Understanding 24-Hour Movement Guideline Adherence and Links to School Achievement, Social-Behavioural Problems, and Emotional Functioning Among Children and Adolescents with Learning Disabilities

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Abstract
This cross-sectional study examined the associations between adherence to 24-hour movement behaviour (24-HMB) guidelines and indicators of school achievement, social-behavioural problems, and emotional functioning among a nationally representative sample of US children and adolescents with learning disabilities (LD). Data were retrieved from the 2020–2021 National Survey of Children's Health (NSCH), including 4999 children and adolescents (aged between 6 and 17 years) with LD. Multivariate logistic regressions were conducted to estimate odds ratios (OR) with 95% confidence intervals (95%CI), adherence to 24-HMB guidelines was considered as independent variables (Model 1: continuous variable; Model 2: categorical variable), and indicators of school achievement, social-behavioural problems, and emotional functioning as dependent variables. Covariates included age, sex, race, overweight status, the severity of learning disability, educational intervention, parental education, and household poverty level. Overall, 2156 participants (41.47%) met one of the three 24-HMB recommendations, 1289 (26.04%) met two 24-HMB recommendations, and 336 participants (6.62%) met all three 24-HMB recommendations. Positive associations between adherence to 24-HMB guidelines and most of the assessed outcomes were observed. Those who adhered to at least two of the three 24-HMB guidelines (PA + SL, PA + ST, SL + ST, and PA + SL + ST)

Keywords: 24-hour movement behaviour; learning disabilities; school achievement; social-behavioural problems；emotional functioning

Introduction

Learning disabilities (LD) cover a heterogeneous group of academic skill disorders (e.g. difficulties in oral expression, listening comprehension, written expression) (Grigorenko et al., 2020). About 1 of 5 children are diagnosed with LD (Horowitz, 2017), so that nearly 2.7 million US children are affected by this disorder (Altarac & Saroha, 2007). Generally, children and adolescents with LD experience difficulties across multiple domains including on-task behaviour, off-task behaviour, distractibility, and withdrawn behaviour in the classroom setting (Bender & Smith, 1990; Horowitz et al., 2017). Thus, children with LD tend to be retained in their academic year-levels compared to their non-LD peers which can negatively impact their long-term academic development. Additionally, children and adolescents with LD are at a higher risk of experiencing social, behavioural, and emotional challenges as compared to their peers without LD (Horowitz et al., 2017). For instance, adolescents with LD reported a significantly higher rate (about 25%) of bullying victimisation in relation to their age-matched peers and they perceived a lower level of happiness (Lung et al., 2019). Likewise, children with LD showed more pronounced bullying behaviours (Twyman et al., 2010). Notably, children and adolescents with LD frequently encountered a sense of failure, rejection from their peers, and high levels of bullying victimisation, leading to an increased likelihood of misbehaviour and absenteeism (Horowitz et al., 2017). Previous studies have shown an association of LD with emotional dysfunctions, including increased levels of anxiety (Nelson & Harwood, 2011) and depression (Maag & Reid, 2006). Such emotional problems can be at least partly attributed to relatively low psychological resilience which is reported in 75% of the children and adolescents with LD (Herrman et al., 2011; Panicker & Chelliah, 2016).

To promote development in school and later in life, early interventions that decrease the negative effects of LD on academic achievement, social-behavioural problems, and emotional functioning are required. Various types of special or individualised education programmes have been designed for individuals with LD in order to help them to acquire specific skills by building on their strengths and developing approaches to compensate for their weaknesses (Center for Parent Information and Resources, 2022; Individuals with Disabilities Education Act; International Dyslexia Association; Learning Disabilities Association of America; National Institute of Neurological Disorders and Stroke, 2023; The Understood Team). Complementing those efforts, researchers have also recommended that children and adolescents with LD should maintain healthy lifestyle behaviours, because a higher level of physical activity (PA) is positively associated with learning success (Demirci et al., 2012; McKenzie et al., 2018; Padma Kumari & Raj, 2016). Bluechardt and Shephard (1995) found that a PA intervention programme improved social skills (as operationalised by measures of cooperation, tolerance of others' activities, and a decrease in conflict frequency) in children and adolescents with LD (Bluechardt & Shephard, 1995). Given that healthy lifestyles including relatively high levels of PA positively influences academic performance and social skills of LD children and adolescents, future investigations on associations between different lifestyle behaviours (e.g., PA, screen time[ST], and sleep) and specific outcomes of interest such as academic performance, behavioural problems, and emotional functions are necessary. The evidence gained by such investigations can help to develop more cost-effective, and evidence based interventions for children and adolescents with LD.

In recent years, a holistic view of different movement behaviours including PA, sedentary behaviours (referring to ST in school-aged children and adolescents), and sleep duration (SL) has emerged in the scientific literature (also referred to as 24-HMB) (da Costa et al., 2022; Lee et al., 2023; Paterson et al., 2021; Tapia-Serrano et al., 2022; Tremblay et al., 2016). The new 24-HMB framework has been increasingly used to investigate the influence of adhering to specific lifestyle recommendations on various types of health outcomes across different age groups and health states (Alanazi et al., 2021; Rollo et al., 2020; Saunders et al., 2016). In particular, there is growing empirical evidence that youths with and without neurodevelopmental conditions (e.g., Autism spectrum disorder [ASD] and Attention deficit hyperactivity disorder [ADHD]) who adhered to 24-HMB guidelines had superior academic and cognitive performance (Cliff et al., 2017; Kong et al., 2023; Liu et al., 2021; Tapia-Serrano et al., 2022; Taylor et al., 2023; Walsh et al., 2018; Watson et al., 2022), lower levels of behavioural problems (Carson et al., 2019; Fung et al., 2023; Kong et al., 2023; Taylor et al., 2023), and better emotional functioning (Sampasa-Kanyinga et al., 2021). However, no study has yet utilised 24-HMB framework to investigate whether adherence to 24-HMB recommendations in children and adolescents with LD is associated with better academic, social, and emotional outcomes. While previous studies provided evidence for beneficial effects of PA engagement on selected aspects (i.e., learning success) of school achievement and social skills among children and adolescents with LD (Bluechardt & Shephard, 1995; Demirci et al., 2012), for a more comprehensive understanding of the influence of movement behaviours it is necessary to investigate the combined effects of 24-HMB guideline adherence on the above-mentioned outcomes among this group.
Given that (a) children and adolescents with LD often do not reach a sufficient level of PA (Hallawell et al., 2012), spend a considerable amount of their waking hours in sedentary behaviours (Cook et al., 2015; Hallawell et al., 2012), and report sleep disturbances (Wiggs, 2012) and (b) meeting 24-HMB recommendations might have synergistic effects on indicators of school achievement, social-behavioural problems, and emotional functioning in children and adolescents with LD, investigation into the associations between the adherence to 24-HMB guideline and above-mentioned outcomes is an important starting point to develop more effective and evidence-based intervention approaches for children and adolescents with LD. Based on our previous studies (Kong et al., 2023; Taylor et al., 2023; Zhao et al., 2023), we hypothesise that adherence to 24HMB recommendations is associated with better performance in school achievement, social-behavioural problems, and emotional functioning indicators (i.e., considering important covariates such as demographic, socioeconomic status and other factors including child's age, sex, ethnicity, overweight status, the severity of learning disability, educational intervention, parental education and household poverty level).

Method

Study population

In this cross-sectional study (Figure 1), data were retrieved from the 2020–2021 National Survey of Children's Health (NSCH). The study protocol is comparable to previous studies (Fanxing et al., 2023; Hou et al., 2023; Kong et al., 2023; Pan et al., 2023; Taylor et al., 2023) and is available at: www.childhealthdata.org. Of note, this is a combined dataset (accumulated number for two years: 93699) including data from 42,777 surveys administered in 2020 and 50,892 survey administered in 2021, with a relatively similar weighted response rate (Year 2020 = 42.4% and Year 2021 = 40.3%). We selected a

sample of children and adolescents aged between 6 and 17 years who were diagnosed with LD (N = 5,470). In this study, LD was determined if their parent answered affirmatively to the following two consecutive questions: (a) “Has a doctor, other health care provider, or educator ever told you that this child has a learning disability?” and (b) “If yes, does this child currently have the condition?”.

Demographic information and independent variables

We extracted data concerning adherence to 24-HMB recommendations and sociodemographic information including child’s age, sex, race/ethnicity, overweight status, the severity of learning disability, educational intervention, family characteristics, including parental data.

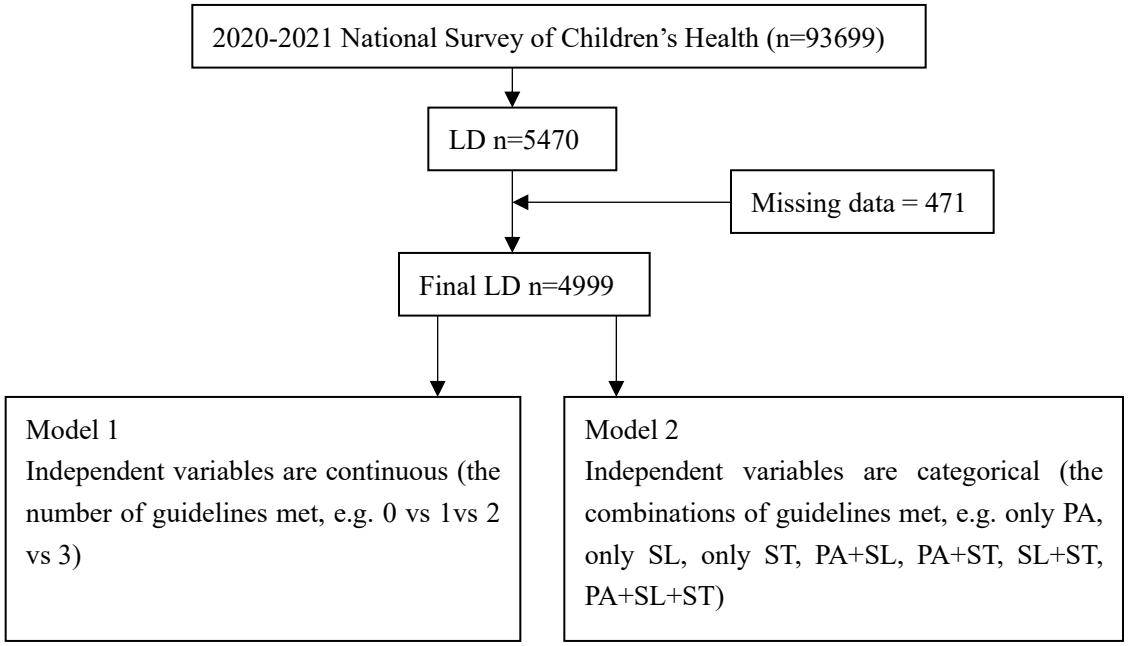

Fig 1. Diagram presents analysis procedure in the current study. Data derived from the 2020–2021 National Survey of Children’s Health (N = 93,699). Participants are children and adolescents with LD with available data (aged 6–17 years, N = 4,999). Two separate regression models were conducted.

education and household poverty level (federal poverty level [FPL]) from the NSCH dataset. Specifically, the 24-HMB guidelines for children and adolescents recommend at least 60-minutes of moderate-to-vigorous PA, less than 2 h of recreational ST, and a SL duration of 9–11 h for 5- to 13-year-olds or 8–10 h for 14-to-17-year-olds per night (Tremblay et al., 2016). 24-HMB guidelines of children and adolescents are detailed in previous studies of our group (Kong et al., 2023; Taylor et al., 2023) and can be found in supplementary material.

Dependent variables

This study used 13 items within three domains to operationalise school achievement, social behavioural problems, and emotional functioning. First, school achievement included questions about learning

interest/curiosity, school engagement, task completion, and memory problems. Second, social-behavioural problems were assessed via items asking for friendship, bullying victimisation and perpetration, school problems, argument and behavioural problems. Third, emotional functioning was measured using questions about negation emotions (anxiety and depression) and resilience. The specific items and their scoring are more extensively detailed in the supplementary material.

Statistical analyses

Statistical analyses were performed using Stata 16. To ensure accurate model estimates, the survey sampling weights were analysed using STRATACROSS (created by NSCH [Child and Adolescent Health Measurement Initiative {CAHMI}]) to account for the multistage-sampling survey design. Sub-populations were defined with the option of survey data in Stata for children and adolescents diagnosed with LD. Descriptive statistics were used to summarise all variables, with mean and standard deviations reported for continuous variables, and categorical variables were presented with unweighted sample counts and proportions. Given that 24-HMB guideline adherence was operationalized via continuous (0 vs. 1 vs. 2 vs. 3) and categorical variable (e.g., PA + SL, PA + ST, SL + ST, PA + SL + ST), multivariate logistic regressions (Model 1 for continuous independent variable, and Model 2 for categorical independent variable) were separately conducted to estimate odds ratios (OR) with 95% confidence intervals (95%CI) between adherence to 24-HMB guidelines and outcomes of interest (academic achievement, social-behavioural problems, and emotional functioning). Covariates included age, sex, race, overweight status, the severity of learning disability, educational intervention, parental education, and household poverty level. The significance level for all statistical tests was set at $p < 0.05$. Statistical results are presented in the tables.

Results

Sample characteristics

This study included 5,470 6 to17-year-old children and adolescents with LD (weighted sample size = 4,301,753) Following the exclusion of 471 participants due to invalid responses, 4,999 participants are included for data analyses. Mean age of participants was 12.00 ± 3.20 years and approximately half of the participants were White (50.49%). Male participants accounted for 62.54% of the sample, while 17.11% of the included children and adolescents were overweight. In our sample, 47.81% of the children and adolescents exhibited mild LD symptoms and the majority of them (71.67% of the participants) had not received an educational intervention. Furthermore, approximately one-fourth of participants' primary caregivers (23.72%) reported incomes between 0% and 99% of the federal poverty level, while only 7.03% of them responded that they had not completed high school (see Table 1).

Adherence to 24-HMB guidelines

The number of children and adolescents with LD who adhered to the single 24-HMB guidelines varied considerably (PA guideline = 4.59%, SL guideline = 26.33%, and ST guideline = 10.55%). Approximately one-quarter of participants (n = 1218, weight% = 25.87) did not adhere to any of the three 24-HMB guidelines, whereas a small number of participants adhered to all three components of 24-HMB guidelines (n = 336, weight % = 6.62). The number of participants who adhered to two of the three 24-HMB

guidelines was influenced by the specific combination of the different 24-HMB components (PA + SL = 4.97%, PA + ST = 3.91%, and SL + ST = 17.16%). Of note, the prevalence of PA-related (PA alone, PA + SL, PA + ST, and PA + SL + ST), SL-related (SL alone, PA + SL, SL + ST, PA + SL + ST), and ST-related (ST alone, SL + ST, PA + ST, and PA + SL + ST) guideline adherence are 19.54%, 58.35%, and 36.97%, respectively (Table 1 and Figure 2).

Association between 24-HMB guideline adherence and school achievement

First, adherence to at least one of 24-HMB guidelines (except for SL guideline adherence) was positively associated with learning interest (Table 2). Second, a positive relationship regarding the adherence to specific combinations of 24-HMB guidelines (PA + SL, PA + ST, SL + ST, and PA + SL + ST) and the number of 24-HMB guidelines met (OR = 1.52, 95% CI: 1.33–1.74, $p < 0.01$; Table 2) with school engagement was observed. Third, the number of 24-HMB guidelines met (OR = 1.47, 95% CI: 1.29–1.67, $p < 0.01$; Table 2) and the adherence to all categories of 24-HMB guidelines (PA, SL, ST, PA + SL, PA + ST, SL + ST, and PA + SL + ST) is linked to a higher likelihood of task completion (Table 2). Fourth, adhering to ST guideline, PA + SL guidelines, and PA + SL + ST guidelines was negatively associated with concentration/memory problems (Table 2).

Association between 24-HMB guideline adherence and social-behavioural problems

First, adhering to at least one of 24-HMB guidelines (i.e., ST, PA + SL, PA + ST, and PA + SL + ST) was associated with lower difficulties in making friendships (Table 3). Second, the adherence to two or more 24-HMB guidelines (PA + SL, PA + ST and PA + SL + ST) and the number of adhered 24-HMB guidelines (OR = 0.85, 95% CI: 0.74–0.97, $p < 0.05$) was negatively correlated with bullying victimisation (Table 3). Third, SL + ST guideline adherence was associated with a lower probability of school problems (Table 3). Fourth, adhering to specific 24-HMB recommendations (PA, SL, and ST) was negatively linked to bullying perpetration (Table 3). Fifth, the adherence to specific 24-HMB guidelines (PA and ST), the SL + ST guideline, and the number of 24-HMB guidelines (OR = 0.81, 95% CI: 0.71–0.92, $p < 0.01$; Table 3) was linked to lower odds of arguments. Finally, adhering to the specific 24-HMB guidelines (SL and ST), the SL + ST guidelines, and the number of adhered 24-HMB guideline (OR = 0.80, 95% CI: 0.69–0.92, $p < 0.01$; Table 3) are linked to lower severity of behavioural problems.

Association between adherence to 24-HMB guideline and emotional functioning

Adhering to the SL guideline and the SL + ST guidelines of 24-HMB recommendations was linked to a reduced likelihood of severe anxiety (Table 4). In addition, the adherence to the SL guideline, PA + SL guidelines, and SL + ST guidelines of 24-HMB recommendations are associated with a lower likelihood of depression (Table 4). Adherence to two or more 24-HMB guidelines (PA + SL, PA + ST, SL + ST, and PA + SL + ST) and the number of adhered 24-HMB guidelines are positively linked to resilience (OR = 1.36, 95% CI: 1.19–1.19, $p < 0.01$; Table 4).

Table 1 Participant characteristics (N = 4999).

Characteristics	Value[a]
Age(year)	12.00±3.20
Sex	
Male	3119(62.54%)
Female	1880(37.46%)
Overweight status	
Yes	769(17.11%)
No	4230(82.89%)
Ethnicity	
Hispanic	644(23.07%)
White, non-Hispanic	3353(50.49%)
Black, non-Hispanic	434(17.95%)
Asian, non-Hispanic	108(1.41%)
Other/Multi-racial, non-Hispanic	460(7.08%)
LD severity	
Mild	2390(47.81%)
Moderate or severe	2609(52.19%)
Educational intervention	
Yes	1404(28.33%)
No	3595(71.67%)
Household poverty level	
0%- 99% FPL	921(23.72%)
100% -199% FPL	1006(24.80%)
200% -399% FPL	1517(27.14%)
400% FPL or greater	1555(24.34%)
Education level of primary caregivers	
Less than high school	149(7.03%)
High school degree	869(25.80%)
Some college or technical school	1409(25.07%)
College degree or higher	2572(42.10%)
24-HMB guideline adherence	
None	1218(25.87%)
Meeting 1 out of 3	2156(41.47%)
Physical activity	207(4.59%)
Sleep	1478(26.33%)
Screen time	471(10.55%)
Meeting 2 out of 3	1289(26.04%)
Physical activity + Sleep	248(4.97%)
Physical activity + Screen time	186(3.91%)
Sleep + Screen time	855(17.16%)
All	336(6.62%)

Learning interest and curiosity	
Never	188(3.36%)
Usually	1673(36.08%)
Sometime	1755(31.33%)
Always	1383(29.23%)
Memory problems	
Yes	2920(57.97%)
No	2079(42.03%)
School engagement	
Sometimes or never	2633(51.29%)
Always or usually	1634(33.66%)
Always	732(15.05%)
Task completion	
Never	354(6.82%)
Usually	2277(45.01%)
Sometime	1795(35.10%)
Always	573(13.07%)
Difficulty in making or keeping friends	
No difficulty	1894(41.80%)
A little difficulty	1857(35.05%)
A lot difficulty	1248(23.15%)
Bullying victimization	
Never in the past 12 months	2049(46.92%)
1-2 times in the past 12 months	1505(27.34%)
1-2 times per month	634(10.37%)
1-2 times per week	463(8.85%)
Almost every day	348(6.52%)
Being contacted about any problems	
None	2498(51.20%)
1 time	764(14.37%)
2 or more times	1737(34.43%)

Bullying perpetration	
Never in the past 12 months	3712(78.04%)
1-2 times in the past 12 months	837(14.21%)
1-2 times per month	223(3.33%)
1-2 times per week	146(2.27%)
Almost every day	81(2.15%)
Argue too much	
Never	955(23.93%)
Usually	2433(45.12%)
Sometime	936(18.71%)
Always	675(12.24%)
Behavioral problems (severity)	
Does not currently have the condition	2978(60.12%)
Current condition, rated as mild	713(14.32%)
Current condition, rated as moderate/severe	1308(25.56%)
Anxiety (severity)	
Does not currently have the condition	3021(67.10%)
Current condition, rated as mild	714(11.52%)
Current condition, rated as moderate/severe	1264(21.38%)
Depression (severity)	
Does not currently have the condition	4119(85.23%)
Current condition, rated as mild	354(6.26%)
Current condition, rated as moderate/severe	526(8.51%)
Resilience	
Never	585(11.66%)
Usually	2464(48.55%)
Sometime	1605(30.66%)
Always	345(9.13%)

[a] Values are mean ± SD or n (weighted [wt]%); n represents unweighted sample counts, and wt% is weighted sample sizes. 24-HMB: 24-hour movement behaviour; LD= Learning Disability.

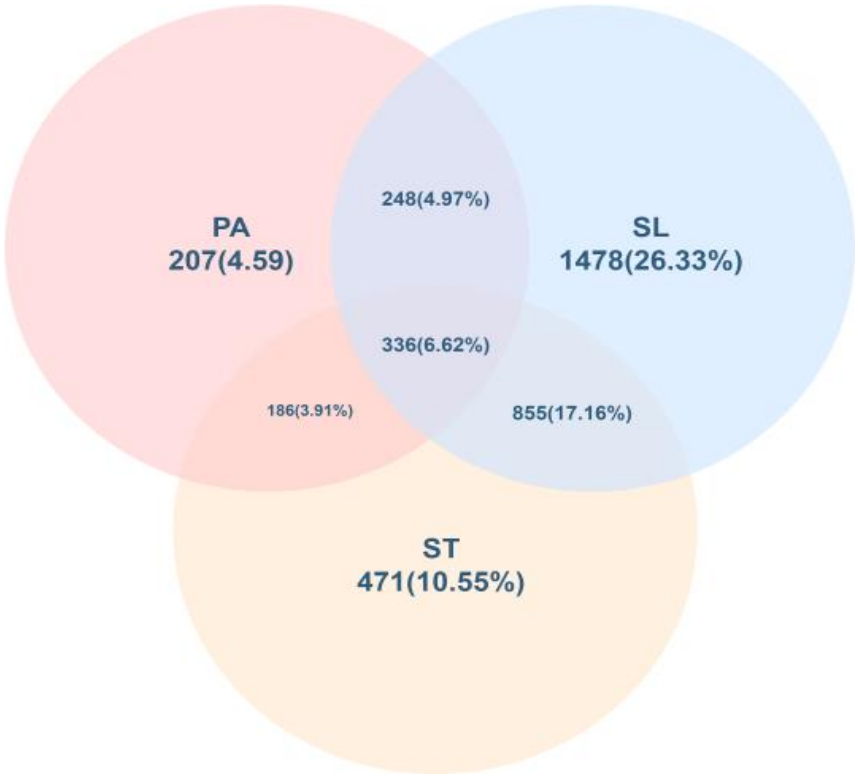

Figure 2. Venn diagram presenting proportions of LD participants (aged 6-17 years) who adhered to independent and integrated components of 24-HMB guidelines. Values are n (wt%); n represents unweighted sample counts and wt% is weighted sample sizes; PA = Physical activity, ST = Screen time, and SL = Sleep

Table 2. Associations between 24-HMB guideline adherence and learning interest.

	Learning interest and curiosity		School engagement		Task completion		Memory problems	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Intercept	—	—	—	—	—	—	0.43 (0.22-0.82)**	0.42 (0.22-0.81)*
Age								
6-13(reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
14-17	0.55 (0.45-0.68)***	0.62 (0.50-0.76)***	1.09 (0.87-1.36)	1.10 (0.87-1.40)	1.41 (1.14-1.76)**	1.49 (1.19-1.87)**	0.73 (0.57-0.92)**	0.70 (0.55-0.90)**
Sex								
Male (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Female	1.36 (1.11-1.68)**	1.37 (1.11-1.69)**	1.69 (1.36-2.10)***	1.71 (1.38-2.12)***	1.21 (0.99-1.49)	1.22 (0.99-1.50)	0.68 (0.53-0.86)**	0.67 (0.53-0.85)**
Overweight status								
No (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Yes	0.64 (0.46-0.88)**	0.66 (0.49-0.90)**	1.02 (0.71-1.47)	1.03 (0.72-1.48)	0.76 (0.58-0.99)	0.79 (0.60-1.03)	2.04 (1.43-2.91)***	2.00 (1.41-2.84)***
Ethnicity								
Hispanic (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
White, non-Hispanic	1.01 (0.74-1.37)	0.98 (0.72-1.33)	1.02 (0.75-1.38)	1.01 (0.74-1.36)	0.95 (0.70-1.28)	0.91 (0.67-1.23)	0.62 (0.44-0.89)**	0.62 (0.44-0.89)**
Black, non-Hispanic	1.05 (0.70-1.57)	0.99 (0.66-1.47)	1.48 (0.95-2.30)	1.46 (0.94-2.27)	1.21 (0.82-1.78)	1.14 (0.77-1.67)	0.64 (0.41-1.00)*	0.67 (0.43-1.04)
Asian, non-Hispanic	0.30 (0.18-0.52)***	0.31 (0.18-0.51)***	0.37 (0.19-0.72)**	0.38 (0.19-0.73)**	0.59 (0.37-0.95)	0.58 (0.36-0.95)*	1.04 (0.49-2.23)	1.03 (0.50-2.12)
Other/Multi-racial, non-Hispanic	1.27 (0.79-2.04)	1.24 (0.77-2.00)	0.96 (0.62-1.47)	0.95 (0.62-1.46)	1.13 (0.75-1.69)	1.05 (0.70-1.58)	0.53 (0.30-0.91)*	0.53 (0.31-0.91)*
LD severity								
Mild (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Moderate or severe	0.64 (0.52-0.79)***	0.64 (0.52-0.80)***	0.47 (0.37-0.59)***	0.47 (0.37-0.59)***	0.42 (0.34-0.52)***	0.41 (0.33-0.51)***	4.52 (3.57-5.71)***	4.58 (3.62-5.79)***
Educational intervention								
No (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)

Yes	0.83 (0.66-1.04)	0.84 (0.67-1.05)	0.92 (0.74-1.16)	0.92 (0.73-1.16)	0.90 (0.71-1.15)	0.91 (0.72-1.15)	1.56 (1.19-2.03)**	1.53 (1.17-1.99)**
Household poverty level								
0%- 99% FPL (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
100%-199% FPL	1.07 (0.77-1.51)	1.09 (0.77-1.53)	0.99 (0.68-1.43)	0.98 (0.68-1.42)	1.24 (0.88-1.74)	1.25 (0.89-1.74)	1.46 (1.01-2.10)*	1.47(1.02-2.11)*
200%-399% FPL	0.94 (0.66-1.34)	0.98 (0.68-1.40)	1.13 (0.80-1.59)	1.13 (0.80-1.60)	1.09 (0.79-1.51)	1.13 (0.81-1.56)	1.15 (0.79-1.67)	1.12 (0.76-1.63)
400% FPL or greater	0.98 (0.69-1.40)	1.05 (0.73-0.73)	1.24 (0.83-1.85)	1.25 (0.84-1.87)	1.05 (0.76-1.46)	1.12 (0.81-1.56)	1.11 (0.76-1.63)	1.08 (0.73-1.58)
Education level of primary caregivers								
Less than high school (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
High school degree	0.86 (0.51-1.45)	0.90 (0.54-0.54)	0.71 (0.39-1.30)	0.72 (0.39-1.31)	0.69 (0.40-1.22)	0.74 (0.42-1.28)	1.75 (0.97-3.14)	1.69 (0.95-3.02)
Some college or technical school	1.10 (0.67-1.82)	1.17 (0.71-0.71)	0.61 (0.34-1.11)	0.62 (0.34-1.12)	0.62 (0.36-1.09)	0.66 (0.38-1.14)	2.88 (1.63-	2.82 (1.60-
College degree or higher	0.96 (0.58-1.61)	1.05 (0.63-0.63)	0.84 (0.46-1.52)	0.85 (0.46-1.55)	0.93 (0.54-1.59)	0.98 (0.58-1.68)	2.20 (1.22-3.97)**	2.17 (1.21-3.89)*
Adherence to the 24-HMBG (continuous)	1.46 (1.27-1.66)***	—	1.52 (1.33-1.74)***	—	1.47 (1.29-1.67)***	—	0.80 (0.70-	—
Adherence to the 24-HMBG (categorical)								
None (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
PA only	—	1.86 (1.07-3.26)*	—	1.71 (0.95-3.09)	—	2.10 (1.16-3.81)*	—	0.96 (0.53-1.76)
SL only	—	1.01 (0.77-1.32)	—	1.35 (0.98-1.84)	—	1.35 (1.04-1.75)*	—	0.94 (0.67-1.31)
ST only	—	1.97 (1.37-2.85)***	—	1.26 (0.86-1.84)	—	1.94 (1.31-2.87)**	—	0.63 (0.41-0.96)*
PA + SL	—	3.03 (1.76-5.20)***	—	2.63 (1.56-4.43)***	—	2.44 (1.61-3.70)***	—	0.60 (0.37-0.95)*
PA + ST	—	2.92 (1.57-5.42)**	—	2.18 (1.29-3.69)**	—	2.73 (1.61-4.63)***	—	0.90 (0.49-1.65)
SL + ST	—	1.69 (1.19-2.40)**	—	2.14 (1.49-3.07)***	—	1.59 (1.12-2.27)*	—	0.85 (0.56-1.28)
All (PA + SL + ST)	—	3.16 (1.89-5.29)***	—	3.50 (2.14-5.72)***	—	4.27 (2.58-7.05)***	—	0.36 (0.23-0.58)***
Probability > F^	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000

Note. Odds Ratio with 95% confidence interval^ Means overall model F statistic; * p < 0.05; ** p < 0.01; *** p < 0.001; 24-HMB: 24-hour movement behaviour; 24-HMBG: 24-hour movement behaviour guidelines; FPL = federal poverty level; LD = Learning Disability; N/A = Not applicable.

Table 3. Associations between 24-HMB guideline adherence and friendship, bullying victimisation, school problems, bullying perpetration, argument and behavioural problems.

	Friendship		Bullying victimisation		School problems		Bullying perpetration		Argument		Behavioural problems (severity)	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Age												
6-13(reference)	1 reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
14–17	1.14 (0.92-1.42)	1.13 (0.90-1.42)	0.79 (0.64-0.97)*	0.79 (0.64-0.99)*	0.88 (0.71-1.10)	0.87 (0.69-1.11)	0.73 (0.55-0.97)*	0.77 (0.57-1.03)	0.75 (0.60-0.94)*	0.81 (0.64-1.02)	0.61 (0.48-0.78)***	0.63 (0.48-0.81)***
Sex												
Male (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Female	0.91 (0.74-1.14)	0.89 (0.72-1.10)	1.23 (0.99-1.53)	1.22 (0.98-1.51)	0.87 (0.70-1.08)	0.88 (0.71-1.10)	0.99 (0.76-1.28)	1.01 (0.77-1.31)	1.18 (0.94-1.49)	1.21 (0.96-1.52)	0.57 (0.45-0.72)***	0.58 (0.46-0.73)***
Overweight status												
No (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Yes	2.13 (1.59-2.86)***	2.06 (1.55-2.73)***	1.66 (1.19-2.31)**	1.63 (1.18-2.26)**	1.11 (0.80-1.54)	1.12 (0.81-1.55)	1.20 (0.88-1.64)	1.24 (0.91-1.70)	1.24 (0.87-1.77)	1.29 (0.91-1.82)	1.10 (0.81-1.49)	1.13 (0.83-1.52)
Ethnicity												
Hispanic (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
White, non-Hispanic	1.04 (0.73-1.48)	1.09 (0.77-1.53)	1.84 (1.30-2.62)**	1.88 (1.34-2.64)***	1.28 (0.91-1.80)	1.26 (0.90-1.77)	2.22 (1.44-3.41)***	2.25 (1.47-3.44)***	1.51 (1.05-2.18)*	1.48 (1.03-2.11)*	1.13 (0.81-1.57)	1.10 (0.80-1.53)
Black, non-Hispanic	0.61 (0.39-0.96)	0.65 (0.41-1.02)	0.99 (0.63-1.54)	1.01 (0.66-1.56)	1.35 (0.86-2.11)	1.31 (0.84-2.04)	1.80 (1.05-3.10)*	1.82 (1.07-3.09)*	0.69 (0.44-1.08)	0.67 (0.43-1.04)	1.19 (0.75-1.88)	1.17 (0.74-1.83)
Asian, non-Hispanic	1.08 (0.38-3.11)	1.08 (0.39-2.97)	0.72 (0.30-1.75)	0.73 (0.30-1.75)	0.95 (0.40-2.25)	0.95 (0.41-2.24)	0.97 (0.41-2.30)	1.02 (0.45-2.31)	0.93 (0.55-1.57)	0.99 (0.59-1.64)	0.61 (0.24-1.58)	0.63 (0.25-1.61)
Other/Multi-racial, non-Hispanic	0.96 (0.59-1.56)	1.05 (0.66-1.69)	1.19 (0.75-1.91)	1.24 (0.79-1.95)	1.35 (0.82-2.23)	1.30 (0.79-2.12)	2.02 (1.17-3.48)*	2.04 (1.20-3.47)**	1.20 (0.67-2.15)	1.13 (0.64-1.98)	1.35 (0.82-2.23)	1.27 (0.77-2.10)
LD severity												
Mild (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)

Moderate or severe	2.58 (2.05-3.26)***	2.61 (2.07-3.29)***	1.12 (0.89-1.39)	1.11 (0.89-1.38)	1.64 (1.30-2.06)***	1.65 (1.32-2.07)***	1.26 (0.97-1.64)	1.28 (0.98-1.67)	1.27 (1.01-1.59)*	1.28 (1.02-1.61)*	2.55 (2.01-3.23)***	2.60 (2.05-3.29)***
Educational intervention												
No (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Yes	1.55 (1.24-1.93)***	1.55 (1.24-1.94)***	1.73 (1.38-2.18)***	1.74 (1.39-2.19)***	1.36 (1.07-1.74)*	1.38 (1.08-1.76)*	0.96 (0.73-1.25)	0.97 (0.74-1.27)	1.11 (0.86-1.43)	1.10 (0.85-1.42)	1.20 (0.92-1.56)	1.20 (0.92-1.57)
Household poverty level												
200%-399% FPL	0.86 (0.60-1.25)	0.82 (0.57-1.19)	0.67 (0.46-0.97)*	0.66 (0.46-0.96)*	0.77 (0.55-1.10)	0.77 (0.54-1.10)	0.81 (0.54-1.21)	0.79 (0.53-1.18)	0.88 (0.61-1.27)	0.89 (0.61-1.28)	1.02 (0.71-1.48)	1.02 (0.71-1.47)
400% FPL or greater	0.89 (0.61-1.30)	0.81 (0.56-1.19)	0.66 (0.45-0.96)*	0.65 (0.45-0.95)*	0.82 (0.57-1.18)	0.82 (0.57-1.18)	0.52 (0.34-0.80)**	0.51 (0.33-0.78)**	0.84 (0.59-1.20)	0.87 (0.61-1.24)	0.80 (0.54-1.19)	0.82 (0.55-1.21)
Education level of primary caregivers												
Less than high school (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
High school degree	1.89 (1.11-3.22)*	1.81 (1.07-3.06)*	1.44 (0.78-2.66)	1.42 (0.77-2.61)	0.77 (0.45-1.34)	0.80 (0.47-1.37)	0.77 (0.36-1.66)	0.77 (0.37-1.62)	1.80 (1.04-3.12)*	1.84 (1.06-3.17)*	1.15 (0.56-2.36)	1.19 (0.59-2.40)
Some college or technical school	1.91 (1.16-3.15)*	1.86 (1.13-3.07)*	1.98 (1.10-3.56)*	1.98 (1.10-3.55)*	1.11 (0.65-1.91)	1.14 (0.68-1.93)	1.09 (0.51-2.35)	1.10 (0.52-2.32)	1.92 (1.15-3.22)*	1.99 (1.19-3.34)**	1.25 (0.61-2.57)	1.28 (0.64-2.60)
College degree or higher	2.23 (1.34-3.72)**	2.20 (1.32-3.67)**	1.78 (0.98-3.23)	1.78 (0.98-3.23)	0.88 (0.51-1.50)	0.88 (0.52-1.50)	0.95 (0.43-2.09)	0.96 (0.44-2.08)	1.41 (0.83-2.39)	1.47 (0.87-2.50)	1.05 (0.51-2.17)	1.08 (0.53-2.20)
Adherence to the 24-HMBG (continuous)	0.85 (0.74-0.98)*	—	0.85 (0.74-0.97)*	—	0.87 (0.76-1.00)	—	0.94 (0.79-1.13)	—	0.81 (0.71-0.92)**	—	0.80 (0.69-0.92)**	—
Adherence to the 24-HMBG (categorical)												
None (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
PA only	—	0.69 (0.42-	—	0.95 (0.57-	—	0.71 (0.43-	—	0.36 (0.21-	—	1.03 (0.57-	—	0.82 (0.46-

		1.13)		1.58)		1.17)		0.63)***		1.85)		1.45)
SL only	—	0.80 (0.59-	—	0.75 (0.56-	—	0.84 (0.61-	—	0.53 (0.38-	—	0.60 (0.45-	—	0.66 (0.47-
		1.10)		1.01)		1.16)		0.74)***		0.80)***		0.93)*
ST only	—	0.66 (0.45-	—	0.71 (0.50-	—	0.72 (0.48-	—	0.56 (0.38-	—	0.54 (0.35-	—	0.51 (0.34-
		0.98)*		1.03)		1.10)		0.85)**		0.84)**		0.78)**
PA + SL	—	0.38 (0.23-	—	0.54 (0.34-	—	0.60 (0.35-	—	1.19 (0.69-	—	0.82 (0.58-	—	0.55 (0.31-
		0.61)***		0.84)**		1.05)		2.04)		1.15)		0.99)*
PA + ST	—	0.53 (0.29-	—	0.60 (0.37-	—	0.67 (0.37-	—	0.60 (0.31-	—	1.05 (0.59-	—	0.82 (0.46-
		0.98)*		0.97)*		1.22)		1.16)		1.88)		1.47)
SL + ST	—	1.20 (0.82-	—	0.87 (0.59-	—	0.60 (0.41-	—	0.73 (0.49-	—	0.53 (0.35-	—	0.50 (0.35-
		1.76)		1.30)		0.88)**		1.09)		0.81)**		0.72)***
All (PA + SL + ST)	—	0.41 (0.24-	—	0.51 (0.30-	—	0.95 (0.61-	—	0.88 (0.44-	—	0.48 (0.30-	—	0.62 (0.36-
		0.70)**		0.87)*		1.48)		1.75)		0.75)**		1.08)
Probability > F[a]	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000

Note. Odds Ratio with 95% confidence interval.[a] Means overall model F statistic; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; 24-HMB: 24-hour movement behaviour; 24-HMBG: 24-hour movement behaviour guidelines; FPL = federal poverty level; LD = Learning Disability; N/A = Not applicable.

Table 4. Associations between 24-HMB guideline adherence and learning interest and anxiety, depression and resilience.

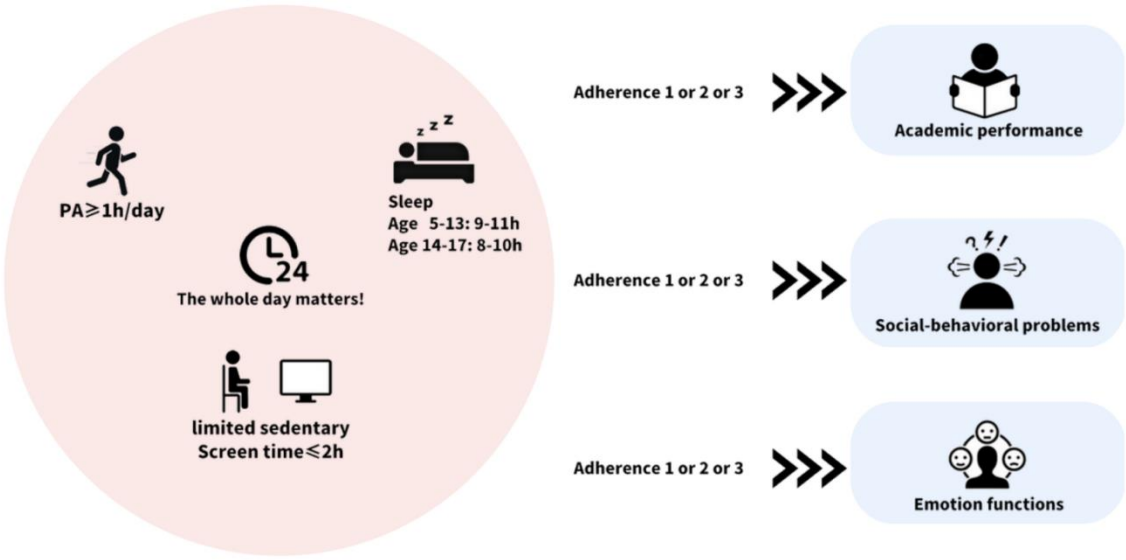

Figure 3. Associations of 24-HMB guideline adherence with school achievement, social-behavioural problems, and emotional functioning among LD children and adolescents

Discussion

In this study, we investigated the associations between 24-HMB guideline adherence and school achievement, social-behavioural problems, and emotional functioning among US children and adolescents with LD. Our findings indicate that adhering to independent and integrated guidelines of 24-HMB is positively associated with the above-mentioned measures.

Adherence to 24-HMB guidelines

Overall, findings indicated that the prevalence of adhering to 24-HMB guidelines is relatively low, especially for specific combinations of the 24-HMB guidelines ranging from 3.91% (PA + ST guideline adherence) to 17.16% (SL + ST guideline adherence). These findings are consistent with previous studies on 6-17-year-old children with developmental disorders including autism spectrum disorder (Kong et al., 2023) and attention deficit/hyperactive disorder (Taylor et al., 2023) as well as individuals without disabilities in terms of three guideline adherence with its prevalence ranging from 2.68% (adolescents) to 11.26% (preschoolers) (Tapia-Serrano, Sevil-Serrano, et al., 2022). Comparatively, a study by Watson and colleagues (2022) who utilized both self-reports and accelerometry to examine the prevalence of 24-HMB guideline adherence among primary school-aged children found that 20.3% of the study cohort met all three 24-HMB guidelines. Notably, the percentage of participants who adhered to specific combinations of the 24-HMb guidelines (PA + SL and PA + ST) was larger. Comparing the results of this study with Watson and colleagues (2022), the prevalence of meeting one or more guidelines of the 24-HMB framework varied considerably when comparing subjective measures with accelerometry-based measures, especially for the prevalence of PA or SL guideline adherence. This comparison highlights the relatively

large change in the prevalence of PA + SL + ST guideline adherence between the two types of assessment (self-reports: 20.3% vs. accelerometry: 12%). Given the considerable difference between subjective and objective measures of movement behaviors, further investigations of children and adolescents with LD should also take objective measures into account to substantiate the current observations.

24-HMB guideline adherence and school achievement

In general, learning interest, school engagement, tasks completion, and memory problems are related to academic performance and success (referring to school achievement) (Aronen, Vuontela, Steenari, Salmi, & Carlson, 2005; Brophy, 2006; Chase, Hilliard, John Geldhof, Warren, & Lerner, 2014; Lavy, 2012; Moffett & Morrison, 2020; Schiefele, Krapp, & Winteler, 1992). The results of the present study indicated that in children and adolescents with LD the number of 24-HMB guidelines that were adhered to are linked to certain outcome measures. These observations that are based on the analysis of continuous and categorical variables are supported by previous studies indicating that healthy adolescents who met two or more 24-HMB guidelines showed a superior academic achievement (reflected by average scores of grades in first language [Spanish], first foreign language [English], and mathematics subjects as well as Grade Point Average) as compared to those who met one or none of these guidelines (Liu et al., 2022; Tapia-Serrano, García-Hermoso, et al., 2022).

Learning interest/curiosity plays a critical role in learner engagement, which is a strong predictor of academic performance (Gruber, Gelman, & Ranganath, 2014; Von Stumm, Hell, & Chamorro-Premuzic, 2011). Our results indicated that adhering to 24-HMB guidelines, both to single components (except for SL guideline alone) and specific combinations of two components of the 24-HMB recommendations were associated with greater learning interest/curiosity among children and adolescents with LD. The values of the odds ratio varied as a function of the adhered 24-HMB recommendations (descending order: PA + ST + SL guideline > PA + SL guideline > PA + ST guideline > ST guideline > PA guideline > SL + ST guideline). Such results are consistent with a previous study on children and adolescents with autism spectrum disorder, indicating that adhering to PA + SL guidelines or PA + SL + ST guidelines is linked to stronger learning interest/curiosity (Kong et al., 2023). Comparably, school engagement as a process-based measure is a multi-component construct related to behavioral, emotional, and cognitive domains (Fredricks, Blumenfeld, & Paris, 2004; Ritoša, Danielsson, Sjöman, Almqvist, & Granlund, 2020; Skinner, Kindermann, & Furrer, 2009), which is positively linked to the adherence to specific combinations of the 24-HMB guidelines (PA + SL + ST guideline > PA + SL guideline, PA + ST guideline > SL + ST guideline). This consistent finding is critical as children with LD tend to experience memory problems including working memory and long-term memory (Kibby & Cohen, 2008; Maehler & Schuchardt, 2009), which can result in difficulties in learning. Children and adolescents with LD who adhered to independent (ST alone) and a specific combination of 24-HMb guidelines (PA + SL and PA + SL + ST) reported reduced likelihood of experiencing memory problems, which is supported by previous studies on US children without disabilities concerning episodic memory and working memory (Walsh et al., 2018) and preschoolers concerning phonological working memory (McNeill, Howard, Vella, & Cliff, 2020). Taken together, regular PA engagement, adequate SL, and a limited amount of ST plays a critical role in facilitating learning interest/curiosity and improving memory function among children with LD, which,

in turn, might better equip them to engage in school-related activities. Importantly, the adherence to a single or a combination of two or more 24-HMB guidelines is associated with an increased likelihood of completing academic tasks.

24-HMB guideline adherence and social-behavioral problems

Maintaining friendships and bullying victimization are interdependent in terms of social relationships. In this study, these outcomes are measured separately. Results indicate that the adherence to single and the combination of 24-HMB guidelines is selectively linked to reduced likelihood of experiencing difficulties in making/keeping friendships, bullying victimization, and perpetration among children and adolescents with LD. Our results are partially supported by previous studies that include children and/or adolescents with other types of neurodevelopment disorders including autism spectrum disorder (bullying victimization: (Kong et al., 2023) and ADHD (friendship, bullying victimization and perpetration (Taylor et al., 2023). Furthermore, empirical evidence suggests that structured PA programs can improve social interaction and communication skills of ASD children~~, especially social skills, communication, prompt response, and expression frequency~~ (Zhao & Chen, 2018).

The adherence to the SL+ST recommendations of the 24-HMB guidelines is linked to reduced likelihood of school problems. The adherence to single (ST or SL) or the combination of specific 24-HMB recommendations (SL + ST and PA + SL + ST) are linked to reduced frequency of argument, suggesting that especially an adequate sleep duration and limited screen time are important to reduce the frequency of argument. Accumulating evidence indicates that adequate sleep quality and duration can improve emotion regulation (Palmer & Alfano, 2017), which, in turn, may contribute to fewer school problems and arguments. Additionally, a meta-analysis indicated that longer screen time duration was linked to externalizing behavior problems such as aggression and inattention, due to potential exposure to inappropriate content including aggression, and violence (Eirich et al., 2022). Finally, adhering to SL and ST guidelines, SL + ST guidelines of the 24-HMB, and the number of 24-HMB guidelines adhered to are linked to lower severity of behavioral problems. This supports findings of a previous cross-sectional study on U.S. youth, in which ST, SL, ST + SL and ST + SL + PA guidelines were associated with a lower risk of problem behaviors (rule-breaking and aggressive behavior syndromes). In summary, our findings suggest that there are positive benefits to adhering to 24-HMB guidelines for children and adolescents with LD. Adherence to PA-related guidelines have superior outcomes concerning friendships, bullying victimization, and bullying perpetration and adherence with SL-related and ST-related guidelines have better outcomes in school problems, arguments and behavioral problems.

24-HMB guideline adherence and emotional functioning

Our findings indicated that all combinations of 24-HMB guidelines (PA + SL, PA + ST, SL + ST, and PA + SL + ST) are linked to a higher level of resilience. Previous studies have established that (i) a high level of PA facilitates resilience during adolescent development (Belcher et al., 2021; Zhang et al., 2022), (ii) more screen time is associated with a series of adverse effects (Lissak, 2018), and (iii) a better sleep quality was linked to stronger resilience (Wang et al., 2020). Thus, our findings support the notion that a healthier lifestyle with relatively high levels of PA, adequate sleep patterns, and limited screen time, as

recommended in the 24-HMB, can promote better resilience in children and adolescents with LD. Adhering to SL and SL + ST recommendations is linked to reduced likelihood of anxiety, while adhering to SL alone, PA + SL and SL + ST recommendations of the 24-HMB guidelines are linked to reduced likelihood of depression. These findings suggest that adherence to SL-related guidelines plays a beneficial role in promoting mental health. This line of interpretation is buttressed by the findings of another study on Chinese children which observed that children who met the SL, ST, PA + SL, PA + ST, and SL + ST recommendations of the 24-HMB have lower odds of developing depressive symptoms and anxiety, with adherence to the SL + ST guideline display the lowest odds. Gunnell and her colleagues who examined the bidirectional relationship between physical activity, screen time, and symptoms of anxiety and depression over a period of 11 years, found that increases in ST were associated with increases in symptoms of depression and anxiety over time (Gunnell et al., 2016).

Limitations and future directions

The current study revealed positive associations between meeting specific 24-HMB recommendations and several important indicators of academic performance and mental health. However, due to our cross-sectional study design, we are not able to draw causal conclusions. Thus, longitudinal studies which examine the effectiveness of prescribing the 24-HMB guidelines as a lifestyle intervention for children and adolescents with LD are needed to broaden our current knowledge. In addition, the caregiver-reported questionnaire used in the current study may be prone to recall bias and inaccuracies. Future studies should aim to combine self-reported instruments with objective device-based digital tools to minimize the risk of potential bias. Moreover, previous studies suggest that the influence of PA and ST varies as a function of dose-related factors. For instance, the cognitive demand posed by the ST activities (i.e., low demand – watching TV vs. high demand – studying) might differentially influence specific outcomes such as academic performance (Twenge & Farley, 2021). Thus, a more comprehensive assessment of PA and ST is needed to obtain a deeper and more nuanced understanding of the influence of different aspects of PA and ST on health-related parameters in children and adolescents with and without LD.

Conclusions

Our results suggest that children and adolescents with LD have difficulties meeting 24-HMB guidelines with respect to PA, SL, and ST. As adhering to the 24-HMB guidelines is associated with better school achievement, fewer social-behavioral problems, and better emotional function, the considerable prevalence of non-adherence among children and adolescents with LD that has been observed in this study calls for public health action. We recommend that further research should aim to (i) elucidate the factors that may hinder children and adolescents with LD in adhering to the 24-HMB guidelines, (ii) investigate strategies that can improve the adherence to the 24-HMB in this population, and (iii) examine via a longitudinal approach whether the adherence to 24-HMB guidelines can positively influence specific health-related parameters. Finally, the findings from this study have important implications for stakeholders. We strongly encourage parents, caregivers, and educators to provide adequate support mechanisms that encourage and enable individuals with LD in their efforts to adopt a healthier lifestyle through meeting 24-HMB guidelines.

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