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Exploring the link between recreational substances and physical activity in children and adolescents: insights from the Health Behavior in School-Aged Children study (2013–2019)

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Abstract

Background Substance use and physical inactivity in youths could influence brain development, academic performance, and long-term physical and mental health outcomes. Therefore, this study examined the associations between substance use and weekly days of moderate to vigorous physical activity (MVPA) among children and adolescents.

Methods Data were drawn from the Health Behavior in School-Aged Children (HBSC) cross-sectional study (2013–2019), comprising 358,391 children and adolescents (51% girls) from 45 countries (aged 10–17 years). Generalized linear mixed models with a Poisson distribution were fitted and mutually adjusted for age, sex, socioeconomic status, body mass index status, and survey year, to estimate the average predicted means of weekly days with at least 60 min of MVPA in relation to substance use (alcohol, tobacco, and cannabis) in non-users versus users and among frequency levels in the last 30 days.

Results Alcohol and cannabis non-users versus users did not differ significantly in physical activity levels. In contrast, children and adolescents who reported tobacco use co-occurred with lower levels of MVPA with a significant mean difference (MD) of 1.09 days/week (95% CI [confidence interval] 1.06 to 1.11; $p < 0.001$) compared to non-users. In terms of substance use frequency levels, alcohol use showed a positive association between MVPA, especially among participants who drunk ≥ 30 days in relation with low to moderate alcohol users (0–5 days) (all $p < 0.05$). Across tobacco users, lower levels of physical activity were observed in relation with higher frequency of use (all $p < 0.001$ compared to non-users), particularly among frequent users. The largest difference was reported between tobacco non-users and those with 20 to 29 days of use (MD = 1.13; 95% CI 1.07 to 1.20; $p < 0.001$). Cannabis use exhibited a nonlinear trend, with no statistically significant differences across use frequencies. Gender analysis showed that

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boys had higher levels of physical activity and different substance use patterns compared to girls. Tobacco use was associated with a stronger reduction in MVPA among girls ($p < 0.001$), while alcohol showed no significant associations (all $p > 0.05$) and cannabis was linked to slightly higher MVPA only in boys ($p = 0.035$).

Conclusion Among the recreational substances examined, both dichotomous and ordinal analyses showed that tobacco use was consistently associated with lower levels of physical activity among children and adolescents. Notably, these associations varied by sex, with boys reporting higher MVPA overall and the negative impact of tobacco use being more pronounced among girls. However, the direction of this relationship remains unclear, underscoring the need for experimental research. These findings support integrated public health strategies that combine substance use prevention with the promotion of physical activity.

Keywords Alcohol, Cannabis, Moderate-to-vigorous physical activity, Tobacco, Youth behaviors

Background

The World Health Organization (WHO) recommends that children and adolescents aged 5–17 years should accumulate at least 60 min of moderate to vigorous physical activity (MVPA) daily [1]. This activity should be developmentally appropriate, enjoyable, and involve a variety of aerobic and muscle- and bone-strengthening activities [1, 2]. Epidemiological data indicate that, globally, approximately 80% of adolescents do not meet these recommendations, classifying them as insufficiently active, with significant disparities among countries, regions, genders, and socioeconomic groups [2, 3]. Insufficient physical activity is associated with an increased risk of cardiometabolic disorders, poorer mental health, and adverse long-term health outcomes [2, 4]. The high prevalence of insufficient activity underscores the need for targeted interventions at the individual, family, school, and community levels.

Adolescence is a critical developmental period characterized by increased risk-taking behaviors, including the initiation and escalation of recreational substance use, which can significantly influence an individual's trajectory in life [5]. First, recreational substance use often begins during adolescence, with alcohol, cannabis, nicotine, and other illicit drugs being the most commonly used substances in this age group [6]. Epidemiological studies reveal that while the use of certain recreational substances has declined, others have seen an upward trend, maintaining overall high consumption rates. For instance, while the incidence of tobacco consumption has declined over the last few decades, there has been a notable rise in the use of cannabis and emerging nicotine products, including vaping [7, 8]. Substance use during adolescence is associated with a range of neurobiological, cognitive, educational, behavioral and physical health effects, as well as potential long-term consequences [9, 10]. The relationship between individual predispositions (such as impulsiveness and blunted reward processing), environmental exposures, and neurodevelopmental trajectories underscores the complexity of recreational substance use behaviors in this population [11].

The association between recreational substance use and physical activity in youths becomes critically important, albeit is complex and varies by type of substance, modality of physical activity, and demographic factors. Previous large-scale cross-sectional and longitudinal studies indicate that higher frequency of weekly physical activity and participation in sports are generally associated with lower odds of tobacco and alcohol use, as well as a reduced risk of cannabis use disorder later in life [12–15]. For example, being physically active (≥ 5 days per week with at least 60 min of physical activity) and insufficiently active (1 to 4 days per week with at least 60 min of physical activity) have been associated with lower odds of smoking, alcohol use, binge drinking, and drunkenness than physical inactivity [14]. However, the relationship is not uniformly beneficial across all recreational substances and activity types. Some studies have shown that while physical activity is associated with lower odds of conventional cigarette use, it is paradoxically associated with higher odds of e-cigarette and smokeless tobacco use, particularly among males [8, 16].

Adolescence is typically viewed as a healthy stage in an individual's life. Nevertheless, many noncommunicable diseases that emerge in adulthood can be attributed, in part, to modifiable risk behaviors in youth, such as insufficient physical activity and substance use [17, 18]. While lifelong physical activity is undeniably crucial for physical and mental health, recreational substance use among youths poses significant risks for both immediate and long-term well-being. Given these competing influences—and the potential of physical activity to mitigate substance-related harms—a rigorous examination of their interplay during this developmental period is urgently needed. Additionally, few previous studies on this topic have included international participants, therefore with limited generalizability and cross-cultural relevance [12–15]. The objective of this secondary analysis of the Health Behavior in School-aged Children Study (HBSC) cross-sectional study (2013/2015 to 2017/2019) was to evaluate the relationships between recreational substance use (alcohol, tobacco and cannabis) and weekly

days of MVPA among a multinational sample of children and adolescents.

Methods

Study design and population

In the present study, we included children and adolescents aged 10–17 years from 45 countries or regions who participated in the HBSC study during the 2013/2015 and 2017/2019 waves. The HBSC is a collaborative research initiative by the WHO that aims to evaluate the health and well-being of youths across Europe and North America, utilizing a standardized methodological framework [19]. Data collection has been conducted every four years since the academic year of 1983–1984 in educational settings, employing independent, nationally representative samples of boys and girls aged 11, 13, and 15 years from each participating country or region [20]. Participants were selected through a multistage stratified random cluster sampling procedure, where school classes or entire schools served as primary sampling units. Inclusion criteria were being within the specified age range and having complete data on the variables relevant to this study. Data were collected using standardized, anonymous questionnaires administered in the students' native language during regular school hours. Participation was voluntary, and respondents were allowed to skip any question they did not wish to answer. Institutional ethics approval was obtained in each participating country, and written informed consent was provided by schools, students, and their parents or legal guardians. Given that this research involved a secondary analysis of anonymized and publicly available data, no additional ethical approval was required from the authors' institutions. Finally, after excluding participants with missing information on relevant variables, the final analytical sample included 358,391 participants.

Procedures

Physical activity (dependent variable)

Physical activity was assessed with the following standardized HBSC question: "Over the past 7 days, on how many days were you physically active for a total of at least 60 minutes per day?" [20]. In addition, response options ranged from 0 to 7 days/week to evaluate the adherence to recommendations on physical activity according to WHO [21].

Recreational substance use (independent variable)

In both waves of the HBSC study (2013/2015 to 2017/2019), all participants were asked about the number of days (from a lifetime perspective and over the past 30 days) they had consumed alcohol and tobacco. In contrast, the number of days of cannabis consumption (from a lifetime perspective and in the past 30 days) was exclusively asked among participants aged 15 years. Consequently, the analytical sample for models involving cannabis was restricted to participants aged ≥ 15 years, whereas models for alcohol and tobacco included participants aged 10–17 years. The responses were categorized into seven distinct options: never, 1–2 days, 3–5 days, 6–9 days, 10–19 days, 20–29 days, and 30 days or more [20].

Covariates

Several covariates were considered in the analyses, including age, sex, body mass index (BMI), socioeconomic status (SES), and survey year. In both study waves, the participants provided their own age and sex. BMI, expressed in kg/m^2, was calculated from the participants' self-reported body weight and height. Moreover, during the 2017/2019 wave, the classification of BMI conformed to the criteria established by the International Obesity Task Force (1 = thinness, 2 = normal weight, 3 = overweight, 4 = obesity). In further analysis, participants were classified as follows: 0 = no excess weight (i.e., thinness or normal weight) and 1 = excess weight (i.e., overweight or obesity). In both HBSC study waves, SES was measured with the Family Affluence Scale-III (FAS-III) [19, 20]. The FAS-III is a composite index (range 0–13) based on items regarding vehicle ownership, computer ownership, bedroom sharing, and the number of bathrooms, dishwashers, and family vacations in the past year, with each item receiving a score between 0 and 3. The total scores were transformed into country-specific proportional ranks and categorized into tertiles for analysis: low (lowest 20%), medium (middle 60%), and high (highest 20%) family affluence.

Statistical analysis

Counts and percentages were used to describe categorical variables, while continuous variables were summarized using means and standard deviations (SDs). Generalized linear models (GLMs) with a Poisson distribution were fitted, accounting for the complex sampling design of the HBSC survey (including country-level stratification, clustering, and sampling weights). Models were mutually adjusted for alcohol, tobacco, and cannabis use simultaneously to account for potential co-occurrence of substance use. GLMs were carried out considering both the use status (yes/no) and the frequency of recreational substance use (never, 1–2 days, 3–5 days, 6–9 days, 10–19 days, 20–29 days, and 30 days or more) for each substance (tobacco, alcohol, and cannabis). Models were adjusted for age, sex, SES, BMI status, and survey year. To examine potential sex-specific patterns, we conducted stratified models separately for boys and girls, applying the same model specifications and covariate adjustments as in the overall analyses. Average predicted

means of weekly MVPA between non-users versus users and across substance use categories were performed. To control for multiple testing, the Benjamini–Hochberg procedure was applied to adjust p-values. In addition, pairwise comparisons were performed with the Bonferroni–Holm method to control the familywise error rate (the probability of making at least one Type I error). As a sensitivity analysis, additional models were fitted separately for each substance. These models followed the same specification as the primary analyses, adjusting for age, sex, SES, BMI status, and survey year. Results were presented both for user versus non-user comparisons (binary models) and across frequency categories (ordinal models), to evaluate whether the observed associations remained consistent when considering separately the use of each recreational substance. Statistical significance was defined as a $p < 0.05$. All analyses were conducted using R statistical software (version 4.4.1; R Core Team, Vienna, Austria) and RStudio (version 2024.09.0 + 375; Posit, Boston, MA, USA).

Results

After excluding individuals with missing values on the variables relevant to each analysis, the analytical sample sizes varied across models. The total initial sample included 358,391 children and adolescents (mean age = 13.6 years; SD = 1.6; 51% female). Table 1 presents the descriptive characteristics of the study participants by survey year (2013/2015 and 2017/2019), including sociodemographic variables, BMI status, substance use, and levels of physical activity. Across both waves, most participants reported no alcohol, tobacco, or cannabis use in the last 30 days, with alcohol being the most commonly used substance. Regarding physical activity, approximately one-fifth of participants reported seven days of MVPA, while a small proportion reported no physical activity.

Figure 1 displays the mutually adjusted average predicted counts of weekly days with at least 60 min of MVPA between non-users and users of alcohol, tobacco, and cannabis in the last 30 days adjusted by age, sex, SES, and BMI. Alcohol use among participants showed no statistically significant difference in MVPA frequency between non-users (3.9 days/week; 95% confidence interval [CI] 3.8 to 3.9) and users (3.9 days/week; 95% CI 3.8 to 4.0). Moreover, tobacco users co-occurred with lower MVPA frequency (3.6 days/week; 95% CI 3.5 to 3.7) in comparison to non-users (3.9 days/week; 95% CI 3.8 to 4.0) with a statistically significant pairwise comparison (mean difference [MD] = 1.09; 95% CI 1.06 to 1.11; $p < 0.001$). Furthermore, participants who did not use cannabis presented almost the same MVPA frequency (3.9 days/week; 95% CI 3.8 to 3.9) in relation to cannabis users (3.9 days/week; 95% CI 3.8 to 4.1) without a statistically significant pairwise comparison.

Figure 2 displays the mutually adjusted average predicted counts of weekly days with at least 60 min of MVPA in relation to alcohol, tobacco, and cannabis use in the last 30 days adjusted by age, sex, SES, and BMI. In alcohol use, MVPA was relatively stable (~ 3.9 days/week) across low to moderate alcohol use (0–5 days) over the last 30 days. However, a descriptive slight increase was observed in those reporting alcohol use for 6–9 days in the last 30 days. After some fluctuation, the highest MVPA was reported in individuals with 30 days or more alcohol use (4.1 days/week) in the last 30 days. Statistically significant differences were observed between participants who drunk 6–9 days in comparison to those who drunk for 1–2 days ($p < 0.05$). Besides, ≥ 30 days alcohol users presented a positive association with higher MVPA in relation with low to moderate alcohol users (0–5 days) (all $p < 0.05$). In terms of tobacco use, individuals who reported never using tobacco had the highest predicted MVPA, averaging 3.9 days/week, whereas 30 days or more users averaged only 3.5 days/week. A statistically significant pairwise comparison was reported among non-users and those with 30 days or more tobacco use (MD = 1.12; 95% CI 1.07 to 1.18; $p < 0.001$). Moreover, tobacco use between 1 and 2 days in the last 30 days was associated with a reduction in MVPA to 3.7 days/week (95% CI 3.6 to 3.8), with a statistically significant pairwise comparison in relation to non-users (MD = 1.06; 95% CI 1.02 to 1.09; $p < 0.001$). The largest difference was observed between never users and those using tobacco within 20–29 days (MD = 1.13; 95% CI 1.07 to 1.20; $p < 0.001$) in the last 30 days. Finally, among cannabis use, the analysis revealed no statistically significant associations across usage frequencies. Non-users reported an average of 3.8 days/week of MVPA, whereas those using cannabis for 20–29 days had the lowest predicted MVPA at 3.7 days/week, indicating a downward trend. However, individuals who used cannabis for 30 days or more reported 3.9 days/week, similar to non-users. These findings suggest a nonlinear and not statistically significant relationship between cannabis use frequency and MVPA. Table S1 presents the complete predicted average weekly days of MVPA for alcohol, tobacco, and cannabis use among participants from the HBSC study (2013–2019).

Figure 3 shows the average predicted counts of weekly days with at least 60 min of MVPA between non-users and users of alcohol, tobacco, and cannabis in the last 30 days stratified by sex (adjusted by age, SES, and BMI). Across all the recreational substances, boys presented more predicted MVPA in comparison to girls. Besides, alcohol use was not associated with significant differences in MVPA frequency between non-users and users in either boys (4.2 vs. 4.3 days/week) or girls (3.5 vs. 3.6

Table 1 Descriptive data of the participants by HBSC study wave (2013/2015 and 2017/2019)

Variable	2013/2015 *N* = 179,104[1]	2017/2019 *N* = 179,287[1]
Age (years)	13.6 (1.6)	13.5 (1.6)
Missing	1,284	1,023
Sex		
Boys	86,970 (48.6%)	87,572 (48.8%)
Girls	92,134 (51.4%)	91,715 (51.2%)
SES		
Low SES	48,445 (27.0%)	50,225 (28.0%)
Medium SES	105,653 (59.0%)	103,164 (57.5%)
High SES	25,006 (14.0%)	25,898 (14.4%)
BMI (status)		
No excess weight	118,328 (80.3%)	117,335 (79.2%)
Excess weight	28,939 (19.7%)	30,893 (20.8%)
Missing	31,837	31,059
Alcohol use in the last 30 days		
Never	135,995 (80.2%)	138,949 (80.5%)
1–2 days	20,715 (12.2%)	20,738 (12.0%)
3–5 days	6,689 (3.9%)	6,539 (3.8%)
6–9 days	3,092 (1.8%)	2,997 (1.7%)
10–19 days	1,488 (0.9%)	1,516 (0.9%)
20–29 days	398 (0.2%)	508 (0.3%)
30 days or more	1,206 (0.7%)	1,442 (0.8%)
Missing	9,521	6,598
Tobacco use in the last 30 days		
Never	158,357 (91.7%)	157,937 (92.7%)
1–2 days	4,545 (2.6%)	4,215 (2.5%)
3–5 days	1,773 (1.0%)	1,639 (1.0%)
6–9 days	1,372 (0.8%)	1,156 (0.7%)
10–19 days	1,447 (0.8%)	1,167 (0.7%)
20–29 days	1,338 (0.8%)	1,019 (0.6%)
30 days or more	3,868 (2.2%)	3,154 (1.9%)
Missing	6,404	9,000
Cannabis use in the last 30 days (only among participants ≥ 15 years)		
Never	63,696 (94.0%)	65,010 (94.2%)
1–2 days	1,925 (2.8%)	1,785 (2.6%)
3–5 days	600 (0.9%)	651 (0.9%)
6–9 days	389 (0.6%)	421 (0.6%)
10–19 days	353 (0.5%)	330 (0.5%)
20–29 days	208 (0.3%)	187 (0.3%)
30 days or more	574 (0.8%)	636 (0.9%)
Missing	111,359	110,267
Days per week with at least 60 min of MVPA (number)		
0	7,404 (4.2%)	8,946 (5.1%)
1	12,171 (6.9%)	12,581 (7.1%)
2	22,295 (12.7%)	22,431 (12.7%)
3	28,419 (16.2%)	29,426 (16.7%)
4	26,360 (15.0%)	27,336 (15.5%)
5	26,076 (14.9%)	26,303 (14.9%)
6	17,307 (9.9%)	16,880 (9.6%)
7	35,349 (20.2%)	32,281 (18.3%)
Missing	3,723	3,103

BMI Body mass index, *MVPA* Moderate to vigorous physical activity, *SES* Socioeconomic status

[1]Mean (standard deviation) or number (percentage)

days/week). Nevertheless, tobacco use showed a negative association, with boys who smoked reporting 3.9 days/week (95% CI 3.9 to 4.1) of MVPA compared to non-smokers (4.3 days/week; 95% CI 4.2 to 4.4), with a statistically significant pairwise comparison (MD = 1.07; 95% CI 1.05 to 1.09; $p < 0.001$). Smoker females presented 3.3 days/week (95% CI 3.1 to 3.4) of MVPA compared to 3.6 days/week (95% CI 3.5 to 3.7) in non-smokers, with a statistically significant pairwise comparison (MD = 1.10; 95% CI 1.06 to 1.13; $p < 0.001$). Regarding cannabis, boys who reported use displayed a slightly higher MVPA compared to non-users (4.4 vs. 4.2 days/week; MD = 0.97; 95% CI 0.95 to 0.99; $p = 0.035$), whereas no significant difference was observed among girls (3.6 vs. 3.5 days/week).

Figure 4 reports the sex-stratified average predicted counts of weekly days with at least 60 min of MVPA in relation to alcohol, tobacco, and cannabis use in the last 30 days adjusted by age, SES, and BMI. Across all the recreational substances, boys presented a higher predicted MVPA in comparison to girls. Among boys, alcohol use showed a slight positive gradient, with non-users presenting 4.2 days/week of MVPA, while those reporting ≥ 30 days of alcohol use reported 4.5 days/week of physical activity. Nevertheless, participants who consumed alcohol at different frequencies did not experience lower or higher MVPA compared to non-users. In addition, tobacco use among boys demonstrated lower MVPA levels compared to non-users, decreasing from 4.3 days/week in never users to 3.8 days/week in users with 6–9 days and a slight increase of 4.0 days/week in those with ≥ 30 days of tobacco use. Foremost, a statistically significant pairwise comparison was observed among non-users and all the subgroup of tobacco users (all $p < 0.05$). Moreover, tobacco use between 1 and 2 days was associated with a reduction in MVPA (4.2 days/week) in comparison to users between 20 and 29 days (3.9 days/week) with a statistically significant pairwise comparison (MD = 1.09; 95% CI 1.00 to 1.18; $p < 0.05$). Cannabis use showed no statistically significant differences between no-users (4.2 days/week) and users (≥ 30 days of cannabis use reported 4.4 days/week) in MVPA frequency.

Among girls, alcohol use was not significantly associated with MVPA, with levels remaining stable across categories (non-users: 3.5 days/week and ≥ 30 days: 3.9 days/week). Tobacco use, however, showed a stronger negative gradient than in boys, with MVPA decreasing from 3.6 days/week among non-users to 3.0 days/week in girls reporting ≥ 30 days of use. Indeed, a statistically significant pairwise comparison was observed among all the subgroup of tobacco users in relation to no smokers ($p < 0.05$), except among girls who smoked 6–9 days. Finally, cannabis use among girls showed no consistent association with MVPA, with estimates remaining close to those of non-users across all categories (non-users: 3.5

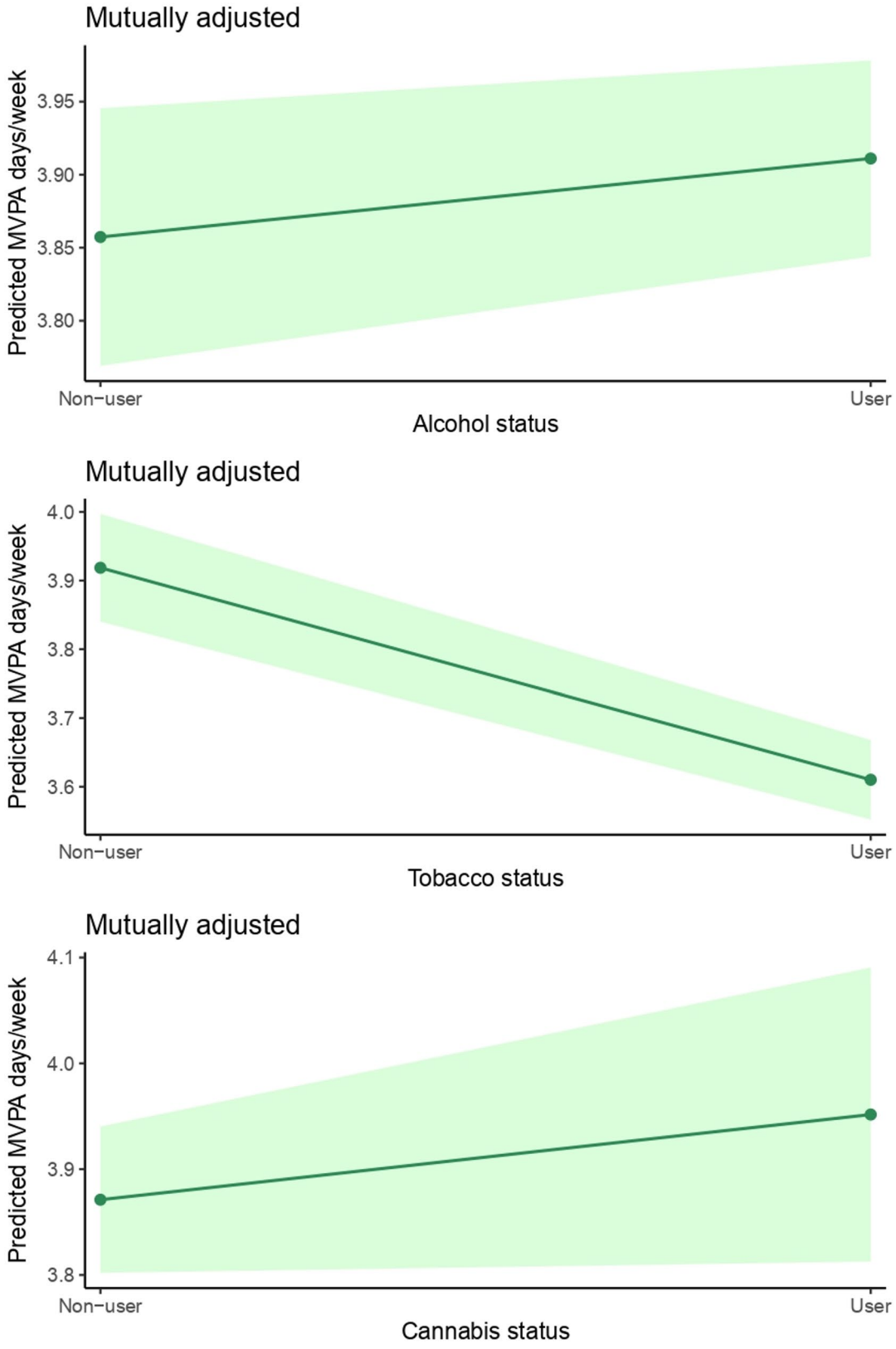


Fig. 1 Mutually adjusted estimated marginal means of weekly days with at least 60 min of moderate vigorous physical activity (MVPA) between non-users and users of alcohol, tobacco, and cannabis in the last 30 days among the 10- to 17-year-old population of the Health Behavior in School-Aged Children study ($N = 358,391$) (2013–2019). Adjusted for age, sex, socioeconomic status, body mass index status, and survey year

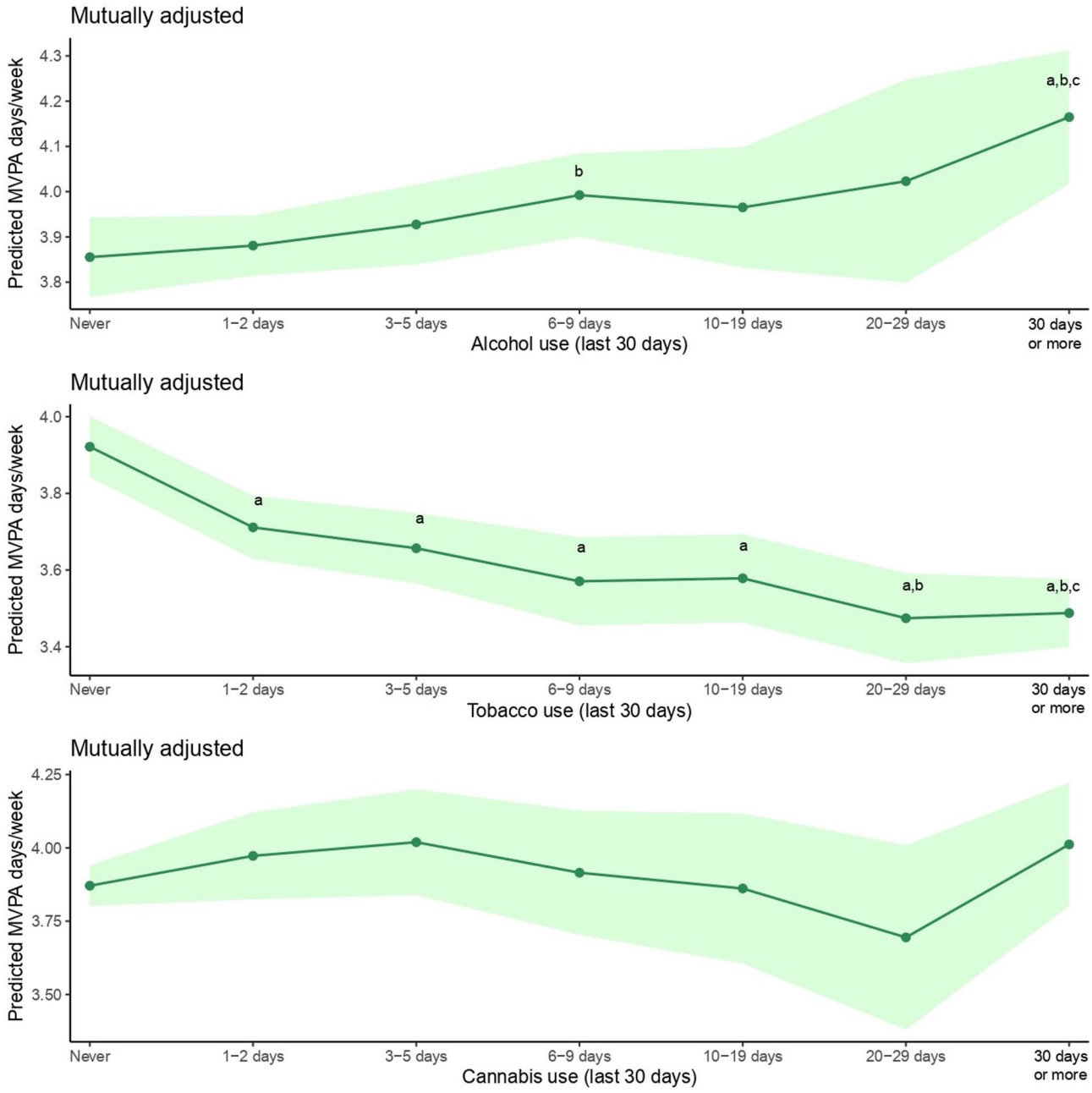


Fig. 2 Mutually adjusted estimated marginal means of weekly days with at least 60 min of moderate vigorous physical activity (MVPA) and recreational substance use (alcohol, tobacco, and cannabis) frequency in the last 30 days among the 10- to 17-year-old population of the Health Behavior in School-Aged Children study ($N = 358{,}391$) (2013–2019). Adjusted for age, sex, socioeconomic status, body mass index status, and survey year. [a]Significant differences from "Never" ($p < 0.05$); [b]Significant differences from "1–2 days" ($p < 0.05$); [c]Significant differences from "3–5 days" ($p < 0.05$)

days/week; ≥30 days: 3.7 days/week). Although an important decrease was observed in girls reporting 20–29 days of cannabis use (3.1 days/week). Table S2 presents the estimated marginal means of weekly moderate-to-vigorous physical activity days by recreational substance use frequency in the last 30 days stratified by sex among the study participants.

The sensitivity analyses including alcohol, tobacco, and cannabis separately (Figures S1 and S2) yielded results that were largely consistent with the main models (Figs. 1 and 2). In both sets of analyses, tobacco use remained robustly associated with lower MVPA, showing the strongest and most consistent negative relationship. Alcohol use continued to show no significant differences in physical activity between users and non-users, while cannabis use was associated with only small and inconsistent variations in MVPA. The inclusion of the three substances in different models did not materially alter the

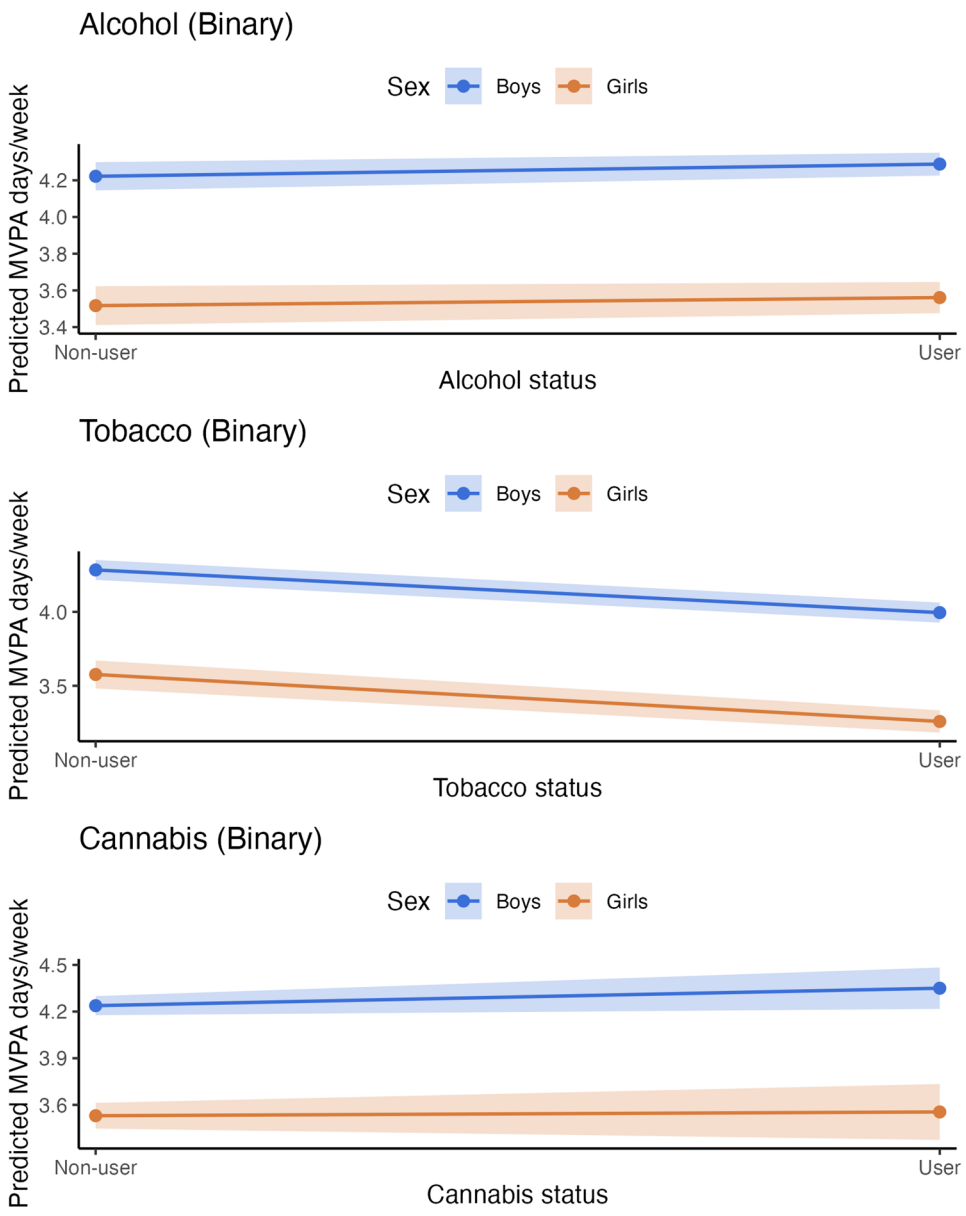


Fig. 3 Estimated marginal means of weekly days with at least 60 min of moderate vigorous physical activity (MVPA) stratified by sex between non-users and users of alcohol, tobacco, and cannabis in the last 30 days among the 10- to 17-year-old population of the Health Behavior in School-Aged Children study ($N = 358,391$) (2013–2019). Adjusted for age, socioeconomic status, body mass index status, and survey year

direction or magnitude of the associations, reinforcing the robustness of the primary findings.

Discussion

The present study explored the associations between the frequency of recreational substance use (alcohol, tobacco, and cannabis) and weekly days of MVPA among children and adolescents via data from the HBSC study (2013–2019). Overall, our findings reveal distinct patterns across substances. Between non-users and users, alcohol and cannabis users showed not statistically significant association with MVPA, while tobacco co-occurred with lower MVPA frequency. In terms of substance use by frequency levels, alcohol users showed a slightly positive association with MVPA which was statistically significant between never users versus 6–9 days and ≥ 30 days users. Foremost, tobacco use was significantly associated with lower MVPA, and cannabis use exhibited a nonlinear trend without significant differences across weekly days of MVPA. In addition, the sex-stratified analyses revealed that boys consistently reported higher levels of physical activity than girls across all categories of substance use, highlighting persistent gender disparities in health behaviors among youths. Moreover, the negative

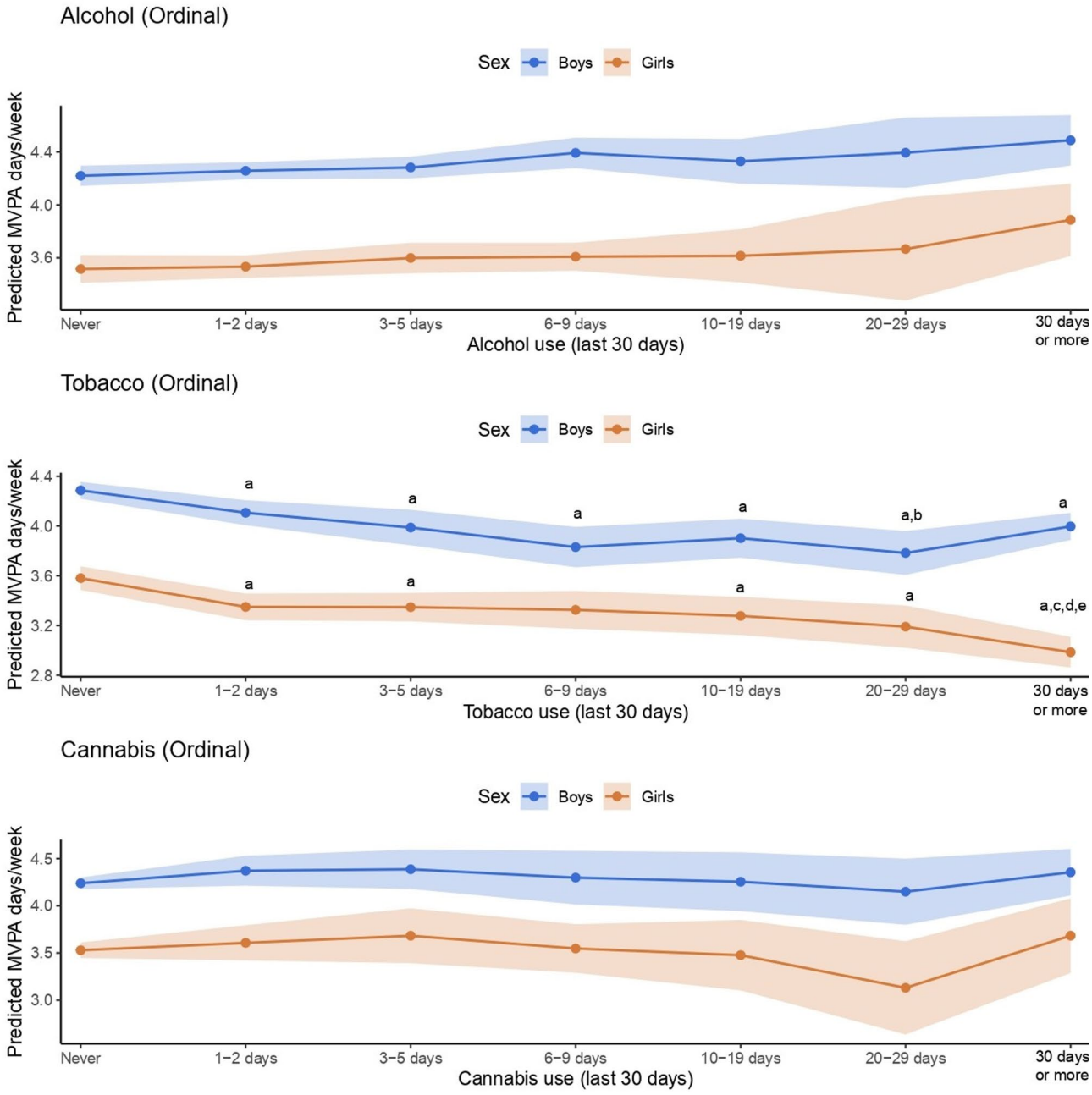


Fig. 4 Estimated marginal means of weekly days with at least 60 min of moderate vigorous physical activity (MVPA) and recreational substance use (alcohol, tobacco, and cannabis) frequency in the last 30 days stratified by sex among the 10- to 17-year-old population of the Health Behavior in School-Aged Children study ($N = 358{,}391$) (2013–2019). Adjusted for age, socioeconomic status, body mass index status, and survey year. [a]Significant differences from "Never" ($p < 0.05$); [b]Significant differences from "1–2 days" ($p < 0.05$); [c]Significant differences from "3–5 days" ($p < 0.05$); [d]Significant differences from "6–9 days" ($p < 0.05$); [e]Significant differences from "10–19 days" ($p < 0.05$)

association between tobacco use and physical activity was more pronounced among girls, whereas alcohol and cannabis use showed weaker or inconsistent associations with MVPA, particularly in female participants. Our results are in line with those of previous large-scale cross-sectional and longitudinal studies demonstrating that higher levels of physical activity are associated with lower odds of cigarette smoking and increased alcohol consumption [14, 22–25]. Longitudinal data from the Avon Longitudinal Study of Parents and Children (ALSPAC) cohort demonstrated that greater MVPA at age 11 was associated with reduced odds of smoking at age 13, and cumulative MVPA from ages 11 to 24 was linked to lower odds of progressive smoking into young adulthood [22]. Similarly, a global analysis of over 220,000 adolescents revealed that being physically active

(≥ 5 days per week with ≥ 60 min of physical activity), even at insufficient levels (1 to 4 days per week with ≥ 60 min of physical activity), was associated with lower odds of tobacco use than inactivity [14]. However, the relationship is not uniform across all forms of tobacco use. For example, U.S. national data showed that more days of physical activity per week were associated with lower odds of cigarette smoking but higher odds of e-cigarette and smokeless tobacco use, especially among males [23]. Additionally, the medical literature consistently demonstrated that participation in team or club sports is associated with higher odds of alcohol use than nonparticipant participation, especially among males and those who participate more frequently or competitively [24, 25]. Besides, the relationship between physical activity and alcohol use may involve compensatory mechanisms, such as shared dopaminergic regulation or moral licensing, where engaging in intense exercise increases the pursuit of hedonic rewards [6]. Additionally, social contexts like team sports may normalize concurrent alcohol use, reinforcing behavior patterns where both activities are closely linked [6, 26]. Furthermore, previous studies have suggested that physical inactivity during adolescence is associated with an increased risk of developing cannabis use disorder in adulthood [15].

Our findings that boys were more physically active than girls, and that gender differences also emerged in patterns of substance use, align with previous evidence documenting multifaceted discrepancies between male and female youths [27–29]. Across different populations, males were more likely to report higher rates of illicit drug use, cigarette smoking, and smokeless tobacco, whereas females showed greater prevalence of prescription opioid misuse and binge drinking, with some regional variation in alcohol use trajectories [28–30]. Similarly, physical activity levels were consistently lower among girls compared to boys, particularly during school hours and weekdays, as confirmed by both self-reported and accelerometer-based assessments [27, 30]. Importantly, the intersection of these behaviors suggests that while greater physical activity may reduce cigarette smoking, it can also be associated with increased use of non-combustible tobacco products, alcohol, or steroids, especially among male athletes [23, 28]. Taken together, these patterns underscores the need for prevention and intervention strategies that simultaneously address both substance use and physical activity, while accounting for their distinct manifestations among boys and girls.

While the current study identifies an inverse association between tobacco use and MVPA, the cross-sectional design precludes causal inference. The underlying mechanisms remain unclear but may involve interrelated behavioral, social, and environmental pathways. For instance, the strong negative association observed for tobacco could be partly mediated by peer group dynamics, where youths who smoke may self-select into or be influenced by social networks that place a lower value on health-promoting behaviors like physical activity [25, 31, 32]. Similarly, the lack of a significant negative association for alcohol and the non-linear trend for cannabis might reflect different social contexts of use. For example, alcohol use, is often integrated into social gatherings that could coincide with or even facilitate physical activity (e.g., post-sport social events), which could attenuate a negative association [6, 24]. At the behavioral level, traits such as sensation seeking, impulsiveness, and reward sensitivity are associated with both an increased risk of recreational substance use and lower engagement in physical activity among US adolescents [31]. Moreover, parental factors, including parental substance use disorders, could also contribute to recreational substance use risk among youths, increased physical inactivity and substance use in offspring, particularly in males, where physical inactivity mediates the association between parental substance use disorders and later cannabis use disorders [15]. In addition, social cohesion, school connectedness, and opportunities for substance use in the environment can also modulate substance use risk among youths [26]. It is important to emphasize that these are potential pathways suggested by previous literature and were not directly tested in the present analysis.

Peer influences are among the strongest predictors of substance use in youths through direct (peer offers and modeling) and indirect mechanisms (perceived approval of substance use) [32]. In fact, evidence demonstrates that peer influence, particularly through social networks and perceptions of peer norms, significantly predicts the initiation and escalation of behaviors such as alcohol, tobacco, and cannabis use [33]. For example, meta-analytic and longitudinal studies using advanced social network modeling confirmed that both peer selection (choosing friends with similar behaviors) and peer influence (adopting behaviors of peers) contribute to recreational substance use in youths, with effect sizes ranging from medium to large [33, 34]. Additionally, the quality of social relationships also moderates susceptibility to peer influence. Youths with higher-quality relationships (both with peers and parents) are more likely to align their substance use behaviors with those of their close friends, whether with increasing or decreasing use [35]. In contrast, the influence of peers on physical activity is less pronounced and more variable. While there is evidence of behavioral similarity within social networks for physical activity among youths, the association was generally weaker than that for recreational substance use [33]. Furthermore, denser and more cohesive peer networks may be associated with lower levels of harmful behaviors, potentially including physical inactivity, suggesting

that network structure can play a protective role [33, 34]. Moreover, SES is a significant determinant of substance use patterns in youths, with lower SES (measured by parental education, family affluence, and community characteristics) generally associated with inc reased risk for initiation and more harmful patterns of use across multiple substances [36, 37]. This could be mediated in part by reduced access to alternative reinforcers and shaped by both family and social network dynamics [37].

Multiple large-scale, cross-sectional and longitudinal studies have demonstrated that insomnia, short sleep duration, sleep disturbances, and irregular sleep timing (such as large differences between weekday and weekend bedtimes) are associated with increased odds of alcohol, tobacco, cannabis, and other drug use, as well as with substance misuse [38–40]. With respect to physical activity, insomnia and poor sleep were associated with lower self-reported physical activity among youths. The combination of insomnia and low physical activity was particularly associated with poor self-reported health, suggesting a synergistic negative effect on overall well-being [38]. In addition, longitudinal data indicated that unhealthy sleep practices in adolescence, particularly sleep disturbance and social jetlag, could predict increased recreational substance use in young adulthood [39]. Foremost, shorter sleep duration and later bedtimes in both childhood and adolescence were prospectively associated with earlier initiation and a higher prevalence of alcohol and marijuana use by mid-adolescence [40].

The present study has several limitations that should be considered. First, all the data were obtained through self-report questionnaires instead of objective methods, which may have led to the introduction of recall or social desirability bias in the results. Second, the cross-sectional design utilized in this research restricted the ability to establish a causal link between the outcomes observed. As a result, future prospective cohort observational studies are essential to yield significant insights into the ways in which various exposures, behaviors, and conditions influence recreational substance use in youths over time. This information will aid in identifying preventive strategies, high-risk populations, and the efficacy of current interventions. Third, the small sample size observed in the higher-frequency substance use categories (such as, 20–29 days and 30 days or more) limit the statistical power and precision of our estimates for these groups. The wider CIs and potential for unstable estimates in these categories necessitate cautious interpretation, particularly for the nonlinear trends observed with cannabis and alcohol models. Fourth, a key limitation is the restriction of cannabis use data to participants aged 15 years or older. This introduces a potential selection bias, as this older subsample may systematically differ from the full cohort in terms of physical activity patterns and other health behaviors. Furthermore, it impedes direct comparability with the alcohol and tobacco models, which included a wider age range (10–17 years). The loss of statistical power and these potential biases may partly explain the less consistent and non-significant findings observed for cannabis use compared to tobacco. Fifth, the slight increase in MVPA observed among participants reporting cannabis use on all 30 days may reflect heterogeneity within this group, potentially due to the design of the survey question, which could have captured a wide range of usage patterns and contexts. Sixth, since we unknown the type, context, or social setting of the physical activity performed by participants (e.g. team vs. individual, competitive vs. recreational). This is an important limitation, as existing literature suggests these factors may differentially influence substance use [24, 25]. Seventh, as previously discussed, we did not measure potential mediating factors such as peer influence, parental factors, or sleep quality, which are crucial for understanding the mechanisms behind the observed associations. However, a major strength of our research was the use of standardized and validated measures for both physical activity and recreational substance use ensures comparability and reliability of the data. Besides, the application of GLMs allowed for the adjustment of key confounders providing more accurate estimates of the associations. Furthermore, the adjustment for country-level stratification in the analysis enhances the generalizability of our findings across diverse national contexts.

Conclusions

Our study revealed divergent patterns in the relationship between recreational substance use and physical activity among children and adolescents. Based on the non-user and user analysis, tobacco use was associated with significantly lower levels of weekly MVPA among youths. In contrast, no meaningful difference in physical activity was observed between alcohol and cannabis users and non-users. On the other hand, frequent alcohol use was associated with a modest increase in MVPA, while tobacco use was clearly associated with lower levels of weekly physical activity, particularly among those with more frequent use. Cannabis use did not show a consistent or statistically significant association with MVPA, suggesting a more complex or weaker relationship. Besides, boys consistently reported higher levels of physical activity and distinct patterns of substance use compared to girls, underscoring the importance of incorporating gender-specific approaches into health promotion strategies among youths. Based on our findings, health promotion efforts targeting children and adolescents should prioritize the prevention and reduction of tobacco and cannabis use, given their consistent negative associations with physical activity levels. School-based

interventions should integrate recreational substance use prevention with strategies to increase physical activity, particularly among high-risk groups. Public health policies may also benefit from adopting a more holistic approach that addresses multiple health behaviors simultaneously, rather than in isolation. Nevertheless, future research is needed to better understand the directionality and mechanisms underlying the observed associations. Additionally, future studies should examine how emerging nicotine products (such as e-cigarettes and heated tobacco) may influence physical activity patterns and interact with traditional substance use behaviors among youths.

Abbreviations

ALSPAC	Avon Longitudinal Study of Parents and Children
BMI	Body mass index
CI	Confidence interval
FASS	III-Family Affluence Scale-III
GLM	Generalized linear model
HBSC	Health Behavior in School-aged Children Study
MD	Mean difference
MVPA	Moderate to vigorous physical activity
SD	Standard deviations
SES	Socioeconomic status
WHO	World Health Organization

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-25448-4.

Additional file 1. Table S1. Estimated marginal means of weekly moderate-to-vigorous physical activity days by recreational substance use frequency in the last 30 days of the HBSC study participants (2013-2019) (N=358,391). Table S2. Estimated marginal means of weekly moderate-to-vigorous physical activity days by recreational substance use frequency in the last 30 days stratified by sex among the HBSC study participants (2013-2019) (N=358,391). Figure S1. Sensitivity analyses including alcohol, tobacco, and cannabis simultaneously. Estimated marginal means of weekly days with at least 60 minutes of moderate vigorous physical activity (MVPA) between non-users and users of alcohol, tobacco, and cannabis in the last 30 days among the 10- to 17-year-old population of the Health Behavior in School-Aged Children study (N=358,391) (2013-2019). Adjusted for age, sex, socioeconomic status, body mass index status, and survey year. Figure S2. Sensitivity analyses including alcohol, tobacco, and cannabis simultaneously. Estimated marginal means of weekly days with at least 60 minutes of moderate vigorous physical activity (MVPA) and recreational substance use (alcohol, tobacco, and cannabis) frequency in the last 30 days among the 10- to 17-year-old population of the Health Behavior in School-Aged Children study (N=358,391) (2013-2019). Adjusted for age, sex, socioeconomic status, body mass index status, and survey year.Description of data: Table S1 presents the complete predicted average weekly days of MVPA for alcohol, tobacco, and cannabis use among youth from the HBSC study (2013–2019). Table S2 presents the complete predicted average weekly days of MVPA for alcohol, tobacco, and cannabis among youth stratified by sex from the HBSC study (2013–2019). Figure S1 presents the sensitivity analyses including alcohol, tobacco, and cannabis simultaneously of the estimated marginal means of weekly days with at least 60 minutes of MVPA between non-users and users of alcohol, tobacco, and cannabis among adolescents from the HBSC study (2013–2019). Figure S2 presents the sensitivity analyses including alcohol, tobacco, and cannabis simultaneously of the estimated marginal means of weekly days with at least 60 minutes of MVPA and recreational substance use (alcohol, tobacco, and cannabis) frequency in the last 30 days among youth from the HBSC study (2013–2019).

Authors' contributions

CM and JFLG conceived the presented idea and conceptualization. JFLG did data curation and conducted statistical analyses. CM drafted the main manuscript text. CM, RY-S, HG-E, JO-A, MR-A, JC, RL-B, and JFLG interpreted study results. JFLG supervision. JFLG prepared all tables and figures. All authors reviewed the manuscript and approved the final manuscript for publication.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Institutional ethics approval was obtained in each participating country. Written informed consent was obtained from schools, students, and their parents or legal guardians.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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