statistical tests, the significance level was set at $\alpha \leq 0.05$.

Results

Sample characteristics

Caregiver's responses included a to a total of 1794 children and adolescents (weighted sample size = 1,027,814) with internalizing problems (anxiety and depression) aged 6 to 17 years, from the 93,669 US households, with complete data on all assessed variables. Mean age of the cohort was 14.19 ± 2.90 years, 59.36% of the youth were male, and 61.91% were White. In addition, 20.75% of the included youth were classified as overweight. A relatively small proportion of youth (8.62%) lived in

households between 0% and 99% of the federal poverty level (The people on 0% - 99% of the federal poverty level have an income below the poverty threshold and qualify for welfare programs), and only a small proportion of the primary caregivers of the youth (2.34%) reported that they had not completed high school. The majority of youth (69.95%) have experienced at least one adverse childhood experience. Most of the caregivers reported no diagnosis of maternal (81.82%) or paternal (85.44%) mental health problems. Only 21.21% of the youth with internalizing problems received mental health care (Table 1).

Meeting 24-HMB guidelines

In the total sample of the current study, 37.22% (n = 575) did not meet any of 24-HMB guidelines. Almost half of the youth (n = 901, (wt) % = 45.88) met only one 24-HMB guidelines. The most frequently met single guideline was the sleep guideline (n = 725, wt% = 35.50), while the least frequently met guidelines was PA guideline (n = 34, wt% = 2.88). Moreover, 15.74% (n = 284) of the youth met two of the three 24-HMB guidelines, with the majority meeting sleep + ST guideline (n = 209, wt% = 11.86). A small proportion of the sample (1.17%, n = 34) met all three 24-HMB guidelines. Results on meeting 24-HMB guidelines are displayed in Figure 1 and Table 1.

Association between meeting 24-HMB guidelines and academic engagement

Table 2 shows the associations between meeting 24-HMB guidelines and learning interest/curiosity. As a continuous variable, the number of meeting 24-HMB guidelines (OR = 1.43, 95% CI: 1.11-1.85, $p < 0.01$) was positively associated with learning interest/curiosity. The odds of showing learning interest/curiosity for those who met PA + sleep guidelines (OR = 3.07, 95% CI: 1.25-7.61, $p < 0.05$), or for those who met all three 24-HMB guidelines (OR = 7.56, 95% CI: 2.68-21.30, $p < 0.01$) were significantly higher than those for peers who did not meet any of 24-HMB guidelines.

Table 3 shows the associations between meeting 24-HMB guidelines and caring about school performance. As a continuous variable, the number of meeting 24-HMB guidelines (OR = 1.39, 95% CI: 1.10-1.76, $p < 0.01$) were positively linked to caring for school performance. Compared with meeting none of 24-HMB guidelines, meeting PA guideline alone (OR = 5.38, 95% CI:1.78-16.26, p

< 0.01) or ST + sleep guidelines (OR = 2.07, 95% CI: 1.07-3.99, p < 0.05), or all three 24-HMB guidelines (OR = 5.11, 95% CI:1.66-15.74, p < 0.01) was associated with a higher likelihood of worrying about school performance.

Table 4 shows the associations between meeting 24-HMB guidelines and completing required homework. As a continuous variable, the number of meeting 24-HMB (OR = 1.38, 95% CI: 1.11-1.70, p < 0.01) was positively linked to completing required homework. Compared with meeting none of 24-HMB guidelines, meeting ST guideline alone (OR =1.78, 95% CI: 1.06-3.03, p < 0.05), or ST + sleep guidelines (OR = 2.44, 95% CI: 1.48-4.01, p < 0.01) was associated with a higher likelihood of completing required homework.

Association between meeting 24-HMB guidelines and psychological functioning

Table 5 shows the associations between meeting 24-HMB guidelines and resilience. As continuous variable, the number of meeting 24-HMB guidelines (OR = 1.31, 95% CI: 1.05-1.63, p < 0.01) was positively linked to resilience. Compared with meeting none of 24-HMB guidelines, meeting ST guideline alone (OR = 2.12, 95% CI: 1.18-3.83, p < 0.05) or PA alone (OR = 6.43, 95% CI: 2.90-14.24, p < 0.01), ST + sleep guidelines (OR = 1.87, 95% CI: 1.06-3.31, p < 0.05), or all three 24-HMB guidelines increased the odds of resilience (OR = 2.62, 95% CI: 1.15-5.98, p < 0.05).

Table 6 shows the associations between meeting 24-HMB guidelines and self-regulation. As continuous variable, the number of meeting 24-HMB guidelines (OR = 1.41, 95% CI:1.09-1.84, p < 0.01) was positively linked to self-regulation. Compared with meeting none of 24-HMB guidelines, meeting ST + sleep guidelines (OR = 2.69, 95% CI: 1.46-4.96, p < 0.01), or all three 24-HMB guidelines (OR = 3.65, 95% CI: 1.51 -8.87, p < 0.01) increased the odds of having higher self-regulation.

Association between meeting 24-HMB guidelines and cognitive difficulties

Table 7 shows the associations between meeting 24-HMB guidelines and cognitive difficulties. As continuous variable, there was no significant association between the number of meeting 24-HMB guidelines and this outcome. Compared with meeting none of 24-HMB guidelines, meeting ST + sleep guidelines was associated with lower odds of cognitive difficulties (OR = 0.55, 95% CI: 0.32-0.96, $p < 0.05$).

Discussion

This cross-sectional study investigated the associations between meeting 24-HMB guidelines and academic engagement, psychological functioning, and cognitive difficulties in a nationally representative sample of U.S. youth aged 6 to 17 years with internalizing problems (anxiety/depression). Significant associations were observed between meeting specific guidelines of 24-HMB guidelines and our outcomes of interest (see Figure 2 for an overview). Considering the evidence that meeting 24-HMB guidelines is associated with health benefits, our findings emphasize the need to support children and adolescents with internalizing problems and their caregivers to foster their ability to adopt a healthy lifestyle (i.e., to meet the 24-HMB guidelines on PA, ST, and sleep).

Meeting 24-HMB guidelines

In this study, nearly half of the youth with internalizing problems met at least one of 24-HMB guidelines (45.88%), whereas only a small proportion of them met two (15.74%), or all three 24-HMB guidelines (1.17%). Such findings are consistent with previous studies on children and adolescents with neurodevelopmental conditions such as autism spectrum disorder (Kong et al., 2023), attention deficit/hyperactive disorder (Taylor et al., 2023), and epilepsy (Brown & Ronen, 2021). Overall, the majority of youth with internalizing problems did not meet the evidence-based lifestyle guidelines outlined in the 24-HMB guidelines. Given the evidence supporting that meeting 24-HMB guidelines is associated with health benefits (Rollo et al., 2020), the findings of the current study clearly emphasize the need to support and promote healthy lifestyles in youth with internalizing problems.

Association between meeting 24-HMB guidelines and academic engagement

Learning interest/curiosity plays a critical role in school engagement, which is a strong predictor of academic performance (Jimerson et al., 2003). The number of meeting 24-HMB guidelines was linked to better academic engagement. This finding is supported by previous studies on exercise-cognition showing that PA (including planned and structured forms of PA such as physical exercise) and physical fitness are known to be important factors that can foster a better brain development (Belcher et al., 2021; Erickson et al., 2019; Hillman et al., 2020; L. Zou et al., 2023). In addition, there is growing evidence that limiting leisure ST can promote children's academic performance, as children have more time to focus on learning tasks, improve school engagement, which, in turn, might contribute to a better academic performance (Adelantado-Renau et al., 2019). In addition, an adequate sleep duration is a critical factor required for brain development. In particular, a meta-analysis indicates a significant negative effect of sleep deprivation on cognitive processing across cognitive domains including executive function, sustained attention, and long-term memory (Lowe et al., 2017), which may lead to a lower level of academic engagement in children and adolescents with internalizing problems.

As a categorical variable, meeting PA + sleep guidelines, or all three 24-HMB guidelines was related to a higher level of learning interest. This finding is in line with the observation of a previous study focusing on youth with autism spectrum disorder (Kong et al., 2023) showing that meeting 24-HMB guidelines was beneficially linked to learning interest/curiosity and less repeating grade. Furthermore, Ghasemi et al. (2018) found that good sleep and adequate PA were beneficial for children development, including children's curiosity about new things. In the current study, youth who adhered to PA guideline alone, ST + sleep guidelines, or PA + sleep + ST guidelines were more likely to care about school performance, reflecting better academic engagement. Consistent with the findings of a systematic review (Kandasamy et al., 2018), these results provide evidence for the idea that promoting PA may be an important approach to improving school engagement. In this regard, another study found that meeting ST + sleep guidelines was associated with better writing performance, an activity that requires active engagement in academic work (Owen et al., 2016). In this study, youth who met the guidelines for ST only and ST + sleep were more likely to complete required homework. These findings are at least partially mirror those of a study by Faught et al. (2017), who found that children aged 5-12 years who met ST guideline alone had higher average academic indices, including higher math and English

scores. There is also evidence from other studies that meeting ST + sleep guidelines is associated with higher academic achievement in youth (Howie et al., 2020; Marciano & Camerini, 2021). Thus, our findings, in conjunction with the available evidence in the literature, suggest that ST within reasonable limits allows for better academic engagement (e.g., by enable children and adolescents with internalizing problems to spend sufficient amount of time to complete assigned homework tasks).

Association between meeting 24-HMB guidelines and psychological functioning

As a continuous variable, a higher number of meeting 24-HMB guidelines is associated with better psychological functioning (resilience and self-regulation). This observation is consistent with evidence that PA interventions can increase resilience, and improve self-perceptions in children and youth (Dale et al., 2019), which, in turn, can promote better mental health in children and adolescents (Andermo et al., 2020). In addition, given that the different movement behaviors are mutually exclusive, reducing recreational ST can help children to engage in PA and increase interactions with family and friends, which can improve social skills and psychological functioning (Braig et al., 2018). In addition to PA and ST, sleep also plays a critical role in emotional regulation, as adequate sleep can reduce the risk of depression and improve youth's ability to cope with stress, which is critical for strengthening psychological functioning in this age group (Alfano et al., 2009).

As a categorical variable, different combinations including meeting only PA, ST, ST + sleep, and all three components of the 24-HMB guidelines are associated with better resilience. This observation further supports the notion that meeting the 24-HMB guidelines may be beneficial in promoting resilience in children and adolescents with internalizing problems. Moreover, this finding is consistent with the observations from other studies. For example, Lissak (2018) found that PA and self-perceived resilience were significantly and positively associated among individuals with high trait anxiety. Faught et al. (2017) found that excessive digital media use by children and adolescents appears to be a major factor that hinder the development of healthy psychophysiological resilience. Furthermore, Hegberg and Tone (2015) found that increased screen use may exacerbate emotional/behavioral difficulties by interfering with sleep quantity and quality. Based on the above-mentioned findings, it seems reasonable to speculate that reallocating leisure ST to other activities (e.g., PA) and limiting ST may be an important step in promoting mental health in children and adolescents with internalizing

problems, although future longitudinal research is needed to empirically support this assumption.

In addition, this study showed meeting ST guideline alone, ST + sleep guidelines, or all three 24-HMB guidelines can predict increased self-regulation in children and adolescents with internalizing problems. Self-regulation is an essential psychological process that primarily involves the ability to regulate internal states or responses related to thoughts, attention, emotions, and even performance components (Lin et al., 2019). Self-regulation is important for the overall development and well-being of children and adolescents with internalizing problems (Robson et al., 2020). Moreover, Vohs and Baumeister (2016) observed that excessive screen exposure is associated with delayed sleep onset and poor self-regulation skills in preschool children. Inadequate sleep and excessive media screen exposure are both associated with poorer mental health and more conduct problems in adolescents (ÖZDEMİR & KELEŞ, 2023). Based on the findings of this study, we advocate for a multi-pronged approach to enhance self-regulation in children and adolescents with internalizing problems. This would likely involve a combination of PA promotion (to reduce sedentary time), working with parents on strategies to curb ST, especially before bedtime (e.g., to prevent sleep disruption and foster good sleep habits), providing self-regulation training through mindfulness and cognitive-behavioral strategies, and integrating health education about these interconnected factors into school curriculums. Together, from a theoretical point of view，these lifestyle intervention strategies constitute a promising option to improve self-regulation and overall mental well-being in this population, and thus we recommend to empirically evaluate their effectiveness in future studies.

Association between 24-HMB guidelines adherence and cognitive difficulties

Our finding that there is no evidence of a significant association between the number of met 24-HMB guidelines and parent-reported cognitive difficulties is somewhat surprising. This finding may be related to the facts that (i) only a relatively small sample size was used in this study and (ii) the measurement of cognitive difficulties is based solely on parent reports without the use of standardized cognitive assessments (e.g., a neuropsychological test battery) which may limited this study's ability to detect statistically significant associations. However, using the number of met 24-HMB guidelines as a categorical variable, ST + sleep guidelines is associated with better cognitive performance, which mirrors the findings of a previous study of our group showing a comparable association in children

and adolescents with attention deficit/hyperactive disorder (Taylor et al., 2023). In addition, observation is also consisted with the results of a cross-sectional analysis of U.S. children aged between 8 to 11 years that reported that participants who met ST + sleep guidelines, performed better on psychometric tasks assessing global cognition (Walsh et al., 2018).

Strengths and Limitations

Our current study has the following strengths: First, our sample consist of information on 1794 children and adolescents obtained from a nationally representative dataset on U.S. youth that was derived from the 93669 households who provided full responses to the nationwide collection of the NSCH 2020 survey. Second, our study provides a holistic understanding of how daily movement behaviors practically influence relevant outcomes of academic engagement, psychological functioning, cognitive difficulty of children and adolescents with internalizing problems. However, some limitations should be considered when interpreting the findings of the current study. First, the cross-sectional design limits the ability to establish causal relationships between meeting specific 24-HMB guidelines and measures of mental and academic performance in children and adolescents with internalizing problems. Thus, future investigations are warranted to establish directionality and causality (e.g., randomized controlled trials investigating the influence of modifying PA, ST, or sleep patterns in children and adolescents with internalizing problems). Second, proxy-reported data provided by a parent/caregiver may be subject to various types of bias (Marciano & Camerini, 2021). For example, social desirability bias could influence parents' reports of their children's internalizing problems and lifestyle-related behaviors (Walsh et al., 2018). This bias could lead to underreporting of behaviors or diagnoses that are perceived as unfavorable. Therefore, future research in this direction should aim to use more comprehensive and objective measures. Third, the use of a caregiver-based questionnaire to assess whether children or adolescents met the 24-HMB guidelines lacks more detailed information on the single components of PA, ST, and sleep (e.g., frequency and types of PA, content of screen viewing, and sleep quality). Therefore, future studies would benefit from combining self-report instruments with more objective device-based tools such as accelerometers (Sigmundová et al., 2016), to minimize potential bias and improve accuracy of collecting data on movement behaviors in ecological valid settings (e.g., via ambulatory assessments)(Biddle et al., 2018; Biddle et al., 2019; Dumuid et al., 2020; Janssen et al., 2020; Murray et al., 2023).

Conclusions

The current study provides evidence that in children and adolescents with internalizing problems, (i) a low number of them meets the 24-HMB guidelines, (ii) those who meet more guidelines of the 24-HMB recommendations have better academic performance and psychological functioning, and (iii) ST is an important factor influencing measures of mental health and academic performance. Accordingly, these findings suggest that promoting the 24-HMB guidelines in children and adolescents with internalizing problems and their caregivers may be an effective approach to improving health and well-being of children and adolescents with internalizing problems. In this regard, future longitudinal studies are needed to examine how the changes or the modification of meeting specific 24-HMB guidelines (especially ST) may influence the mental health and academic performance of children and adolescents with internalizing problems. In addition, the findings of the current study are valuable to inform physical and mental health promotion programs for children and adolescents with internalizing problems because our findings providing initial evidence that meeting of 24-HMB guidelines is associated with specific health benefits in this special population.

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Authors’ contributions

Yanping Gao analyzed the data and wrote the manuscript drafts; All the co-authors read and critically revised manuscript drafts. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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827 Table 1. Characteristics of the children and adolescents with internalizing problems included in the
828 sample of the current study (n = 1794)

Characteristics	Value[a]
Age (year) (M±SD)	14.19 ± 2.90
Sex	
Male (n, %)	708 (40.65%)
Female (n, %)	1086 (59.36%)
Ethnicity	
White (n, %)	1370 (61.91%)
Hispanic (n, %)	200 (25.19%)
Black (n, %)	46 (4.80%)
Asian (n, %)	38 (1.00%)
Other/Multi-racial (n, %)	140 (7.09%)
Household poverty level	
≤ 0%-99% federal poverty level (n, %)	149 (8.62%)
≥ 100% federal poverty level (n, %)	1645 (91.4%)
Highest education level of primary caregivers	
Less than high school (n, %)	18 (2.34%)
High school (n, %)	199 (18.87%)
Some college credit or associated degree (AA, AS) (n, %)	437 (22.83%)
College degree or higher (n, %)	1140 (55.96%)
Overweight	
Yes (n, %)	1457 (79.26%)
No (n, %)	337 (20.75%)
Children experienced one or more ACEs	
No (n, %)	635 (30.05%)
One (n, %)	451 (29.09%)
Two or more (n, %)	708 (40.86%)
Mental health status of mother	
Fair or poor (n, %)	300 (18.18%)
Good (n, %)	646 (34.76%)
Excellent or very good (n, %)	848 (47.06%)
Mental health status of father (n, %)	
Fair or poor (n, %)	226 (14.56%)
Good (n, %)	553 (31.39%)
Excellent or very good (n, %)	1015 (54.05%)
Received mental health care status	
No (n, %)	343 (21.21%)
Yes (n, %)	1451 (78.79%)
Adherence to the 24-HMB guidelines	
None (n, %)	575 (37.22%)
Meeting 1 out of 3 (n, %)	901 (45.88%)
Physical activity (n, %)	34 (2.88%)
Screen time (n, %)	142 (7.50%)

Sleep (n, %)	725 (35.50%)
Meeting 2 out of 3 (n, %)	284 (15.74%)
Physical activity + Screen time (n, %)	23 (1.72%)
Physical activity + Sleep (n, %)	52 (2.15%)
Screen time + Sleep (n, %)	209 (11.86%)
All (n, %)	34 (1.17%）
Learning interest/curiosity	
Always (n, %)	386 (21.93%)
Usually (n, %)	659 (31.62%)
Sometimes (n, %)	680 (41.67%)
Never (n, %)	69 (3.79%)
Caring about school performance	
Always (n, %)	549 (28.31%)
Usually (n, %)	569 (34.65%)
Sometimes (n, %)	522 (31.56%)
Never (n, %)	154 (5.48%)
Completing required homework	
Always (n, %)	422 (21.26%)
Usually (n, %)	639 (37.93%)
Sometimes (n, %)	572 (34.14%)
Never (n, %)	161 (6.67%)
Resilience	
Always (n, %)	201 (11.42%)
Usually (n, %)	694 (36.01%)
Sometimes (n, %)	812 (47.28%)
Never (n, %)	87 (5.30%)
Self-regulation	
Always (n, %)	72 (3.90%)
Usually (n, %)	517 (25.10%)
Sometimes (n, %)	994 (58.36%)
Never (n, %)	211 (12.64%)
Difficulty concentrating, remembering, or making decisions	
Yes (n, %)	887 (50.11%)
No (n, %)	907 (49.89%)

[a] Values are mean ± SD or n (weighted [wt]%); n represents unweighted sample counts, and wt% is weighted sample sizes. Abbreviations: 24-HMB = Canadian 24-Hour Movement and Behavior guidelines. AA = associate in arts; AS = associate in science

Table 2. Associations between the met 24-HMB guidelines and learning interest / curiosity

Learning interest / curiosity	24-HMB guideline adherence as continuous variable		24-HMB guideline adherence as categorical variable	
	Odds Ratio	*p*	Odds Ratio	*p*

	(95% CI)		(95% CI)	
Adherence to 24-HMB (continuous)	1.43 (1.11 -1.85)	0.006**	—	—
Adherence to 24-HMB (categorical)				
None (reference)	1 (reference)	N/A	1 (reference)	N/A
Physical activity	—	—	3.57 (0.92-13.80)	0.07
Screen time	—	—	1.47 (0.78-2.79)	0.23
Sleep	—	—	1.33 (0.90-1.96)	0.16
Physical activity + Screen time	—	—	1.34 (0.25-7.05)	0.73
Physical activity + Sleep	—	—	3.07 (1.25-7.61)	0.001**
Screen time + Sleep	—	—	1.74 (0.87-3.45)	0.12
All	—	—	7.56 (2.68-21.30)	<0.001**
Probability > F[a]	< 0.001		< 0.001	

[a] Means overall model F statistic. * $p < 0.05$; ** $p < 0.01$. Abbreviation: 95% CI = 95% confidence interval; 24-HMB = 24-hour movement behavior; N/A = Not applicable.

Table 3. Associations between met 24-HMB guidelines and caring about school performance

caring about school performance	Met 24-HMB guidelines as continuous variable		Met 24-HMB guidelines as categorical variable	
	Odds Ratio (95% CI)	*p*	Odds Ratio (95% CI)	*p*
Met 24-HMB guidelines (continuous)	1.39 (1.10 -1.76)	0.006**	—	—
Met 24-HMB guidelines (categorical)				
None (reference)	1 (reference)	N/A	1 (reference)	N/A
Physical activity	—	—	5.38 (1.78-16.26)	0.003**
Screen time	—	—	1.37 (0.79 -2.37)	0.26
Sleep	—	—	0.95 (0.64 -1.40)	0.79
Physical activity + Screen time	—	—	1.79 (0.99 -3.21)	0.05
Physical activity + Sleep	—	—	2.02 (0.71 -5.75)	0.19
Screen time + Sleep	—	—	2.07 (1.07 -3.99)	0.030*
All	—	—	5.11 (1.66-15.74)	0.005**
Probability > F[a]	< 0.001		< 0.001	

[a] Means overall model F statistic. * $p < 0.05$; ** $p < 0.01$. Abbreviation: 95% CI = 95% confidence interval; 24-HMB = 24-hour movement behavior; N/A = Not applicable.

Table 4. Associations between met 24-HMB guidelines and completing required homework.

Completing required homework	Met 24-HMB guidelines as continuous variable		Met 24-HMB guidelines as categorical variable	
	Odds Ratio (95% CI)	*p*	Odds Ratio (95% CI)	*p*
Met 24-HMB guidelines	1.38 (1.11 -1.70)	0.003**	—	—

(continuous)				
Met 24-HMB guidelines (categorical)				
None (reference)	1 (reference)	N/A	1 (reference)	N/A
Physical activity	—	—	1.69 (0.68 -4.24)	0.26
Screen time	—	—	1.78 (1.06 -3.03)	0.030*
Sleep	—	—	1.18 (0.77 -1.77)	0.44
Physical activity + Screen time	—	—	1.25 (0.34 -4.62)	0.74
Physical activity + Sleep	—	—	1.05 (0.35 -3.14)	0.93
Screen time + Sleep	—	—	2.44 (1.48 -4.01)	<0.001**
All	—	—	1.85 (0.77 -4.45)	0.17
Probability > F[a]	< 0.001		< 0.001	

[a] Means overall model F statistic. * $p < 0.05$; ** $p < 0.01$. Abbreviation: 95% CI = 95% confidence interval; 24-HMB = 24-hour movement behavior; N/A = Not applicable.

Table 5. Associations between met 24-HMB guidelines and resilience.

Resilience	Met 24-HMB guidelines as continuous variable		Met 24-HMB guidelines as categorical variable	
	Odds Ratio (95% CI)	*p*	Odds Ratio (95% CI)	*p*
Met 24-HMB guidelines(continuous)	1.31 (1.05 -1.63)	0.018*	—	—
Met 24-HMB guidelines (categorical)				
None (reference)	1 (reference)	N/A	1 (reference)	N/A
Physical activity	—	—	6.43 (2.90-14.24)	<0.001**
Screen time	—	—	2.12 (1.18 -3.83)	0.012*
Sleep	—	—	1.26 (0.84 -1.90)	0.27
Physical activity + Screen time	—	—	0.98 (0.20 -4.90)	0.98
Physical activity + Sleep	—	—	0.76 (0.22 -2.64)	0.67
Screen time + Sleep	—	—	1.87 (1.06 -3.31)	0.032*
All	—	—	2.62 (1.15 -5.98)	0.022*
Probability > F[a]	< 0.001		< 0.001	

[a] Means overall model F statistic. * $p < 0.05$; ** $p < 0.01$. Abbreviation: 95% CI = 95% confidence interval; 24-HMB = 24-hour movement behavior; N/A = Not applicable.

Table 6. Associations between met 24-HMB guidelines and self-regulation.

Self-regulation	Met 24-HMB guidelines as continuous variable		Met 24-HMB guidelines as categorical variable	
	Odds Ratio (95% CI)	*p*	Odds Ratio (95% CI)	*p*
Met 24-HMB guidelines (continuous)	1.41 (1.09 -1.84)	0.009**	—	—

Met 24-HMB guidelines (categorical)				
None (reference)	1 (reference)	N/A	1 (reference)	N/A
Physical activity	—	—	1.12 (0.58 -2.15)	0.74
Screen time	—	—	1.70 (0.97 -2.99)	0.06
Sleep	—	—	1.25 (0.83 -1.88)	0.28
Physical activity + Screen time	—	—	0.29 (0.03 -2.62)	0.27
Physical activity + Sleep	—	—	1.56 (0.67 -3.65)	0.30
Screen time + Sleep	—	—	2.69 (1.46 -4.96)	0.002**
All	—	—	3.65 (1.51 -8.87)	0.004**
Probability > F[a]	< 0.001		< 0.001	

[a] Means overall model F statistic. * $p < 0.05$; ** $p < 0.01$. Abbreviation: 95% CI = 95% confidence interval; 24-HMB = 24-hour movement behavior; N/A = Not applicable.

Table 7. Associations between met 24-HMB guidelines and cognitive difficulties.

Cognitive difficulties	Met 24-HMB guidelines as continuous variable		Met 24-HMB guidelines as categorical variable	
	Odds Ratio (95% CI)	*p*	Odds Ratio (95% CI)	*p*
Met 24-HMB guidelines (continuous)	0.92 (0.73 -1.18)	0.52	—	—
Met 24-HMB guidelines (categorical)				
None (reference)	1 (reference)	N/A	1 (reference)	N/A
Physical activity	—	—	1.76 (0.55 -5.65)	0.35
Screen time	—	—	0.63 (0.33 -1.21)	0.17
Sleep	—	—	1.06 (0.69 -1.66)	0.77
Physical activity + Screen time	—	—	2.16 (0.25-18.88)	0.49
Physical activity + Sleep	—	—	1.80 (0.60 -5.36)	0.29
Screen time + Sleep	—	—	0.55 (0.32 -0.96)	0.035*
All	—	—	1.30 (0.55 -3.03)	0.55
Probability > F[a]	< 0.001		< 0.001	

[a] Means overall model F statistic. * $p < 0.05$; ** $p < 0.01$. Abbreviation: 95% CI = 95% confidence interval; 24-HMB = 24-hour movement behavior; N/A = Not applicable.

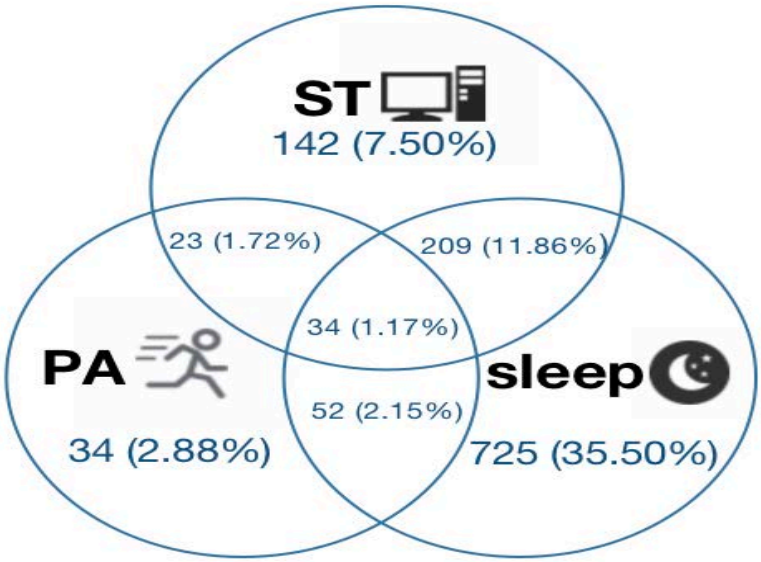

Figure 1：Venn diagram showing proportions of participants meeting 24-HMB guidelines. Values are n (wt%), N represents unweighted sample counts and wt% is weighted sample sizes. PA = physical activity; ST = screen time. PS: 575 (37.22%) met none of the 24-HMB guidelines

Dependent variable / Independent variable	Academic engagement			Psychological functioning		Cognition difficulties
	Learning interest/ curiosity	Caring about school per-formance	completing required homework	Resilience	Self-regulation	difficulties concentra-ting, re-membering or making decisions
Met 24-HMB components (0-3)	+	+	+	+	+	ns
PA	+	ns	ns	+	ns	ns
ST	ns	ns	+	+	+	ns
sleep	ns	ns	ns	ns	ns	ns
PA + ST	ns	ns	ns	ns	ns	-
PA + sleep	+	ns	ns	ns	ns	ns
ST + sleep	ns	+	+	+	+	ns
PA + ST + sleep	+	+	ns	+	+	ns

Figure 2：Associations of meeting 24-h movement behavior guidelines with academic engagement，psychological and cognitive function among children and adolescents with internalizing problems "ns" represents no significant "+" represents a positive correlation, "-" represents a negative correlation.