Title

Associations Between Adverse Childhood Experiences and Early Adolescent Physical Activity in the United States

Journal

Academic Pediatrics, 24(4)

ISSN

1876-2859

Authors

Al-Shoaibi, Abubakr AA
Iyra, Puja
Raney, Julia H
et al.

Publication Date

2024-05-01

DOI

10.1016/j.acap.2023.10.004

Associations Between Adverse Childhood Experiences and Early Adolescent Physical Activity in the United States

Abubakr A.A. Al-shoaibi, PhD, MS[1]; Puja Iyra, BA[1]; Julia H. Raney, MD; Kyle T. Ganson, PhD, MSW; Erin E. Dooley, PhD; Alexander Testa, PhD; Dylan B. Jackson, PhD, MS; Kelley P. Gabriel, MS, PhD; Fiona C. Baker, PhD; Jason M. Nagata, MD, MSc

From the Division of Adolescent and Young Adult Medicine (AAA Al-shoaibi, P Iyra, JH Raney, and JM Nagata), Department of Pediatrics, University of California, San Francisco, Calif; Factor-Inwentash Faculty of Social Work (KT Ganson), University of Toronto, Toronto, Ontario, Canada; Department of Epidemiology (EE Dooley and KP Gabriel), University of Alabama at Birmingham; Department of Management (A Testa), Policy and Community Health, University of Texas Health Science Center at Houston; Department of Population (DB Jackson), Family, and Reproductive Health, Johns Hopkins Bloomberg School of Public Health, Johns Hopkins University, Baltimore, Md; Center for Health Sciences (FC Baker), SRI International, Menlo Park, Calif; School of Physiology (FC Baker), University of the Witwatersrand, Johannesburg, South Africa

[1]Equal contributions.

Address correspondence to Jason M. Nagata, MD, MSc, 550 16th Street, 4th Floor, Box 0503, Mailroom 4100, San Francisco, Calif 94143 (e-mail: jason.nagata@ucsf.edu).

Received for publication June 5, 2023; accepted October 19, 2023.

Abstract

Objective: To determine the associations between the number of adverse childhood experiences (ACEs) and objectively-measured physical activity (PA) in a population-based, demographically diverse cohort of 9–14-year-olds and to determine which subtypes of ACEs were associated with physical activity levels.

Methods: We analyzed data (n = 7046) from the Adolescent Brain Cognitive Development (ABCD) Study 4.0 release at baseline and year 2 follow-up. ACE (cumulative score and subtypes) and physical activity (average Fitbit daily steps assessed at Year 2) were analyzed using linear regression analyses. Covariates included race and ethnicity, sex, household income, parent education, body mass index, study site, twins/siblings, and data collection period.

Results: Adjusted models suggest an inverse association between number of ACEs and Fitbit daily steps, with ≥4 (compared to 0) ACEs associated with 567 fewer daily steps (95% CI -902.2, -232.2). Of the ACEs subtypes, emotional abuse (B = −719.3, 95% CI −1430.8, −7.9), physical neglect (B = −423.7, 95% CI −752.8, −94.6), household mental illness (B = −317.1, 95% CI −488.3, −145.9), and household divorce or separation (B = −275.4, 95% CI −521.5, −29.2) were inversely and statistically significant associated with Fitbit daily steps after adjusting for confounders.

Conclusions: Our results suggest that there is an inverse, dose-dependent relationship between cumulative number of ACEs and physical activity as measured by daily steps. This work highlights the importance of screening for ACEs among young people at an early age to help identify those who could benefit from interventions or community programs that support increased physical activity.

Keywords: adolescents; adverse childhood experiences; Fitbit; physical activity

Academic Pediatrics 2024; 24:662–668

What's New

In a demographically diverse national sample of early adolescents, we found an inverse, dose-dependent relationship between cumulative number of adverse childhood experiences and physical activity as measured by daily steps.

Adverse childhood experiences (ACEs) are highly prevalent and defined as environmental stressors such as abuse, various household challenges, and neglect, experienced in childhood and that have associations with future mental and physical well-being.[1] Moreover, an increased number of ACEs in childhood is associated with developing a greater number of risk factors for leading causes of death such as smoking, obesity, depression, attempted suicide, substance use, and sexually transmitted infection (STI) history in adulthood.[2] ACEs pose a serious risk to the health and well-being of young people; however, physical activity has been shown to attenuate the influence of ACEs on future adverse health outcomes, diminishing their negative associations.[3,4] Physical activity has a myriad of positive associations for adolescent health, including being associated with healthy cardiovascular health, bone mass, weight, improved academic outcomes, and better sleep, mood and cognition.[5–9] Studies have shown that physical activity in adolescents leads

to future benefits for bone health, asthma, and is associated with reduced risk for breast cancer in adulthood.[3,4] Moreover, physical activity in adolescents has also been shown to improve self-esteem, mental health and behavioral health practices that continue into adulthood[3]. Yet, despite the known benefits of adolescent physical activity on health, less than 30% of all high-school aged youth met recommended daily physical activity guidelines in the United States.[10]

Though the literature suggests that physical activity has promising mitigating factors, few studies have investigated levels of physical activity among adolescents who have experienced ACEs. One such study showed that adolescents experiencing no ACEs had higher odds of meeting 60 minutes of daily physical activity (i.e., meeting physical activity guidelines) than those with one or more ACEs using caregiver self-reported questionnaires.[11] Another study examined the relationship between ACEs and moderate-to-vigorous intensity physical activity (MVPA) during the early COVID-19 pandemic among young adolescents from the Adolescent Brain Cognitive Development (ABCD) Study. This research found that adolescents who reported greater levels of stress, increased worry due to COVID-19, and worse mental health were found to self-report lower levels of MVPA early in the pandemic. However, adolescents who reported higher levels of positive coping behaviors and social support self-reported higher levels of MVPA during the pandemic.[12] Research building upon this previous work showed that the proportion of adolescents from the ABCD study meeting MVPA guidelines, declined as a result of the COVID-19 pandemic based on self-report–decreasing from 16.4% pre-pandemic, to 11.0% during the onset of the pandemic, to 4.7% during the midst of the pandemic.[13] Most recently, a 2022 study also using the ABCD study population found that 4+ ACEs were associated with increased screen time and decreased duration and frequency of physical activity reported among youth during the early COVID-19 pandemic.[12]

While physical activity measures have historically been based on self-report, which is limited by recall errors and response bias, few studies of adolescents have leveraged objective data collection via accelerometry devices, which have become increasingly available.[14] Devices like the Fitbit use accelerometry to measure daily step count to provide more accurate and consistent physical activity data, which has now been employed by large, national studies such as the ABCD Study.[15,16] A 2023 abstract looking at ABCD Fitbit metrics reports higher resting heart rate (a proxy for aerobic fitness), lower time spent in MVPA, and increased time spent sedentary were associated with higher number of internalizing symptoms, externalizing symptoms, and psychotic-like experiences.[17] This study offers interesting insight into the use of Fitbit device metrics in the ABCD study to explore physical and mental health.[17]

There are few studies in the literature describing ACEs and adolescent physical activity that have information on how ACE subtypes (abuse, household difficulties, neglect) may affect physical activity and health-related behaviors.[11,12] One study that looked at ACE subtypes showed that parent divorce, domestic violence, and substance use in the household were negatively associated with healthy sleep, television and electronic utilization behaviors in children and young adolescents.[11] In particular, parent divorce and household mental illness were two ACEs inversely associated with healthy physical activity, media use, family meals, and sleep among adolescents.[11] Another study showed that higher levels of physical activity attenuate the negative influence of total ACEs, and those of the subtypes of child abuse (physical, sexual, emotional) and household dysfunction (household mental illness, household substance use, household domestic violence, parental separation, divorce, incarceration of household member) on self-reported health related quality of life, physically unhealthy days, and mentally unhealthy days in adulthood. While presenting interesting insights into the role of physical activity in mitigating ACEs association with adult health, this research does not allow for generalizability to adolescents and does not include analysis of all ACE subtypes (neglect not studied) and adolescent outcomes.[18] Another study found that young adults who had experienced any type of childhood household dysfunction were more likely to have a left ventricular mass that was less than those of their peers who had never experienced household dysfunction as a child, potentially putting this group at higher risk for decreased physical activity capacity and cardiac disease later in life.[19] This study provides another insight into the potential relationship between ACE subtypes on physical activity in young people; however, it does not directly measure physical activity trends and does not apply to younger adolescents.

The relationship between increased digital media use among adolescents who have experienced more ACEs has been well established in the literature.[12,20,21] The association with increased sedentary behaviors may shed light on to why ACEs may relate to adolescent physical activity.[12] Using daily steps as a marker for physical activity may provide novel insight into how ACEs are associated with adolescent health-related behaviors. The release of accelerometer data by the ABCD study provides the unique opportunity to build upon the previous literature that has described ACEs and their association with report-based measures of physical activity and to further support this area of research.[12,22,24]

The objective of this study was to determine the associations between number of ACEs and objectively-measured physical activity in a population-based, demographically diverse cohort of 9–14-year-olds from the ABCD study and to determine which subtypes of ACEs (i.e., abuse, neglect, household challenges) were most associated with averaged daily steps, an estimate of physical activity volume. We hypothesized that a greater number of ACEs would be associated with a lower number of daily steps among early adolescents.

METHODS

We analyzed data from the Adolescent Brain Cognitive Development (ABCD) Study, a prospective, national study of adolescent cognitive and physical health comprising of 11,875 youth. The ABCD study recruited participants by partnering with school systems and implementing epidemiologic sampling methods to better represent the diversity of the United States adolescent population.[23] Additional details are described in Appendix A. Baseline (9–10 years old, 2016–2018), and year 2 follow up (10–14 years old, 2018–2020) data were analyzed using the ABCD 4.0 release. Participants who had missing physical activity data at two-year follow-up (n = 4829) were excluded from the study (Appendix B). The total study population after these exclusions was n = 7046 and compared to the total ABCD study population, included fewer Black participants and those with lower household income (Appendix B). Both centralized Institutionalized Review Board (IRB) approval and individual study site IRB approval were obtained**.** Participant caregivers gave written, informed consent and participants provided their written assent.[23]

MEASURES

EXPOSURE: ACE SCORE

The ABCD Study uses the ten items from the original CDC-Kaiser ACE study in order to determine an ACE score, as has been studied in prior literature.[12,24–26] The ten ACEs included in the study are household violence, household mental illness, household substance use, divorce or separation, incarceration of household member, emotional neglect, physical neglect, sexual abuse, and physical abuse, and emotional abuse.[27] Information on coding of ACE variables can be found in Appendix C. Responding in the affirmative by either participant or caregiver proxy as having experienced any of these ten counted as one point. Points were totaled to yield a cumulative score, of 0, 1, 2, 3, or 4+, based on prior literature that has shown four ACEs to be the threshold point associated with increased risk of negative physical and mental health outcomes.[2,12,24,28–30] This score was calculated using both parent proxy reports and youth surveys at baseline, year 1, and year 2 follow-up (2016–2020).

OUTCOME: PHYSICAL ACTIVITY IN STEPS PER DAY (YEAR 2)

Physical activity data was collected by Fitbit Charge HR 2 devices over a period of up to 21 days and averaged to get a daily step count. Data were collected from November 2018 to November 2020. Previous literature has shown that when used over time, Fitbit devices collect consistent and accurate measurements of physical activity as measured by daily step count, including in adolescents.[16] As established by the ABCD study and previous studies using Fitbit technology, we included all days in the 21-day study period during which participants had more than 599 minutes of Fitbit waking wear time and at least 1000 steps.[15,31–34]

COVARIATES

Covariates included race and ethnicity (White, Latino/Hispanic, Black, Asian, Native American, other), sex (female, male), household income [Less than $75,000 vs. more than $75,000 (approximate median household income in the U.S.)[35]], parent education (high school or less vs. college or more), and participant age (years) collected from the parent self-report. Geographic variation based on study site location, body mass index (BMI, kg/m^2), study period (e.g., before or during COVID-19 pandemic), and being in the same family (e.g., twins/siblings) were also controlled for as covariates.

STATISTICAL ANALYSES

All data analyses were performed using R studio (version 4.2.2). We used the R package (Survey)[36] to estimate coefficients and confidence intervals (CI) for the association between ACEs (number of ACEs and specific subtypes in separate models) and Fitbit daily steps using linear regression. Model 2 was adjusted for age, sex, race and ethnicity, household income, parent education, data collection site, and participants who were twins or siblings. We used multiple imputation with chained equations to handle missing data in the exposures and confounders. We imputed 10 datasets and pooled the estimates from each dataset. Using guidance from previous literature using ABCD data, propensity weighting based on the American Community Survey provided by the US Census was incorporated into the analysis to provide representative population estimates.[37] Two-sided $P < .05$ was considered to indicate statistical significance.

RESULTS

Participants' mean age at the year 2 follow-up was 12.0 ± 0.6 years, 48.4% of the participants identified as female, 41.3% identified as being a racial or ethnic minority, 63.8% reported annual household incomes of less than $75,000, and 12.6% of participants had caregivers who had received a college education or more (Table 1). Comparisons of sociodemographic characteristics by ACE score (0, 1–3, 4+) are shown in Appendix D, with differences by age, race and ethnicity, and household income. 88.7% of youth reported having experienced at least 1 ACE in their lifetime. In the included sample, 57.3% of participants reported household mental illness, the most commonly reported ACE. The proportion of specific ACE type by ACE score is shown in Appendix E. The study population's median steps per day was 9004 steps (Table 1).

Adjusted models suggest a significant, inverse association of ACEs (1 or more), with Fitbit daily steps (ACEs = 1, B = -347.0, 95% CI -652.6, -42.6, $P = .03$); (ACEs =2, B = -390.9, 95% CI -686.6, -93.3, $P = .01$); (ACEs = 3, B = −318.4, 95% CI −633.4, −3.3, $P = .05$); (ACEs = 4, B = −567.2, 95% CI −902.2, −232.2, $P = .01$) (Table 2) in adjusted models. For instance, 4+ ACEs was associated with 526 fewer daily steps compared to 0 ACEs. Of the ACEs subtypes, emotional abuse (B = −719.8, 95% CI

Table 1. Sociodemographic, Adverse Childhood Experiences (ACEs), and Daily Steps of Adolescent Brain Cognitive Development (ABCD) Study Participants (Year 2, N = 7046)

Sociodemographic Characteristics (Baseline)	Mean (SD)/%
Age (years)	12.0 (0.6)
Sex, n (%)	
Female	48.4%
Male	51.6%
Race and ethnicity (%)	
White	58.7%
Latino/Hispanic	15.6%
Black	15.3%
Asian	5.7%
Native American	3.7%
Other	1.0%
Household income (%)	
Less than $75,000	63.8%
≥$75,000	36.2%
Parent with college education or more (%)	12.6%
Number of ACEs	
0	11.3%
1	24.4%
2	27.6%
3	20.7%
4+	16.0%
ACEs type	
Physical Abuse	0.9%
Sexual Abuse	1.1%
Emotional Neglect	0.8%
Physical Neglect	6.8%
Household Substance Use	46.4%
Household Divorce or Separation	12.2%
Household Mental Illness	57.3%
Household Violence	55.6%
Household Criminal Justice Involvement	30.2%
Emotional Abuse	1.7%
Steps per day (median)	9004

SD indicates standard deviation.

Propensity weights were applied to yield estimates based on the American Community Survey from the US Census.

−1430.8, −7.9, P = .05), physical neglect (B = −423.7, 95% CI 752.8, −94.6, P = .01), household mental illness (B = −317.1, 95% CI −488.3, −145.9, P % .01), and household divorce or separation (B = −275.4, 95% CI −521.5,−29.2, P = .03) were inversely and statistically significantly associated with Fitbit daily steps after adjusting for confounders.

Discussion

Our results suggest that there is an inverse relationship between experiencing ACEs and physical activity as measured by daily steps. Beyond the association suggesting incrementally lower averaged daily steps with increasing count of ACEs, we also found that the subtypes of emotional abuse, physical neglect, household divorce or separation, and household mental illness are significantly associated with fewer steps per day.

These results show that experiencing potentially traumatic events in childhood is negatively associated with levels of physical activity in adolescence. This association may be in part due to the relationship between ACEs and adolescent mental health, with an increased number of ACEs associated with poorer mental health outcomes.[1,17,38] This association with worsened mental health may in turn lead to lower amounts of physical activity.[39–41] Our results shed light on to subsequent negative associations of experiencing ACEs with healthy behaviors among adolescents, such as physical activity.

These results add to the literature studying the association between ACEs and adolescent physical activity by utilizing device-based assessments of steps; a common and easily understandable metric of physical activity accumulated across the day. Being able to measure physical activity with accelerometers and investigating both ACE scores and individual subtypes provides unique strengths to our study and adds an additional perspective to current research. The use of a large, diverse, national study population of adolescents, provides new insight into an area that is often limited to research on ACEs and their relation to adult health, and builds upon previous research using the same dataset but exploring ACEs and their association with self-reported measures of physical activity,[12] which can be prone to recall bias. Additionally, highlighting the specific subtypes of ACEs associated with decreased physical activity among adolescents provides further context to understand total ACE score and daily steps.

Despite the strengths of our study, there are several limitations to note. Given our observational study approach, we cannot make determinations regarding causality or the temporal relationship between ACEs and physical activity in adolescents. The Fitbit and ACE data were not measured every year, so we are unable to perform a prospective analysis. However, our research lays a foundation on which future studies following the ABCD cohort can examine prospective associations across the adolescent to adulthood life course transition. Moreover, we do not explore mediators in our analyses, which is a potential area of future longitudinal research. Given that ACEs items are based on participant and caregiver report, our exposure measure is susceptible to reporting bias, and as seen in our study results, a greater proportion of young people reported having experienced at least one ACE compared to the national adolescent population. This may be because the ABCD study did not have a standalone ACE survey or measure, and ACE reports varied from parent to participants. However, previous research has identified questions across the many validated ABCD surveys similar to those on the original ACE measure.[12,25,26] In addition, our approach is consistent with public health guidance that recommends using the higher of the two ACE scores if caregiver and adolescent self-report surveys differ.[42] Some of the effect sizes were small; however, even a small difference in daily steps aggregated over months and years could be associated with clinically meaningful health outcomes. 500 steps a day translates to roughly 0.25 miles daily, which may have cumulative implications, with young people with higher ACE scores having up to 1.25 miles less per week or 7 miles less per month of movement compared to their peers.

Table 2. Associations Between Adverse Childhood Experiences (ACEs) and Fitbit Daily Steps at Two-Year Follow-Up in the Adolescent Brain Cognitive Development Study

	Unadjusted		Adjusted*	
	Steps per day		Steps per day	
	B (95% CI)	*P*	B (95% CI)	*P*
Number of ACEs			Adjusted	
0			Ref	
1	**−321.7 (−627.1, −16.4)**	**.04**	**−347 (−652.6, −42.6)**	**.03**
2	**−266.2 (−562.3, 30.1)**	**.08**	**−390.9 (−686.6, −95.3)**	**.01**
3	**−213.8 (−531.6, 103.9)**	**.19**	**−318.4 (−633.4, −3.3)**	**.048**
4+	**−645.2 (−977.7, −312.6)**	**< .01**	**−567.2 (−902.2, −232.2)**	**.01**
ACE subtypes†				
Physical Abuse	528.9 (−865.3, 1923.1)	.46	637.7 (−676.0, 1951.6)	.34
Sexual Abuse	−325.4 (−1191.9, 541.0)	.46	174.5 (−642.4, 991.5)	.68
Emotional Neglect	−926.0 (−1867.6, 15.6)	.05	−696.3 (−1601.4, 208.8)	.13
Physical Neglect	−323.2 (−650.5, 4.1)	.05	**−423.7 (−752.8, −94.6)**	**.01**
Household Substance Use	**−521.6 (−762.0, −281.2)**	**< .01**	−149.4 (−314.9, 16.0)	.08
Household Divorce or Separation	**−521.6 (−762.0, −281.2)**	**< .01**	**−275.4 (−521.5, −29.2)**	**.03**
Household Mental Illness	**−202.6 (−373.8, −31.5)**	**.02**	**−317.1 (−488.3, −145.9)**	**< .01**
Household Violence	56.4 (−110.0, 222.9)	.51	65.9 (−101.1, 232.9)	.44
Household Criminal Justice Involvement	−157.5 (−343.4, 28.3)	.1	−44.2 (−230.5, 141.9)	.64
Emotional Abuse	**−991.6 (−1758.9, −224.3)**	**.01**	**−719.3 (−1430.8, −7.9)**	**.047**

Bold indicates $P < .05$.

* Covariates: age, race and ethnicity, sex, household income, parent education, study site, body mass index (BMI), study period (pre- or during COVID pandemic), participants who were twins or siblings.

† Outputs represent the abbreviated output for a series of linear regression models with each ACE subtype as the independent variable and steps per day as the dependent variable. Thus, the table represents the output from ten regression models in total.

Knowing that levels of physical activity are diminished among adolescents who have experienced more ACEs highlights the importance of screening for ACEs among young people at an early age to help identify those who could benefit from interventions and community programs that support increased physical activity. Physical activity has been identified as a resiliency builder in young people, mitigating the negatives of traumatic experiences and bolstering one's mental and physical well-being. Several studies have shown that physical activity, fitness, exercise, and participation in a sport promote resilience among adolescents.[3,11,43,44] To best facilitate a positive relationship for young people with physical activity, current literature suggests promoting physical activity opportunities that support adolescent self-esteem, connectedness, autonomy, identity, and resilience such as through team sports.[41,44] Though our results show that daily steps are fewer in those who have experienced ACEs compared to youth who have not, the fact that physical activity is a modifiable factor suggests that deliberate, tailored scaffolds that promote adolescent health through physical activity may serve as a beneficial, trauma-informed intervention. To leverage the resiliency building aspects of physical activity in youth, screening must be implemented in order to refer young people to interventions that may help deliberately counteract the detrimental outcomes associated with experiencing ACEs and intentionally increase the total amount of physical activity in which young people are able to partake. Moreover, our results suggest that while physical activity interventions may be beneficial for all young people, efforts should be focused in on those with higher cumulative ACE scores and those whose have experienced emotional neglect, physical neglect, household divorce or separation, or household mental illness.

Declaration of Competing Interest

The authors have no conflict to declare.

Acknowledgments

The authors thank Anthony Kung, Derek Hsu, and Sue Lee for editorial assistance. The ABCD Study was supported by the National Institutes of Health and additional federal partners under award numbers U01DA041022, U01DA041025, U01DA041028, U01DA041048, U01DA041089, U01DA041093, U01DA041106, U01DA041117, U01DA041120, U01DA041134, U01DA041148, U01DA041156, U01DA041174, U24DA041123, and U24DA041147. A full list of supporters is available at https://abcdstudy.org/federal-partners/. A listing of participating sites and a complete listing of the study investigators can be found at https://abcdstudy.org/principal-investigators.html. ABCD consortium investigators designed and implemented the study and/or provided data but did not necessarily participate in analysis or writing of this report.

Financial Statement: J.M.N. was supported by the National Institutes of Health (K08HL159350 and R01MH135492) and the Doris Duke Charitable Foundation (2022056). The funders had no role in the study analysis, decision to publish the study, or the preparation of the manuscript.

Authorship Statement: Abubakr Al-shoaibi – Conceptualization, Data analysis, Writing – original draft and revisions. Puja Iyra – Conceptualization, Data analysis, Writing – original draft and revisions. Julia H. Raney, Kyle T Ganson, Erin Dooley, Alexander Testa, Dylan Jackson, Kelley Pettee Gabriel – Writing – critical revisions. Fiona Baker – Conceptualization, Data acquisition, Methods, Writing – critical revisions. Jason Nagata – Conceptualization, Analysis, Writing – original draft and revisions, Supervision. All authors approve of the final submitted version.

SUPPORTING MATERIAL

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.acap.2023.10.004.

REFERENCES

1. Hadwen B, Pila E, Thornton J. The associations between adverse childhood experiences, physical and mental health, and physical activity: a scoping review. *J Phys Act Health.* 2022;19:847–854. https://doi.org/10.1123/jpah.2022-0298
2. Felitti VJ, Anda RF, Nordenberg D, et al. Relationship of childhood abuse and household dysfunction to many of the leading causes of death in adults. The adverse childhood experiences (ACE) study. *Am J Prev Med.* 1998;14:245–258. https://doi.org/10.1016/s0749-3797(98)00017-8
3. Hallal PC, Victora CG, Azevedo MR, et al. Adolescent physical activity and health: a systematic review. *Sports Med.* 2006;36:1019–1030. https://doi.org/10.2165/00007256-200636120-00003
4. Marker AM, Steele RG, Noser AE. Physical activity and health-related quality of life in children and adolescents: a systematic review and meta-analysis. *Health Psychol Off J Div Health Psychol Am Psychol Assoc.* 2018;37:893–903. https://doi.org/10.1037/hea0000653
5. Santana CCA, Azevedo LB, Cattuzzo MT, et al. Physical fitness and academic performance in youth: a systematic review. *Scand J Med Sci Sports.* 2017;27:579–603. https://doi.org/10.1111/sms.12773
6. Donnelly JE, Hillman CH, Castelli D, et al. Physical activity, fitness, cognitive function, and academic achievement in children: a systematic review. *Med Sci Sports Exerc.* 2016;48:1197–1222. https://doi.org/10.1249/MSS.0000000000000901
7. Kumar B, Robinson R, Till S. Physical activity and health in adolescence. *Clin Med.* 2015;15:267–272. https://doi.org/10.7861/clinmedicine.15-3-267
8. Sibley BA, Etnier JL. The relationship between physical activity and cognition in children: a meta-analysis. *Pediatr Exerc Sci.* 2003;15:243–256. https://doi.org/10.1123/pes.15.3.243
9. Davies SC, Lemer C, Strelitz J, et al. Our children deserve better: prevention pays. *The Lancet.* 2013;382:1383–1384. https://doi.org/10.1016/S0140-6736(13)62004-8
10. Increase the proportion of adolescents who do enough aerobic physical activity — PA-06 - Healthy People 2030 | health.gov. ⟨https://health.gov/healthypeople/objectives-and-data/browse-objectives/physical-activity/increase-proportion-adolescents-who-do-enough-aerobic-physical-activity-pa-06⟩. Accessed March 15, 2023.
11. Harada M, Guerrero A, Iyer S, et al. The relationship between adverse childhood experiences and weight-related health behaviors in a national sample of children. *Acad Pediatr.* 2021;21:1372–1379. https://doi.org/10.1016/j.acap.2021.05.024
12. Raney JH, Testa A, Jackson DB, et al. Associations between adverse childhood experiences, adolescent screen time and physical activity during the COVID-19 pandemic. *Acad Pediatr.* 2022;22:1294–1299. https://doi.org/10.1016/j.acap.2022.07.007
13. Cortez CA, Yuefan Shao I, Seamans MJ, et al. Moderate-to-vigorous intensity physical activity among U.S. adolescents before and during the COVID-19 pandemic: findings from the adolescent brain cognitive development study. *Prev Med Rep.* 2023;35:102344. https://doi.org/10.1016/j.pmedr.2023.102344
14. Althubaiti A. Information bias in health research: definition, pitfalls, and adjustment methods. *J Multidiscip Healthc.* 2016;9:211–217. https://doi.org/10.2147/JMDH.S104807
15. Bagot KS, Matthews SA, Mason M, et al. Current, future and potential use of mobile and wearable technologies and social media data in the ABCD study to increase understanding of contributors to child health. *Dev Cogn Neurosci.* 2018;32:121–129. https://doi.org/10.1016/j.dcn.2018.03.008
16. Godino JG, Wing D, de Zambotti M, et al. Performance of a commercial multi-sensor wearable (Fitbit Charge HR) in measuring physical activity and sleep in healthy children. *PloS One.* 2020;15:e0237719. https://doi.org/10.1371/journal.pone.0237719
17. Physical and mental health in adolescence: novel insights from a transdiagnostic examination of Fitbit data in the adolescent brain cognitive development (ABCD) study - Biological Psychiatry. ⟨https://www.biologicalpsychiatryjournal.com/article/S0006-3223(23)00244-5/fulltext⟩. Accessed September 22, 2023.
18. Moon I, Han J. Moderating effects of physical activity on the relationship between adverse childhood experiences and health-related quality of life. *Int J Environ Res Public Health.* 2022;19:668. https://doi.org/10.3390/ijerph19020668
19. Ks D, Dd O, Aj M, et al. Childhood household dysfunction is associated with reduced left ventricular mass in young adulthood. *Am J Physiol Heart Circ Physiol.* 2023;324. https://doi.org/10.1152/ajpheart.00128.2022
20. Jackson DB, Testa A, Fox B. Adverse childhood experiences and digital media use among U.S. children. *Am J Prev Med.* 2021;60:462–470. https://doi.org/10.1016/j.amepre.2020.09.018
21. Domoff SE, Borgen AL, Wilke N, et al. Adverse childhood experiences and problematic media use: perceptions of caregivers of high-risk youth. *Int J Environ Res Public Health.* 2021;18:6725. https://doi.org/10.3390/ijerph18136725
22. Nagata JM, Alsamman S, Smith N, et al. Social epidemiology of Fitbit daily steps in early adolescence. *Pediatr Res.* 2023:1–7. https://doi.org/10.1038/s41390-023-02700-4
23. Garavan H, Bartsch H, Conway K, et al. Recruiting the ABCD sample: design considerations and procedures. *Dev Cogn Neurosci.* 2018;32:16–22. https://doi.org/10.1016/j.dcn.2018.04.004
24. Testa A, Jackson DB. Adverse childhood experiences and food insecurity in adulthood: evidence from the national longitudinal study of adolescent to adult health. *J Adolesc Health.* 2020;67:218–224. https://doi.org/10.1016/j.jadohealth.2020.02.002
25. Chu J, Raney JH, Ganson KT, et al. Adverse childhood experiences and binge-eating disorder in early adolescents. *J Eat Disord.* 2022;10:168. https://doi.org/10.1186/s40337-022-00682-y
26. Nagata JM, Trompeter N, Singh G, et al. Adverse childhood experiences and early adolescent cyberbullying in the United States. J Adolesc. n/a. doi:10.1002/jad.12124.
27. Hoffman EA, Clark DB, Orendain N, et al. Stress exposures, neurodevelopment and health measures in the ABCD study. *Neurobiol Stress.* 2019;10:100157. https://doi.org/10.1016/j.ynstr.2019.100157
28. Briggs EC, Amaya-Jackson L, Putnam KT, et al. All adverse childhood experiences are not equal: the contribution of synergy to adverse childhood experience scores. *Am Psychol.* 2021;76:243–252. https://doi.org/10.1037/amp0000768
29. Sacks V, Murphey D. The prevalence of adverse childhood experiences, nationally, by state, and by race/ethnicity.
30. Testa A, Jackson DB, Ganson KT, et al. Adverse childhood experiences and criminal justice contact in adulthood. *Acad Pediatr.* 2022;22:972–980. https://doi.org/10.1016/j.acap.2021.10.011
31. Hoeger WWK, Bond L, Ransdell L, et al. One-mile step count at walking and running speeds. *ACSMs Health Fit J.* 2008;12:14. https://doi.org/10.1249/01.FIT.0000298459.30006.8d

32. van Woudenberg TJ, Bevelander KE, Burk WJ, et al. A randomized controlled trial testing a social network intervention to promote physical activity among adolescents. *BMC Public Health.* 2018;18:542. https://doi.org/10.1186/s12889-018-5451-4
33. Hemphill NM, Kuan MTY, Harris KC. Reduced physical activity during COVID-19 pandemic in children with congenital heart disease. *Can J Cardiol.* 2020;36:1130–1134. https://doi.org/10.1016/j.cjca.2020.04.038
34. St Fleur RG, St George SM, Leite R, et al. Use of Fitbit devices in physical activity intervention studies across the life course: narrative review. *JMIR MHealth UHealth.* 2021;9:e23411. https://doi.org/10.2196/23411
35. US Census Bureau. Income and poverty in the United States: 2018. Census.gov. ⟨https://www.census.gov/library/publications/2019/demo/p60-266.html⟩. Accessed March 24, 2023.
36. Lumley T. Analysis of complex survey samples. *J Stat Softw.* 2004;9. https://doi.org/10.18637/jss.v009.i08
37. Heeringa SG, Berglund PA. A guide for population-based analysis of the adolescent brain cognitive development (ABCD) study baseline data. Published online February 10, 2020. ⟨doi:10.1101/2020.02.10.942011⟩.
38. Nelson CA, Bhutta ZA, Burke Harris N, et al. Adversity in childhood is linked to mental and physical health throughout life. *BMJ.* 2020:m3048. https://doi.org/10.1136/bmj.m3048. Published online October 28,.
39. Gu J. Physical activity and depression in adolescents: evidence from China family panel studies. *Behav Sci Basel Switz.* 2022;12:71. https://doi.org/10.3390/bs12030071
40. Ma L, Hagquist C, Kleppang AL. Leisure time physical activity and depressive symptoms among adolescents in Sweden. *BMC Public Health.* 2020;20:997. https://doi.org/10.1186/s12889-020-09022-8
41. Murphy J, McGrane B, White RL, et al. Self-esteem, meaningful experiences and the rocky road-contexts of physical activity that impact mental health in adolescents. *Int J Environ Res Public Health.* 2022;19:15846. https://doi.org/10.3390/ijerph192315846
42. ACEs Aware frequently asked questions.
43. Easterlin MC, Chung PJ, Leng M, et al. Association of team sports participation with long-term mental health outcomes among individuals exposed to adverse childhood experiences. *JAMA Pediatr.* 2019;173:681–688. https://doi.org/10.1001/jamapediatrics.2019.1212
44. Norris G, Norris H. Building resilience through sport in young people with adverse childhood experiences. *Front Sports Act Living.* 2021;3. ⟨https://www.frontiersin.org/articles/10.3389/fspor.2021.663587⟩.