Physical Activity in Adolescence and Cannabis Use in Adulthood: Evidence from the National Longitudinal Study of Adolescent Health in the United States (1994-2018)

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Abstract

Adolescence is a key period when many individuals change their physical activity behaviors and may initiate cannabis use, making it an important time to both promote physical activity and prevent cannabis use. This study examined the association between physical activity in adolescence and cannabis use in adulthood. We analyzed data from 2,196 adolescents who participated in Waves 1 to 5 of the National Longitudinal Study of Adolescent Health (Add Health) from 1994-2018. The mean baseline age was 15, and participants were followed for 24 years. Using weighted mixed-effects Poisson models, we estimated the association between physical activity in Wave 1 (1994-1995) and time-varying cannabis use across subsequent waves, adjusting for sociodemographic factors and baseline substance use. Results were stratified by type of physical activity (i.e., sports, exercise). At baseline, participants engaged in physical activity an average of six times per week. Age, sex, cigarette smoking, and alcohol use were significantly associated with cannabis use over time. Physical activity was associated with lower cannabis use when defined as daily versus less than daily (IRR = 0.63, 95% CI = 0.41, 0.95; p = 0.03), but not when analyzed as a continuous frequency variable (IRR = 1.01, 95% CI = 0.99, 1.02; p = 0.483). Participation in sports and exercise showed a protective association when categorized by weekly frequency. These findings suggest physical activity may protect against cannabis use depending on how activity is measured. Future research should explore the association of different types and contexts of physical activity on cannabis use over time.

Keywords: adolescence, physical activity, sports, exercise, cannabis use, longitudinal, epidemiology

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Introduction

Cannabis use among US adolescents has increased over time (Ignaszewski, 2021). This trend is associated with potential long-term consequences such as substance use disorders, mood disorders, severe mental illnesses, and lower educational and employment outcomes (Ignaszewski, 2021; Karila et al., 2014). In 2019, approximately 17.5% of adolescents aged 12-17 used cannabis in the past year (Ignaszewski, 2021). There have been substantial increases in cannabis vaping over the past decade (Ignaszewski, 2021; Lim et al., 2022), particularly among Hispanic adolescents and those from low socioeconomic backgrounds (Keyes et al., 2022).

Research on adolescent cannabis use has predominantly focused on biological, social, and policy-related factors. For example, previous studies have reported a common underlying genetic architecture for multiple substance use disorders, including cannabis (Hatoum et al., 2023). Additionally, negative perceived social norms are a strong determinant of cannabis use prevention (Ajzen, 1991; Wu et al., 2015). Research

indicates that legalization or changes in the price of recreational cannabis lead to reduced cannabis use in young adolescents (Cerdá et al., 2018; Coley et al., 2021; Pacula & Lundberg, 2014). Studies also report that alcohol and tobacco use initiation are risk factors for cannabis use (Guxensa et al., 2007). However, the role of physical activity as a behavioral determinant of cannabis use remains understudied. The association between physical activity and cannabis use from adolescence throughout adulthood is not yet fully understood (West et al., 2020). One reason for this link during adolescence may be the influence of peer groups, as individuals at this stage often begin to identify with peers, including those engaged in sports or physical activity, who can shape their attitudes, norms, and behaviors related to substance use, including cannabis (Brown, 1990; Cole et al., 2024; Thorlindsson & Bernburg, 2006; Veliz et al., 2015).

Research exploring the association between physical activity and cannabis use has produced mixed findings (Kwan et al., 2014; West et al., 2020). Studies reporting significant negative associations between physical activity and cannabis use have been conducted in samples of high school adolescents. Engaging in sports was associated with lower of cannabis into young adulthood (Barber et al., 2001; Terry-McElrath & O'Malley, 2011), particularly among Black males and females, and White males (Dawkins et al., 2006). Conversely, studies that did not find significant associations have been conducted in samples of young adults. Participation in organized sports during adolescence was independent of cannabis use in adulthood (Aaron et al., 1995; Mahoney & Vest, 2012; Wichstrøm & Wichstrøm, 2009).

This existing literature provides valuable insights into how physical activity may influence cannabis use in adulthood; however, these studies' methodological limitations include long follow-up times, grouped rather than individual measurement of cannabis use or physical activity, samples of youth in narrow periods of adolescence, and little use of statistical models to account for the change in variables over time. Most studies also have restricted their analysis to exercise or sports only, excluding other dimensions of physical activity. Our study addresses these limitations and research gaps by including follow-up times from adolescence to adulthood, individual measurements of cannabis use and physical activity, and by considering changes across adolescence into adulthood. We aimed to assess the longitudinal relationship between physical activity in adolescence and cannabis use in adulthood in a nationally representative sample of US adolescents. Clarifying the association between physical activity and cannabis use can inform physical activity-based interventions for cannabis use prevention.

Methods

Study Design and Sample

This cohort study used data from the National Longitudinal Study of Adolescent to Adult Health (Add Health), a nationally representative survey of non-institutionalized US adolescents aged 12-19. Participants, with parental consent, completed questionnaires in 80 pre-selected high schools from 1994-1995 (grades 7-12) and were followed in five waves into adulthood through 2018, with an average follow-up time of five years between waves (Harris et al., 2019; Harris & Udry, 2022). Add Health employed a stratified, school-based design (Harris, 2013).

The publicly available baseline sample included 6,504 participants, of whom 4,194 completed Wave 5. We excluded individuals who used cannabis at baseline to focus on newly incident cannabis use, resulting in 5,531 eligible participants. After excluding 3,335 individuals lost to follow-up in any

wave, the final analytic sample included 2,196 participants. Of the 2,196 participants, 167 participants had missing data, but were retained. This study was deemed non-human-subjects research by the Indiana University - Bloomington Institutional Review Board (#15879).

Measures

The primary outcome of interest was "past 30-day cannabis use," defined as any use in Waves 2-5 as adolescents aged into adulthood. The primary exposure of interest was "past 7-day physical activity," measured as a continuous variable. Adolescents were asked how many times they had engaged in the following activities in the past week: 1) Bicycling, skateboarding, dancing, hiking, hunting, or yard work; 2) Rollerblading, roller skating, downhill skiing, snowboarding, racquet sports, or aerobics; 3) Strenuous team sports (e.g., football, soccer, basketball, lacrosse, rugby, field hockey, ice hockey); 4) Individual sports (e.g., running, wrestling, swimming, cross-country skiing, cycle racing, martial arts); 5) Gymnastics, weightlifting, or strength training; 6) Golf, fishing, bowling, softball, or baseball; and 7) Walking for exercise.

In Waves 1 and 2, physical activity was assessed via three categorical questions; in Waves 3-5, seven questions with numerical responses were used (See Supplement 1). To create a consistent variable across waves, we harnessed a prior methodology (Ali et al., 2014; Rees & Sabia, 2010; Richmond et al., 2006) in converting categorical responses into numeric values: "not at all" = 0; "1 or 2 times" = 1.5; "3 or 4 times" = 3.5; "5 or more times" = 5. A total weekly activity score (range: 0-35) was computed by summing responses across all activities. For sensitivity analyses, physical activity was dichotomized as daily vs. non-daily to follow the latest physical activity guidelines (American Heart Association, 2023). From our continuous physical activity measure, we created a binary variable to measure whether the adolescent exercised seven or more times per week.

Covariates

Covariates included age (years), sex (male, female), and race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, non-Hispanic Other) based on prior literature (Agrawal et al., 2006; Córdoba-Grueso et al., 2024), along with past 30-day cigarette smoking and past 12-month alcohol use, both known to co-occur with cannabis use (Parker et al., 2021; Weinberger et al., 2021). Alcohol use was not available for the past 30 days. Variable definitions and details can be found in the Add Health codebook (Harris & Udry, 2022).

Statistical Analysis

We used a weighted generalized linear mixed-effect Poisson model with a log link function to estimate incidence rate ratios (IRRs) for cannabis use. We selected a Poisson model because it provides more robust variance estimates than binomial models (Chen et al., 2018; Ibáñez-Pinilla et al., 2023), and the resulting IRRs are generally more reliable and easier to interpret than odds ratios (Thompson et al., 1998; Wilson, 2022). The model included a random intercept for each individual to account for repeated measures. Cannabis use was treated as a time-varying outcome. Models were adjusted by sex, race/ethnicity, cigarette smoking, and alcohol use. Sampling weights from Wave 5 were used to account for the stratified, clustered survey design as recommended in the "Guidelines for Analyzing Add Health" (Chen & Harris, 2020). Descriptive analyses were conducted in RStudio (version 2023.06.1+524), while multivariate models were run using SAS Viya for Learners (version 3.5) to account for the repeated measures and complex survey design.

Supplement 1
Questions on Physical Activity, Exercise and Sports, Add Health Study 1994-2018

Waves	Variable Name in Add Health	Question	Original Answer	Original Variable Type	New Answer	New Variable Type	Used in Sensitivity Analysis to Assess
1, 2	H1DA5 (W1) H2DA5 (W2)	During the past week, how many times did you play an active **sport**, such as baseball, softball, basketball, soccer, swimming, or football?	0 (not at all), 1 (1 or 2 times), 2 (3 or 4 times), 3 (5 or more times), 6 (refused), 8 (don't know)	Categorical	0 (0 times), 1.5 (1 or 2 times), 3.5 (3 or 4 times), 5 (5 or more times)	Numeric	Sports, Physical Activity
1, 2	H1DA6 (W1) H2DA6 (W2)	During the past week, how many times did you **exercise**, such as jogging, walking, karate, jumping rope, gymnastics, or dancing?	0 (not at all), 1 (1 or 2 times), 2 (3 or 4 times), 3 (5 or more times), 6 (refused), 8 (don't know)	Categorical	0 (0 times), 1.5 (1 or 2 times), 3.5 (3 or 4 times), 5 (5 or more times)	Numeric	Exercise, Physical Activity
1, 2	H1DA4 (W1) H2DA4 (W2)	During the past week, how many times did you go rollerblading, roller-skating, skateboarding, or bicycling?	0 (not at all), 1 (1 or 2 times), 2 (3 or 4 times), 3 (5 or more times), 6 (refused), 8 (don't know)	Categorical	0 (0 times), 1.5 (1 or 2 times), 3.5 (3 or 4 times), 5 (5	Numeric	Physical Activity

					or more times)		
3, 4	*H3DA10 (W3) H4DA4 (W4)*	*In the past seven days, how many times did you participate in strenuous team **sports** such as football, soccer, basketball, lacrosse, rugby, field hockey, or ice hockey?*	0 (not at all), 1 (1 time), 2 (2 times), 3 (3 times), 4 (4 times), 5 (5 times), 6 (6 times), 7 (7 times), 96 (refused), 98 (don't know)	*Numeric*	0 (0 times), 1.5 (1 or 2 times), 3.5 (3 or 4 times), 5 (5 or more times)	Numeric	Sports, Physical Activity
3, 4	*H3DA11 (W3) H4DA5 (W4)*	*In the past seven days, how many times did you participate in individual sports such as running, wrestling, swimming, cross-country skiing, cycle racing, or martial arts?*	0 (not at all), 1 (1 time), 2 (2 times), 3 (3 times), 4 (4 times), 5 (5 times), 6 (6 times), 7 (7 times), 96 (refused), 98 (don't know)	*Numeric*	0 (0 times), 1.5 (1 or 2 times), 3.5 (3 or 4 times), 5 (5 or more times)	Numeric	Physical Activity
3, 4, 5	*H3DA8 (W3) H4DA2 (W4) H5ID24 (W5)*	*In the past seven days, how many times did you bicycle, skateboard, dance, hike, hunt, or do yard work?*	0 (not at all), 1 (1 time), 2 (2 times), 3 (3 times), 4 (4 times), 5 (5 times), 6 (6 times), 7 (7 times), 96 (refused), 98 (don't know)	*Numeric*	0 (0 times), 1.5 (1 or 2 times), 3.5 (3 or 4 times), 5 (5 or more times)	Numeric	Physical Activity

3, 4, 5	*H3DA9 (W3) H4DA3 (W4) H5ID25 (W5)*	*In the past seven days, how many times did you roller blade, roller skate, downhill ski, snow board, play racquet sports, or do aerobics?*	0 (not at all), 1 (1 time), 2 (2 times), 3 (3 times), 4 (4 times), 5 (5 times), 6 (6 times), 7 (7 times), 96 (refused), 98 (don't know)	*Numeric*	0 (0 times), 1.5 (1 or 2 times), 3.5 (3 or 4 times), 5 (5 or more times)	Numeric	Physical Activity
3, 4, 5	*H3DA12 (W3) H4DA6 (W4) H5ID26 (W5)*	*In the past seven days, how many times did you participate in gymnastics, weightlifting, or strength training?*	0 (not at all), 1 (1 time), 2 (2 times), 3 (3 times), 4 (4 times), 5 (5 times), 6 (6 times), 7 (7 times), 96 (refused), 98 (don't know)	*Numeric*	0 (0 times), 1.5 (1 or 2 times), 3.5 (3 or 4 times), 5 (5 or more times)	Numeric	Physical Activity
3, 4, 5	*H3DA13 (W3) H4DA7 (W4) H5ID28 (W5)*	*In the past seven days, how many times did you play golf, go fishing or bowling, or play softball or baseball?*	0 (not at all), 1 (1 time), 2 (2 times), 3 (3 times), 4 (4 times), 5 (5 times), 6 (6 times), 7 (7 times), 96 (refused), 98 (don't know)	*Numeric*	0 (0 times), 1.5 (1 or 2 times), 3.5 (3 or 4 times), 5 (5 or more times)	Numeric	Physical Activity
3, 4, 5	*H3DA14 (W3)*	*In the past seven days, how many times did you walk for **exercise**?*	0 (not at all), 1 (1 time), 2 (2 times), 3 (3	*Numeric*	0 (0 times), 1.5 (1 or 2 times), 3.5	Numeric	Exercise, Physical Activity

	H4DA8 (W4) H5ID29 (w5)		times), 4 (4 times), 5 (5 times), 6 (6 times), 7 (7 times), 96 (refused), 98 (don't know)		(3 or 4 times), 5 (5 or more times)		
5	H5ID27 (W5)	*In the past seven days, how many times did you participate in individual **sports** such as running, wrestling, swimming, cross-country skiing, cycle racing, martial arts OR in strenuous team sports such as football, soccer, basketball, lacrosse, rugby, field hockey, or ice hockey??*	0 (not at all), 1 (1 time), 2 (2 times), 3 (3 times), 4 (4 times), 5 (5 times), 6 (6 times), 7 (7 times), 96 (refused), 98 (don't know)	Numeric	0 (0 times), 1.5 (1 or 2 times), 3.5 (3 or 4 times), 5 (5 or more times)	Numeric	Sports, Physical Activity

**Note*. W1=wave 1, W2=wave 2, W3=wave 3, W4=wave 4, W5=wave 5.

We conducted three sensitivity analyses. The first model explored estimates using a binary physical activity variable. Participants were classified based on whether they met the American Heart Association's daily physical activity recommendations (American Heart Association, 2023). An interaction term between physical activity and age assessed whether the association changed over time. The second model applied a binomial model with a logit link function using the same binary exposure to compare to our Poisson model. The third model examined sports-only and exercise-only models to evaluate associations by type of physical activity. We also assessed differential attrition by age, sex, race/ethnicity, and cigarette use.

Results

At baseline (1994-1995), adolescents engaged in physical activity an average of six times per week. The mean age was 15 years; 50% were female, and 70% identified as non-Hispanic White. Nearly 19% had smoked cigarettes in the past 30 days, and 37% used alcohol in the past 12 months (Table 1). The frequency of physical activity decreased from adolescence through Wave 3, then returned to baseline physical activity levels. Cannabis use increased during adolescence, peaking at 21% in young adulthood (around age 21), declining to 15% at age 28, and rising again to 19% by age 37 (Table 1).

In the adjusted Poisson model, adolescent physical activity measured as a continuous frequency was not significantly associated with cannabis use in adulthood. Each additional instance of physical activity per week was associated with an IRR of 1.01 (95% CI=0.99, 1.02, p=0.483), indicating no protective effect (Table 2). However, several covariates were significantly associated with cannabis use: age, sex, cigarette smoking, and alcohol use. Each additional year of age was associated with a 3% increase in cannabis use incidence (IRR=1.03, 95% CI=1.02, 1.04, p<0.0001). Males had 1.35 times the incidence of cannabis use compared to females (IRR=1.35, 95% CI=1.16, 1.58, p=0.0002). Individuals who smoked cigarettes had 2.76 times the incidence of cannabis use compared to those who did not smoke (IRR=2.76, 95% CI=2.34, 3.24, p<0.001). Those who used alcohol had 3.29 times the incidence of cannabis use compared to those who did not drink (IRR=3.29, 95% CI=2.60, 4.16, p<0.001) (Table 2).

Findings from our sensitivity analyses revealed that when physical activity was modeled as a binary variable (daily versus less than daily), it was significantly protective against cannabis use in adulthood. Adolescents who met daily activity recommendations had lower incidence of cannabis use (IRR=0.54, 95% CI=0.53, 0.54, p<0.001) (Supplement 2a) compared to those who did not. An interaction term between physical activity and age showed that the association between physical activity and cannabis use changed over time (p<0.001) (Supplement 2a).

The protective association persisted across model types: Poisson model using binary physical activity (IRR=0.64, 95% CI=0.42, 0.97, p=0.034) and Binomial model (IRR=0.46, 95% CI=0.24, 0.88, p=0.018).

Table 1

Sociodemographic and substance use characteristics of study participants in Add Health Study, 1994-2018

Variables	Wave 1 1994-1995	Wave 2 1996	Wave 3 2001-2002	Wave 4 2008-2009	Wave 5 2016-2018
Age (years)					
Mean	**15**	**16**	**21**	**28**	**37**
Standard Error	0.051	0.052	0.052	0.052	0.055
Race/Ethnicity					
Non-Hispanic White	1489	1489	1489	1489	1489
%	**70.43%**	**70.43%**	**70.43%**	**70.43%**	**70.43%**
Hispanic	194	194	194	194	194
%	10.90	10.90	10.90	10.90	10.90
Non-Hispanic Black	418	418	418	418	418
%	15.04	15.04	15.04	15.04	15.04
Non-Hispanic Other	85	85	85	85	85
%	3.63	3.63	3.63	3.63	3.63
Total	2186	2186	2186	2186	2186
Sex/Gender					
Female	1308	1308	1308	1308	1308
%	**49.98%**	**49.98%**	**49.98%**	**49.98%**	**49.98%**
Total	2196	2196	2196	2196	2196
Past 12-month Alcohol Use					
n	778	870	1609	1634	1858
%	**37.06%**	**41.26%**	**72.60%**	**73.93%**	**83.49%**
Total*	2192	2191	2191	2194	2196
Past 30-day Cigarette Smoking					
n	357	582	618	663	470
%	**19.38%**	**29.46%**	**32.49%**	**37.24%**	**26.79%**
Total*	2189	2189	2192	2180	2182
Past 30-day Cannabis Use					
n	0	171	408	279	359
%	**0%**	**8.81%**	**20.61%**	**14.83%**	**19.37%**
Total*	2196	2175	2193	2195	2193
Past 7-day Physical Activity (Times/week)					
Mean	**6.32**	**6.18**	**5.84**	**6.11**	**6.35**
Standard Error	0.101	0.096	0.158	0.159	0.142

**Note.* Some counts do not add up to total sample size due to missing data; Only baseline (Wave 1) sociodemographic characteristics, alcohol use, cigarette smoking, and physical activity were included in models, though cannabis use was time-varying (i.e., included from Wave 1 to Wave 5).

Table 2

Poisson regression model evaluating the association between physical activity in adolescence and cannabis use in adulthood

Variables	Adjusted IRR*	95% CI	p-value
Physical Activity (times/week)	1.01	0.99, 1.02	0.4834
Age (years)	1.03	1.02, 1.04	**<0.0001**
Sex/Gender (Ref=Female)	1.35	1.16, 1.58	**0.0002**
Race/Ethnicity Hispanic (Ref=Non-Hispanic White)	0.92	0.70, 1.21	0.5731
Race/Ethnicity Non-Hispanic Black (Ref=Non-Hispanic White)	1.22	0.98, 1.52	0.0725
Race/Ethnicity Non-Hispanic Other (Ref=Non-Hispanic White)	1.00	0.71, 1.41	0.9968
Cigarette smoking (Ref=No Smoking)	2.76	2.34, 3.24	**<0.0001**
Alcohol Use (Ref=No Drinking)	3.29	2.60, 4.16	**<0.0001**

*Incidence Rate Ratio.

**Note.* Model adjusted for Age, Sex, Race/Ethnicity, Cigarette smoking, and Alcohol Use

Stratified models showed an inverse relationship between frequency of sports or exercise in adolescence and cannabis use in adulthood. IRR estimates for sports participation decreased with increasing frequency compared to those who did not do sports: 1-2 times per week (IRR=0.31, 95% CI=0.30, 0.31, p<0.001), 3-4 times per week (IRR=0.23, 95% CI=0.23, 0.24, p<0.001), and five or more times per week (IRR=0.10, 95% CI=0.09, 0.10, p<0.001). Estimates were similar for exercise participation compared to those who did not exercise: 1-2 times per week (IRR=0.27, 95% CI=0.26, 0.27, p<0.001), 3-4 times per week (IRR=0.19, 95% CI=0.18, 0.19, p<0.001), and five or more times per week (IRR=0.23, 95% CI=0.23, 0.24, p<0.001) (Supplement 2b).

Differential attrition was observed by age (p<0.001), sex (p<0.001), race/ethnicity (p<0.001), and cigarette smoking (p=0.023). Participants who were older, female, non-Hispanic White, and smoked cigarettes were more likely to drop out than their counterparts. These patterns have been reported previously in Add Health, and sampling weights were used to reduce non-response bias in the design of the study (Harris et al., 2019).

Supplement 2a

Sensitivity Analysis with physical activity as continuous and binary outcome

Model Terms	**Physical activity (continuous)**		**Physical activity (binary outcome; ref = "Non-Daily")**	
	IRR	95% CI	IRR	95% CI
Exercise (ref = "Inactive")	0.96	(0.95, 0.96)	0.54	(0.53, 0.54)
Sex (ref = "Female")	0.40	(0.21, 0.78)	0.40	(0.21, 0.78)
Race/Ethnicity (ref = "non-Hispanic White")				
Hispanic	0.42	(0.13, 1.40)	0.42	(0.13, 1.40)
Non-Hispanic Black	1.40	(0.59, 3.31)	1.40	(0.59, 3.30)
Non-Hispanic Other	0.99	(0.18, 5.46)	0.99	(0.18, 5.47)
Cigarette smoking (ref = "No Smoking")	1.85	(1.84, 1.86)	1.87	(1.86, 1.87)
Alcohol Use (ref = "Drinking Alcohol")	2.52	(2.50, 2.53)	2.51	(2.50, 2.53)
Age	1.03	(1.03, 1.03)	1.03	(1.03, 1.03)
Exercise * Age	1.00	(1.00, 1.00)	1.02	(1.02, 1.02)

**Note.* IRR = Incidence Rate Ratio = $\exp(\beta)$

Discussion

This study examined the longitudinal association between physical activity during adolescence and cannabis use in adulthood using data from the nationally representative Add Health cohort. Our findings between physical activity and cannabis use differed depending on how physical activity was conceptualized and measured. Specifically, when physical activity was treated as a continuous frequency variable, we found no significant association. However, when it was operationalized as a binary variable, daily versus less than daily, or stratified into specific types (sports-only and exercise-only), we observed a protective association with cannabis use in adulthood.

Our results align with previous research showing mixed findings on the association between physical activity and cannabis use. Several studies have reported no relationship between physical activity and cannabis use. One study combined exercise and sports, as we did, but it also included three dimensions of physical activity (at work, home, or transportation) (Henchoz et al., 2014). Some cohort studies have focused on athletic activity or sports participation and cannabis use among adolescents with shorter follow-up periods (Mahoney & Vest, 2012). Another cohort study explored sport participation in 12-year-old adolescents and followed them for 13 years but grouped cannabis with other illicit drugs (Barber et al., 2001).

Supplement 2b

Sensitivity Analysis with exercise and sports for physical activity separately

Model Terms	Physical activity (exercise only)		Physical activity (sports only)	
	IRR	95% CI	IRR	95% CI
Exercise (ref = "0 times a week")				
1-2 times	0.27	(0.27, 0.27)	0.31	(0.30, 0.31)
3-4 times	0.19	(0.18, 0.19)	0.23	(0.23, 0.24)
5 times or more	0.23	(0.23, 0.24)	0.10	(0.09, 0.10)
Sex (ref = "Female")	0.43	(0.22, 0.84)	0.39	(0.20, 0.75)
Race/Ethnicity (ref = "non-Hispanic White")				
Hispanic	0.42	(0.13, 1.38)	0.41	(0.12, 1.34)
Non-Hispanic Black	1.44	(0.61, 3.39)	1.43	(0.61, 3.37)
Non-Hispanic Other	0.98	(0.18, 5.41)	0.96	(0.17, 5.30)
Cigarette smoking (ref = "No Smoking")	1.87	(1.86, 1.88)	1.82	(1.81, 1.83)
Alcohol Use (ref = "Drinking Alcohol")	2.36	(2.35, 2.37)	2.28	(2.27, 2.30)
Age	1.01	(1.01, 1.01)	1.01	(1.01, 1.01)
Age * 1-2 times	1.04	(1.04, 1.04)	1.04	(1.04, 1.04)
Age * 3-4 times	1.05	(1.05, 1.05)	1.04	(1.04, 1.04)
Age * 5 times or more	1.04	(1.04, 1.04)	1.08	(1.07, 1.08)

**Note.* IRR = Incidence Rate Ratio = $\exp(\beta)$

In contrast, studies reporting negative associations typically focused on adolescents and analyzed sports participation specifically (Dawkins et al., 2006; Terry-McElrath & O'Malley, 2011). For example, varsity sports involvement and team participation have been linked to lower cannabis use during adolescence and early adulthood. Our stratified findings showing that sports and exercise both had protective effects reinforce this literature and suggest that activity type and context may be critical to understanding this association.

Notably, our sensitivity analysis found that the association changed over time. This interaction is consistent with findings from prior studies on sports participation and cannabis, which have varied across developmental stages (Kwan et al., 2014). This finding highlights the importance of considering age as a moderating factor when

evaluating behavioral factors related to substance use.

Our study has several strengths. We used a prospective, nationally representative cohort study that followed adolescents into adulthood, allowing us to establish temporality between exposure and outcome. Mixed-effects modeling accounted for individual-level variability and a time-varying outcome. Unlike prior studies, we assessed cannabis use independently of other substances and evaluated multiple dimensions of physical activity, including frequency, type, and adherence to recommendations. Additionally, we adjusted for relevant confounders and applied sampling weights to enhance generalizability.

Limitations

Despite its strengths, this study has limitations. As an observational study, causality cannot be inferred (Hernán & Robins, 2006). Physical activity was self-reported and measured only for the past seven days, which may not accurately reflect habitual behavior. Moreover, the physical activity questions varied across waves, requiring harmonization, which could introduce measurement error. While we assessed multiple dimensions of physical activity, we could not evaluate activity in occupational, household, or transportation contexts, which have shown differential associations with substance use (Henchoz et al., 2014; Poortinga, 2007). Another limitation is the absence of state-level cannabis policy data in Add Health, which may have influenced cannabis use trends over time (Gruber, 2001). Further, we did not include variables such as SES or depressive symptoms as these variables were assessed differently for adolescents and adults in Add Health. Because we were measuring the incidence of cannabis use, persons with cannabis use at baseline were excluded from the analysis, so findings may not generalize to this group. Finally, attrition in the sample was non-random, although sampling weights were used to mitigate potential bias.

Conclusion

In conclusion, physical activity may be protective against cannabis use, but the association depends on how physical activity is defined and measured. The protective effect was more evident when it was categorized as meeting daily recommendations or when specific types, such as sports or exercise, were examined. This study encourages future research with alternative measures of physical activity, more detailed categorizations, and consideration of additional social and policy factors.

Implications for Health Behavior Research

Future studies should incorporate objective measures of physical activity (e.g., accelerometers) and explore different domains and social contexts of physical activity, such as team versus individual sports. Analytical methods like inverse probability weighting or standardization could help address residual confounding (VanderWeele & Hernán, 2013). It is also important to consider emerging recreational cannabis laws that could impact youth behaviors in future cohorts. Expanding the measurement of cannabis use – such as examining frequency, mode of use (vaping vs. smoking), and motivations may also clarify how health behaviors cluster across development.

Due to the mixed findings, our study does not support a definitive conclusion regarding the protective effect of adolescent physical activity on cannabis use in adulthood. While no association was found when physical activity was measured continuously, protective associations emerged when physical activity was defined categorically or by type. These findings suggest that the

relationship between physical activity and cannabis use is complex and may depend on how physical activity is framed and experienced.

Given these nuances, we emphasize the importance of continued longitudinal research that disaggregates physical activity by type, context, and social dimensions. Until more conclusive evidence emerges, public health strategies should be cautious in using physical activity promotion as a standalone cannabis use prevention strategy. However, given the broad benefits of physical activity for adolescent health, exploring its role in shaping long-term cannabis use patterns remains an important avenue for future research.

Discussion Questions

How do different types and contexts of physical activity (e.g., team sports vs. solo exercise) shape adolescent identity and social environments in ways that might influence substance use behaviors later in adulthood?

Given the study's mixed findings, what methodological innovations or alternative research designs could better capture the true relationship between adolescent physical activity and adult cannabis use?

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