BMC Medicine

https://doi.org/10.1186/s12916-026-04668-4

Article in Press

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Received: 13 Apr 2025

Accepted: 22 Jan 2026

Published online: 02 February 2026

Cite this article as: Wang, M., Xu, Y., Huang, R. *et al.* Household cannabis cessation and adolescent mental health outcomes in a prospective cohort study. *BMC Med* (2026). https://doi.org/10.1186/s12916-026-04668-4

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Household Cannabis Cessation and Adolescent Mental Health Outcomes in a Prospective Cohort Study

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Word count: 4508

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Abstract

Background: Household cannabis use is a risk factor for adolescents' mental health problems. However, little is known about the association of the cessation with psychological impairments in affected adolescents. This study examined the associations of household cannabis cessation with adolescents' mental health outcomes and potential pathways.

Methods: This cohort study used data from the Adolescent Brain Cognitive Development study and included adolescents aged 10-13 years with household cannabis use within 12 months at wave 2. Household cannabis cessation was defined as the absence of cannabis use by household members (excluding the adolescent participant) at wave 3 among households that reported use at wave 2. Internalizing and externalizing problems were assessed using the Child Behavior Checklist, and psychotic-like experiences (PLEs) were evaluated using the Prodromal Questionnaire-Brief Child Version. Family conflict and sleep problems were assessed using the Family Environment subscale and the Sleep Disturbance Scale for Children, respectively. Demographic and psychometric confounders were balanced with propensity score matching (PSM). Linear regression was applied to investigate the associations between cessation and mental health outcomes. Mediation analyses of family conflict and adolescent sleep problems were performed. We further considered the influence of genetic predisposition to cannabis use disorder (CUD) and examined whether brain connectivity patterns, measured by resting-state fMRI, modified the relationships.

Results: Of the 1,426 adolescents exposed to household cannabis within 12 months, 438 (30.7%) were no longer exposed by wave 3. After PSM, cessation was associated with lower levels of internalizing and externalizing problems, and PLEs (mean ratios, 0.84-0.86, all $P<0.02$), adjusting for baseline scores. The

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associations persisted after additionally adjusting for the adolescents' polygenic risk for CUD among White participants. Family conflict and sleep problems mediated the associations of cessation with internalizing (proportion mediated, 6.8% and 25.8%, respectively) and externalizing symptoms (14.3% and 24.8%, respectively). Adolescents with weaker connections between cingulo-parietal and dorsal attention networks showed stronger associations between cessation and PLEs.

Conclusions: Household cannabis cessation was linked to a lower level of adolescent mental health problems at follow-up. These findings suggest that interventions aimed at reducing or eliminating household cannabis exposure may be beneficial for youth well-being.

Keywords: Substance use, Mental health, Adolescent, Family environment, Sleep, Brain function

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Background

The prevalence of parental cannabis use in households with children has grown substantially in the United States, increasing from approximately 5% in 2002 to nearly 12% in 2017[1, 2]. This notable rise has heightened public health concerns about the potential consequences for child and adolescent well-being. Emerging evidence links household cannabis use to a variety of adverse outcomes in youth, including emotional and behavioral problems[3, 4], cognitive impairments[5], and psychiatric symptoms in children[6]. While these associations underscore the risk posed by cannabis use in the home, little is known about the association between the cessation of such exposure and mental health impairments in affected children.

Cannabis use in the home may impact children's mental health through both direct and indirect pathways[7]. Directly, children's health can be compromised due to the inhalation of harmful substances from secondhand cannabis smoke. Δ9-tetrahydrocannabinol (THC), the primary psychoactive component of cannabis, is transmitted through this smoke and can be inhaled and absorbed by children[8]. Under unventilated conditions, blood THC levels peaked immediately following exposure (mean THC concentration = 3.2 ng/mL) and remained detectable for up to 3 hours[5, 9]. Once in the bloodstream, THC interacts with the endocannabinoid system, potentially disrupting critical neurobiological processes[10-14]. These disruptions have been associated with both disrupted sleep patterns and adverse mental health outcomes, including emotional and behavioral problems and psychotic-like experiences (PLEs)[15-19]. Notably, given the well-established role of sleep in children's cognitive development and emotional regulation[20, 21], THC-induced sleep disturbances may amplify the risks for adverse mental health outcomes and serve as a mediator. Clinical evidence suggests that these THC-related biological effects are, at least partially, reversible in cannabis users following cessation of use[22, 23]. However, it remains

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unclear whether similar situations occur in children after exposure to secondhand cannabis ends.

Indirectly, family-level stressors often accompany household cannabis use, including higher rates of parental conflict, negative parenting practices, and less stable home environments[24-26]. These dynamics can result in heightened family conflict, a well-established predictor of worse child mental health outcomes[27-29]. These familial factors can also induce sleep problems in adolescents[30], thereby exacerbating mental health problems[31]. The cessation of cannabis use in the household may mitigate these adverse family dynamics. Furthermore, social learning theory posits that parental cannabis cessation can function as an influential behavioral model for children while fostering better family relationships[32]. Through these mechanisms, household cannabis cessation may attenuate family conflict and subsequently facilitate enhanced child mental health outcomes.

Beyond these direct and indirect pathways, the relationship between household cannabis cessation and child mental health may be further complicated by genetic and neurobiological factors. Parents who achieve cannabis cessation may possess distinct genetic profiles associated with lower susceptibility to cannabis use disorders (CUD) compared to persistent users[33, 34]. These heritable predispositions, which demonstrate substantial genetic overlap with various psychiatric conditions, may be transmitted to offspring and consequently influence their mental health outcomes. Regarding neurobiological factors, children with specific patterns of functional connectivity may demonstrate differential responsiveness to THC[35, 36], suggesting functional brain connectivity as a potential effect moderator.

This study aims to fill this critical research gap by using longitudinal data from the Adolescent Brain Cognitive Development (ABCD) study to examine the relationship between household cannabis cessation and adolescent mental health. Using a matched cohort design, we first investigated whether household

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cannabis cessation was associated with better mental health outcomes at follow-up. We then examined two potential pathways: a direct pathway through the elimination of harmful compounds such as THC[37, 38], and an indirect pathway mediated by family environmental factors[27, 28]. For the direct pathway, we hypothesized that: (1) compared to unexposed adolescents, those with persistent exposure would exhibit elevated psychological symptoms, with a less pronounced risk in the smokeless cannabis group; and (2) among adolescents who experienced household cannabis cessation, the smokeless cannabis group would show a less pronounced difference in symptom scores. For the indirect pathway, we investigated family conflict as a mediator. In addition, we examined alternative mechanistic pathways, including the mediating role of sleep problems, the confounding role of genetic predisposition to CUD, and the moderating role of brain functional connectivity.

Methods

Participants

This study utilized data from the ABCD study (release 5.1; https://abcdstudy.org/), which enrolled over 11,000 children from 21 centers across the United States[39]. Written informed consent from parents and adolescents were obtained at recruitment[40]. Among the adolescents who were exposed to cannabis use in the home at wave 2 and had complete data on cannabis use and mental health measures at both wave 2 and wave 3 (N = 1,621; 10-13 years old), we randomly selected one adolescent from each family to account for the within-family phenotypic correlation, resulting in a final sample size of 1,426. In the sub-analyses examining the smoked effect, we included 5,546 adolescents who reported no household cannabis exposure at either wave 2 or 3 and denied any lifetime cannabis use.

Household Cannabis Use

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Household cannabis use was assessed through a parent survey at waves 2 and 3. Notably, no adolescents in this study reported lifetime cannabis use. Parents were asked about the cannabis use of adults and youth (other than the adolescent participant) in the household over the past year (Additional file 1: Table S1). Household cannabis use was defined as any use by any home member other than the adolescent participant. Adolescents from households reporting cannabis use at wave 2 were eligible for inclusion in the study. These adolescents were then categorized into two groups based on their household cannabis use status at wave 3: cessation of use and persistent use.

Emotional and Behavioral Problems

The Child Behavior Checklist (CBCL), a parent-reported 113-item questionnaire, was used to assess the adolescents' emotional and behavioral problems over the past 6 months[41, 42]. Each item rated on a 3-point Likert scale ranging from 0 (not true) to 2 (very true or often true). Scores for syndrome scales were computed by summing the relevant items, yielding continuous variables. These included two broad-band scales that were of our primary interest (internalizing and externalizing symptoms), as well as eight narrow-band subscales: anxious/depressed, withdrawn/depressed, somatic complaints, social problems, thought problems, attention problems, rule-breaking behavior, and aggressive behavior. Higher scores indicated greater severity of emotional and behavioral problems. Additionally, we applied a T-score cutoff of 60, age- and sex-adjusted, to define clinically significant emotional and behavioral problems (binary variable)[43].

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Psychotic-Like Experiences

The Prodromal Questionnaire - Brief Child Version (PQ-BC) is a well-validated self-report tool used to evaluate adolescents' PLEs[44, 45]. Adolescents were asked about the presence of 21 PLEs (0 = no, 1 =

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yes) over the past month. For each "Yes" response, they were then asked how much it bothered them, rating the severity of distress on a 5-point Likert scale ranging from 1 (not very bothered) to 5 (extremely bothered). A distress score was calculated based on the total number of endorsed items and their corresponding distress level (i.e., 0 = no, 1 = yes [no distress], 2-6 = yes [1 + PLE distress score]). The total score thus ranged from 0 to 126, with higher scores indicating greater distress (continuous variable). Additionally, "likely significant" PLEs were defined using a distress score of ≥2 standard deviations above the mean (binary variable)[46, 47].

Covariates

We selected covariates using directed acyclic graphs, which included adolescent age, sex (male or female), race/ethnicity (White, Black, Hispanic, or other), family income level (≤$34,999, $35,000-$74,999, $75,000-$99,999, ≥$100,000), adolescents' lifetime alcohol and tobacco exposure (yes, or no, respectively), household alcohol and tobacco exposure at wave 2 (yes, or no, respectively), parental history of depression (yes, or no), and the corresponding mental health variable at wave 2 (Additional file 1: Figure S1 and Table S2). The highest missing data rate was 9.0% for parental history of depression. Missing data were imputed using multivariate imputation by chained equations[48].

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Potential mediators included adolescents' sleep problems and family conflict at wave 3, adjusting for their respective baseline values at wave 2. Effect moderators included resting-state fMRI connectivity at wave 2.

Sleep Problems

At wave 2 and wave 3, parents completed the Sleep Disturbance Scale for Children, which assesses adolescents' sleep conditions over the past 6 months[49, 50]. This questionnaire consists of 26 items

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scored on a 5-point Likert scale and has established validity. The total score was calculated by summing all item responses, and it was used to evaluate adolescents' sleep health in this study. Higher scores indicated greater severity of sleep problems.

Family Conflict

Family conflict was assessed using the Family Conflict subscale of the Family Environment Scale at wave 2 and 3[51, 52]. This 9-item dichotomous questionnaire was completed by parents, with scores ranging from 0 to 9. Higher scores reflected a more conflictual family environment.

Resting-State fMRI Connectivity

Imaging acquisition, scanning parameters, and preprocessing procedures have been comprehensively described by the ABCD team elsewhere[53]. In brief, fMRI data were collected using harmonized protocols on a 3T scanner platform. Participants underwent four 5-minute resting-state scans with their eyes open, ensuring a minimum of 8 minutes of relatively low-motion data. In the full sample (N = 1,426), fMRI data were available for 1,072 adolescents. According to the literatures, we excluded images that did not pass quality control assessed by the ABCD team[54], images with $\leqslant$375 frames of good data after motion/outlier regression, and data from Philips scanners given a known preprocessing issue (N = 260)[55]. The final dataset included 812 adolescents. Herein, intra- and inter-network-level resting-state functional connectivity (rsFC; Pearson correlation) was calculated using the Gordon parcellation scheme, which divides cortical-surface regions into 13 predefined resting-state networks[56]. These networks include the auditory network (AN), cingulo-opercular network (CON), cingulo-parietal network (CPN), default mode network (DMN), dorsal attention network (DAN), fronto-parietal network (FPN), "none" network (NN), retrosplenial temporal network (RTN), sensorimotor hand network (SHN), sensorimotor mouth network

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(SMN), salience network (SN), ventral attention network (VAN), and visual network (VN). The data were Fisher z-transformed, resulting in 91 network-level rsFC correlation averages (13 intra- and 78 inter-network circuits) at wave 2.

Polygenic Risk Score (PRS) for CUD

The genome-wide association study (GWAS) of CUD was from the latest release of the Psychiatric Genomics Consortium Substance Use Disorders working group, iPSYCH, and deCODE, involving 20,916 case samples and 363,116 controls[33]. Genetic quality control followed the Ricopili pipeline[57]. PRS from the CUD GWAS were generated at nine p-value thresholds (i.e., PT = 0.0001, 0.001, 0.01, 0.1, 0.2, 0.3, 0.4, 0.5, and 1). Notably, to account for the effect of race/ethnicity on PRS, analyses were restricted to 681 White participants of European ancestry. Although genetic data were unavailable for the household members who ceased cannabis use, the majority were biological parents who share approximately 50% of their genetic variants with adolescents. Therefore, adolescents' PRS for CUD should serve as a reasonable proxy for parental genetic predisposition to cannabis use.

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Statistical Analysis

All analyses were conducted using R version 4.3.1.

Association between Cessation and Mental Health Outcomes

A 1:1 propensity-score matching (PSM) was performed to balance wave-2 characteristics between the two groups[58, 59]. The propensity score calculation incorporated all previously described covariates, including baseline mental health indicators comprising internalizing, externalizing problem scores, and PQ-BC distress score. An absolute standardized mean difference (|SMD|) of <0.1 and a generally overlapping density plot of propensity scores between the two groups indicate a well-balanced match. In

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the matched sample, we examined the associations of household cannabis cessation with adolescents' emotional and behavioral problems and PLEs using linear regression, adjusting for adolescents' corresponding mental health variables at wave 2. Because the CBCL and PQ-BC scores exhibited right-skewed distributions, these scores were log-transformed prior to analysis. The estimated β coefficients were exponentiated to calculate mean ratios and their 95% confidence intervals (CIs). Logistic regression analyses were also conducted to estimate odds ratios (ORs) and 95% CIs for the association between cessation and clinically significant emotional and behavioral problems and PLEs.

Sensitivity analysis was performed using the full (unmatched) sample, adjusting for all covariates, for comparison with the matched analysis. Subsequent analyses investigating effect moderators and mediators were conducted in the full cohort using the same adjustment approach.

To investigate the confounding effect of genetic predisposition to CUD, we additionally adjusted for the PRS for CUD in a subsample of White adolescents, comparing these adjusted risk estimates with the unadjusted estimates.

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Direct and Indirect Pathways

Using the full sample for our primary analyses, we examined both direct and indirect pathways linking household cannabis cessation to child mental health problems. Additionally, sensitivity analyses were performed in the propensity-score matched sample.

Direct Pathways: We considered cannabis smoke exposure as the primary direct pathway. Adolescents were categorized based on family members' exclusive use of smokeless cannabis products versus those using smoked cannabis. Adolescents unexposed to household cannabis at either wave 2 or 3 were included as the reference group (N = 5,546). Linear regression was applied to

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investigate mental health outcomes at wave 3 across exposure groups. Two models were specified: Model 1 adjusted for all covariates except for the corresponding mental health variables at wave 2, while Model 2 adjusted for all covariates.

To examine potential modification effect by adolescents' brain function at wave 2, we included an interaction term between household cannabis cessation and each network-level rsFC correlation average. Stratified analyses were performed by tertiles of specific rsFC measures of interest that passed the false discovery rate (FDR) correction. Additionally, we tested the association between cannabis exposure and the rsFC measures of interest.

Indirect Pathways: Mediation analyses were conducted to examine family conflict as a mediator of the indirect pathway. We also investigated the mediating role of adolescents' sleep problems that could result from both direct biological effects and indirect psychosocial effects. These analyses were performed in the full cohort using path model[60, 61], adjusting for all covariates and the wave 2 scores of sleep problems or family conflict, respectively. The two mediators were first assessed sequentially then examined simultaneously in one mediation model that accounted for their covariance. The variance of the estimates was estimated using the bias-corrected bootstrap method with 1,000 random samplings.

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Results

A total of 1,426 adolescents were exposed to household cannabis at wave 2, of which 438 (30.7%) were no longer exposed by wave 3 (Table 1), and 1366 (95.8%) and 197 (13.8%) reported cannabis use of adults and youth (other than the adolescent participant) in the household at wave 2, respectively. Compared to adolescents with persistent exposure, those in the cessation group were more likely to belong to racial and

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ethnic minority groups, have lower family income levels, and have higher average PLE scores. In contrast, they were less likely to have a history of lifetime alcohol use or parental depression. After PSM, baseline demographic and psychological characteristics were well-balanced between the groups (N = 876; all |SMD| < 0.10; Table 1; Additional file 1: Figure S2).

Cessation and Mental Health Outcomes

In the matched sample (N = 876), adolescents who experienced household cannabis cessation exhibited lower levels of internalizing problems (adjusted mean ratio, 0.84; 95% CI, 0.77-0.93), externalizing problems (adjusted mean ratio, 0.88; 95% CI, 0.80-0.96), and PLEs (adjusted mean ratio, 0.86; 95% CI, 0.77-0.97), compared to those with persistent exposure (Figure 1A; Additional file 1: Table S3). When outcomes were categorized using clinically meaningful thresholds, household cannabis cessation was consistently associated with a lower likelihood of internalizing (T-score ⩾60; OR, 0.64; 95% CI, 0.43-0.95) and externalizing problems (OR, 0.53; 95% CI, 0.30-0.90) at follow-up. Though, the 95% CI for PLEs crossed unity (above 2 standard deviations; OR, 0.65; 95% CI, 0.33-1.14), possibly due to the low case number (21 cases in the cessation group; Figure 1B; Additional file 1: Table S4). Additional analyses on CBCL subscales showed generally consistent results across different psychopathological dimensions (Figure 1), with subscales for withdrawn/depressed and thought problems reaching statistical significance in both continuous and bivariate analyses. Sensitivity analyses adjusting for confounders in the full cohort (N = 1,426) yielded similar results (Additional file 1: Table S5). The analyses additionally adjusting for PRS for CUD in the White sample resulted in similar risk estimates (N=681 from the full sample; Additional file 1: Table S6 and Table S7).

Smoked versus Smokeless

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To investigate smoke effect of cannabis, we included adolescents who were unexposed to household cannabis as the reference group (N = 5,546). Compared to unexposed adolescents, those with persistent exposure to household cannabis exhibited higher levels of internalizing, externalizing symptoms, and PLEs at wave 3, with similar risk estimates between adolescents exposed to smoked (N = 827) versus smokeless (N = 66) cannabis (Table 2). After adjusting for wave 2 mental health measures, adolescents with household cannabis cessation showed mental health outcomes at wave 3 that were comparable to those unexposed, with similar risk estimates between smokeless (N = 65) and smoked (N = 373) cannabis exposure groups. However, the limited sample size in the smokeless group resulted in wide confidence intervals for risk estimates, precluding definitive conclusions about smoke-specific effects.

Mediation analysis

We then investigated potential mediators that could explain the favorable mental health outcomes associated with household cannabis cessation. In the full cohort, household cannabis cessation was associated with less conflictual family environment (adjusted β = -0.20; 95% CI, -0.29 to -0.11; p = 0.019), adjusting for covariates and the family conflict score at wave 2. Mediation analyses showed that family conflict mediated the association with internalizing symptoms (proportion mediated = 9.8%) and externalizing symptoms (proportion mediated = 16.0%), but no significant mediating effect was observed for PLEs (N = 1,426; Figure 2D-F). Regarding sleep problems, cannabis cessation was associated with a lower level of adolescents' sleep problems (adjusted β = -1.00; 95% CI, -1.35 to -0.65; p = 0.004), adjusting for covariates and the sleep problem score at wave 2. Mediation analyses revealed that sleep problems mediated the association with internalizing symptoms (proportion mediated = 26.5%) and externalizing symptoms (proportion mediated = 26.7%), but no significant mediating effect was found for

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PLEs (N = 1,422; Figure 2G-I). An integrative model (N = 1,422) showed that both family conflict and adolescents' sleep problem mediated the association with internalizing (proportion mediated, 6.8% and 25.8%, respectively; Figure 2A) and externalizing problems (proportion mediated, 14.3% and 24.8%, respectively; Figure 2B). Likewise, no significant mediating effect was observed for PLEs (Figure 2C). Sensitivity analyses in the propensity-score matched sample showed similar results (N = 873; Additional file 1: Figure S3).

Effect modification by Functional Brain Connectivity

In the analyses exploring the moderating effect of rsFC measures (N=812), we found a significant interaction between household cannabis cessation and CPN-DAN connectivity on PLEs (FDR, 0.036; Additional file 1: Table S8), though no significant interaction was observed in internalizing or externalizing problems (Additional file 1: Table S9). Stratified analyses revealed distinct patterns of associations across different baseline CPN-DAN connectivity levels (Figure 3). Specifically, among adolescents in the lowest tertile of CPN-DAN connectivity (N = 268), cannabis cessation was strongly associated with a lower level of PLEs (adjusted mean ratio, 0.67; 95% CI, 0.54-0.84). In contrast, among adolescents with higher CPN-DAN connectivity, the association was attenuated. An additional analysis revealed that household cannabis use at wave 2 was not associated with CPN-DAN connectivity (β = -0.004; 95% CI, -0.05 to 0.04). Sensitivity analyses restricting to the propensity-score matched sample (N=501) showed that no interaction terms survived FDR adjustment, though the interaction with CPN-DAN still reached nominal significance (Additional file 1: Table S8 and Table S10).

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Discussion

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Our findings provide evidence that household cannabis cessation was associated with lower levels of emotional and behavioral problems and PLEs in adolescents at wave 3, after adjusting for wave 2 corresponding scores and covariates, potentially through both direct physiological exposure and indirect psychosocial stressors. These associations were independent of adolescents' genetic predisposition to CUD. Moreover, sleep problems and family conflict at wave 3 significantly mediated the associations after adjusting for wave 2 corresponding scores and covariates. Finally, lower CPN-DAN functional connectivity at wave 2 amplified the beneficial impact of cessation on PLEs.

Our findings indicate that household cannabis cessation was linked to favorable adolescents' mental health outcomes at follow-up across multiple domains, including internalizing, externalizing, and psychotic-like symptoms. This observation aligns with earlier research demonstrating the detrimental impact of household cannabis use on child and adolescent outcomes[3, 6, 62]. While existing research has predominantly examined differences between cannabis-exposed and unexposed adolescents[4, 63, 64], the potential reversibility of these impairments following cessation of exposure has remained largely unexplored. Our study extended previous knowledge by showing that household cannabis cessation within one year was associated with higher levels of mental health domains. The study underscores the importance of educating parents about secondhand cannabis smoke exposure as well as incorporating parental substance use assessment and intervention into comprehensive child and family health services[1]. Healthcare providers should inform cannabis-using parents about the potential mental health benefits that their children may experience following cannabis cessation, which may enhance motivation for reduction or discontinuation of use[65]. The implications of these findings are particularly salient for clinical practice and public health policy, especially given the increasing prevalence of parental cannabis use in households with children following the legalization of recreational and medical cannabis across the United States[2,

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8].

To elucidate the potential mechanisms underlying these associations, we examined both direct and indirect pathways of household cannabis exposure[7]. First on the direct side, THC, the major psychoactive component of cannabis, exerts both acute and chronic effects on the endocannabinoid system, which plays a crucial role in regulating cognitive and physiological processes[66-70]. Some studies showed that down-regulation of cannabinoid-1 (CB1) receptors in several brain regions was reversible after abstinence from chronic cannabis use[37, 38, 71, 72]. We speculate that improvements in mental health may be partially attributed to the restoration of endocannabinoid system function following reduced environmental THC exposure. Further investigation incorporating direct measurement of THC biomarkers is warranted to test this hypothesis. Second indirectly, parental cannabis use is frequently associated with negative family functioning, including lack of parent-child interactions, and increased family conflict[24, 26, 27]. Dysfunctional family dynamics, consistently observed in our analyses, have been consistently linked to adverse mental health outcomes in children and adolescents[73, 74]. In our analyses stratified by smokeless cannabis, the limited sample size of the smokeless cannabis group prevented us from ruling out either pathway. Mediation analyses demonstrated that both family conflict and sleep problems were significant mediators of the associations. Still, in the absence of direct blood THC measurements and other measurements on family functioning, we were unable to disentangle these mechanistic pathways. Future studies incorporating biomarkers of THC exposure are required to delineate the relative contributions of direct biological effects versus family-level changes.

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It is also important to consider the possibility that predispositions for cannabis cessation could confound the relationship between cessation and adolescent outcomes. Drawing on directed acyclic graphs, we posited that cessation motivations might be inversely related to genetic predisposition toward CUD,

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measured here by PRS. However, adjusting for PRS for CUD did not materially alter our results, suggesting that genetic confounding was minimal. Previous studies have identified an array of psychological and practical motivators for cannabis cessation, ranging from health and legal concerns to social acceptability and self-efficacy[65]. These factors may overlap with our proposed indirect psychosocial pathway, given their likely effects on family dynamics. While this overlap could lead to an overestimation of the mediation role of family conflict, it may also mean that conditioning on family conflict provides a conservative estimate of the exposure–outcome relationship by partially accounting for indication bias. In other words, the estimated average direct pathway in the mediation analysis provided a risk estimate that partially accounted for the indication bias.

Lastly, our exploratory analyses revealed that lower CPN-DAN functional connectivity at wave 2 magnified the association between household cannabis cessation and PLEs. Given the roles of the CPN and DAN in executive function and attentional processes[75, 76], and their connections to diverse psychopathologies[77-81], these results point to the importance of neurobiological heterogeneity in shaping adolescents' responses to changes in household drug use. Our analysis showed that household cannabis exposure was not associated with CPN-DAN connectivity, suggesting this moderation effect reflects an intrinsic vulnerability rather than a reversible neural alteration. Further research integrating biomarkers and longitudinal neuroimaging assessments is needed to disentangle the extent to which neurobiological traits amplify or mitigate the mental health benefits of household cannabis cessation.

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This study has several strengths. First, this study utilized PSM methods to compare outcomes between two highly comparable groups, enhancing the robustness of our findings and strengthening potential causal inferences. Second, to our knowledge, this investigation provides the first empirical evidence examining the health implications of household cannabis cessation among children and adolescents. Third, the ABCD

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study's large sample size, comprehensive longitudinal assessments, and rich phenotypic measures enabled both rigorous control of potential confounding variables across multiple dimensions and systematic investigation of hypothesized mediating pathways.

The study should be interpreted in light of the following limitations. First, we could not rule out the potential reversal causality that adolescents' mental health could have influenced family members' decisions to cease cannabis use. Though, existing evidence more strongly supports the hypothesized directional relationship. Specifically, substantial literature demonstrates that modifications in parental behavior and family environment can significantly impact adolescent mental health outcomes[26, 27]. In contrast, evidence supporting the alternative pathway, where children's psychological symptoms drive parental substance use cessation, remains limited. Second, the household cannabis exposure status was ascertained through self-reported data without details on frequency, proximity, and exposure severity. This limitation potentially introduces misclassification bias and precludes investigation of dose-dependent relationships that could substantiate the causal relationship and the reduced environmental THC hypothesis. Although our smokeless cannabis analysis provides preliminary supporting evidence, future studies employing more detailed exposure assessments and physiological measurement are warranted to elucidate the causal mechanisms and further evaluate the efficacy of dose-reduction strategies versus complete cessation. Furthermore, the concurrent assessment of mediators and outcome variables limited a causal interpretation, warranting future longitudinal research. Third, the small sample size in specific subgroups provided insufficient statistical power to draw definitive conclusions. Fourth, although we investigated the confounding role of PRS for CUD, several limitations warrant consideration. The PRS analyses were restricted to participants of European ancestry due to methodological requirements, which limited both sample size and generalizability. Moreover, our analyses assumed genetic relatedness between children and

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household cannabis users (presumably parents), but this assumption lacks empirical verification in our dataset. Fifth, the interpretation of fMRI findings warrants caution due to inherent challenges in test-retest reliability of neural activation measurements[82]. Sixth, although the current study investigated the moderating role of functional connectivity, neuroimaging evidence suggests that functional connectivity alterations may be relevant to environmental exposure such as THC[83], and these functional alterations may be reversible upon cessation of THC exposure[84]. Future longitudinal neuroimaging studies are warranted to elucidate this pathway.

Conclusions

Ceasing household cannabis use was associated with higher levels of mental health in adolescents, which may be partly related to better family dynamics and sleep, and may be influenced by neurobiological factors such as lower CPN-DAN functional connectivity. In an era of expanding cannabis legalization and rising prevalence of use, these findings suggest that interventions aimed at reducing or eliminating cannabis exposure within the home may be beneficial for youth well-being.

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Abbreviations

ABCD	Adolescent Brain Cognitive Development
AN	Auditory network
CBCL	Child Behavioral Checklist
CI	Confidence interval
CON	Cingulo-opercular network
CPN	Cingulo-parietal network
CUD	Cannabis use disorder
DAN	Dorsal attention network
DMN	Default mode network
FDR	False discovery rate
FPN	Fronto-parietal network
GWAS	Genome-wide association study
NN	“None” network
OR	Odds ratio

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PLEs	Psychotic-like experiences
PQ-BC	Prodromal Questionnaire - Brief Child Version
PRS	Polygenic risk score
PSM	Propensity score matching
PT	P-value thresholds
rsFC	Resting-state functional connectivity
RTN	Retrosplenial temporal network
SD	Standard deviation
SHN	Sensorimotor hand network
|SMD|	Absolute standardized mean difference
SMN	Sensorimotor mouth network
SN	Salience network
THC	Δ9-tetrahydrocannabinol
VAN	Ventral attention network
VN	Visual network

Declarations

Acknowledgements

Data used in the preparation of this article were obtained from the ABCD study (https://abcdstudy. org), held in the NIMH Data Archive. This is a multisite, longitudinal study designed to recruit more than 10 000 children aged 9-10 years and follow them over 10 years into early adulthood. The ABCD study is supported by the National Institutes of Health and additional federal partners under award numbers U01DA041048, U01DA050989, U01DA051016, U01DA041022, U01DA051018, U01DA051037, U01DA050987, U01DA041174, U01DA041106, U01DA041117, U01DA041028, U01DA041134, U01DA050988, U01DA051039, U01DA041156, U01DA041025, U01DA041120, U01DA051038, U01DA041148, U01DA041093, U01DA041089. A full list of supporters is available at https:// abcdstudy.org/federal-partners.html. A listing of participating sites and a complete listing of the study investigators can be found at https:// abcdstudy.org/scientists/workgroups/. ABCD consortium investigators designed and implemented the study and/or provided data but did not necessarily participate in analysis or writing of this report. This manuscript reflects the views of the authors and may not reflect the opinions or

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views of the NIH or ABCD consortium investigators. The data that support the findings of this study are openly available in the ABCD Dataset Data Release 5.0 at https://nda.nih.gov/abcd. The scripts used for these analyses will be made available upon publication (doi: 10.15154/y39a-zp25). The computations in this paper were run on the π 2.0 (or the Siyuan-1) cluster supported by the Center for High Performance Computing at Shanghai Jiao Tong University.

Authors' Contributions

MW, XYX, TR, and FL designed the study. MW, TR, and RQH conducted data analysis. MW, XYX, and TR drafted the manuscript. MW, XYX, RQH, YJS, LLZ, WZ, QLZ, QL, WCD, TR, and FL contributed to the interpretation of the data and critically and substantively revised the manuscript. TR and FL contributed equally to the work as senior investigators. They designed the study, supervised the data analyses, and supervised the drafting and revising of the manuscript. The corresponding author attests that all the listed authors meet authorship criteria and that no others meeting the criteria have been omitted. All authors read and approved the final manuscript.

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Funding

Authors received funding support from the National Natural Science Foundation of China (82430104, 82125032, 81930095, 82204048; Drs TR and FL), the China Brain Initiative Grant (STI2030-Major Projects 2021ZD0200800; Dr FL), the Science and Technology Commission of Shanghai Municipality (19410713500, 23Y21900500, 2018SHZDZX01; Dr FL), the Shanghai Municipal Commission of Health and Family Planning (GWVI-11.1-34, 2020CXJQ01, 2018YJRC03; Dr FL), the Innovative research team of high-level local universities in Shanghai (SHSMU-ZDCX20211100; Dr FL), the Chenguang Program of Shanghai Education Development Foundation and Shanghai Municipal Education Commission (Dr TR),

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and the Guangdong Key Project (2018B030335001; Dr FL).

Data Availability

Data are publicly released on an annual basis through the National Institute of Mental Health (NIMH) data archive (NDA, https://nda.nih.gov/abcd). The ABCD study are openly available to qualified researchers for free. Access can be requested at https://nda.nih.gov/abcd/request-access. The data that support the findings of this study are openly available in the ABCD Dataset Data Release 5.1. An NDA study has been created for the data used in this report and will be made available upon publication (doi: 10.15154/y39a-zp25).

Ethics approval and consent to participation

In the ABCD study, all procedures were approved by a central Institutional Review Board (IRB) at the University of California, San Diego (IRB Approval No. 160091), and in some cases by individual site IRBs (e.g., Washington University in St. Louis) (https://www.sciencedirect.com/science/article/pii/S1878929317300622). Parents or guardians provided written informed consent after the procedures had been fully explained and children assented before participation in the study.

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Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Supplementary Information

The online version contains supplementary material (Additional file 1) available at the website of BMC

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Medicine.

Additional file 1: Tables S1-S10 and Figures S1-S3. Table S1. Details of household cannabis measures. Table S2. Details of covariate measures. Table S3. Linear associations between household cannabis cessation and adolescents' mental health outcomes in the matched sample (N=876). Table S4. Logistic associations between household cannabis cessation and adolescents' mental health outcomes in the matched sample (N=876). Table S5. Linear associations between household cannabis cessation and adolescents' mental health outcomes in the full sample (N=1426). Table S6. Associations of household cannabis cessation with adolescents' mental health outcomes before and after adjustment for PRS for cannabis use disorder in the White sample (N=681 from the full sample). Table S7. Associations of household cannabis cessation with adolescents' mental health outcomes before and after adjustment for PRS for cannabis use disorder in the White sample (N=369 from the matched sample). Table S8. Interaction analyses of household cannabis cessation with adolescents' rsFC measures on psychotic-like experiences. Table S9. Interaction analyses of household cannabis cessation with adolescents' functional brain connectivity on internalizing and externalizing problems (N=812 from the full sample). Table S10. Interaction analyses of household cannabis cessation with adolescents' functional brain connectivity on internalizing and externalizing problems (N=501 from the matched sample). Figure S1. Directed Acyclic Graph. Figure S2. Distribution of propensity scores (A) before and (B) after matching. Figure S3. Mediation analyses of family conflict and adolescent sleep problems in the association between household cannabis cessation and (A, D, G) internalizing and (B, E, H) externalizing problems, and (C, F, I) psychotic-like experiences from the matched sample.

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Table 1. Baseline demographic and psychological characteristics before and after propensity score matching.

	Before matching					After matching				
	Persistent exposure (N=988)		**Ceased exposure (N=438)**		**|SMD|**	**Persistent exposure (N=438)**		**Ceased exposure (N=438)**		**|SMD|**
	N	**%**	**N**	**%**		**N**	**%**	**N**	**%**	
Adolescent variables										
Age, mean (SD), year	11.60	0.70	11.55	0.71	0.072	11.55	0.70	11.55	0.71	0.006
Male gender	522	52.8	223	50.9	0.038	226	51.6	223	50.9	0.014
Race										
White	612	61.9	231	52.7	0.187	230	52.5	231	52.7	0.005
Black	86	8.7	61	13.9	0.165	64	14.6	61	13.9	0.020
Hispanic	149	15.1	85	19.4	0.115	81	18.5	85	19.4	0.023
Others	141	14.3	61	13.9	0.010	63	14.4	61	13.9	0.013
Family annual income										
$49,999 and less	221	22.4	131	29.9	0.172	138	31.5	131	29.9	0.035
$50,000 through $74,999	161	16.3	59	13.5	0.079	58	13.2	59	13.5	0.007
$75,000 through $99,999	146	14.8	52	11.9	0.086	54	12.3	52	11.9	0.014
$100,000 and higher	460	46.6	196	44.7	0.036	188	42.9	196	44.7	0.037
Lifetime substance exposure										
Has tried alcohol	316	32.0	117	26.7	0.116	121	27.6	117	26.7	0.021
Has tried tobacco	11	1.1	4	0.9	0.020	5	1.1	4	0.9	0.023
Emotional and behavioral problems, mean (SD)										
Internalizing broad band score	5.92	6.09	5.75	5.56	0.029	5.78	6.13	5.75	5.56	0.005
Externalizing broad band score	4.47	5.70	4.50	5.31	0.005	4.59	5.92	4.50	5.31	0.016
Psychotic-like experiences										

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Distress score	3.61	8.17	4.74	9.99	0.124	4.51	9.19	4.74	9.99	0.022
Parent variables										
Household substance use										
Alcohol	918	92.9	405	92.5	0.017	402	91.8	405	92.5	0.025
Tobacco	503	50.9	219	50.0	0.018	225	51.4	219	50.0	0.027
Parental history of depression	412	41.7	144	32.9	0.183	149	34.0	144	32.9	0.024

Abbreviations: SD, standard deviation; SMD, standard mean difference.

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Table 2. Smoke effects of household cannabis on adolescents' mental health outcomes.

Outcome	N	Wave 2	Wave 3	Model 1		Model 2	
		Mean (SD)	Mean (SD)	Mean ratio (95% CI)	P value	Mean ratio (95% CI)	P value
CBCL Internalizing Problems							
Unexposed	5546	4.78 (5.43)	4.94 (5.65)	1.00 (ref)	-	1.00 (ref)	-
Persistent exposure, smoked	827	6.04 (6.21)	6.95 (7.16)	1.24 (1.15 to 1.33)	<0.001	1.13 (1.07 to 1.19)	<0.001
Persistent exposure, smokeless	66	4.92 (4.44)	5.94 (5.55)	1.22 (0.98 to 1.52)	0.075	1.19 (1.00 to 1.40)	0.044
Ceased exposure, smoked	373	5.85 (5.73)	5.76 (6.24)	1.12 (1.01 to 1.23)	0.029	0.99 (0.92 to 1.07)	0.882
Ceased exposure, smokeless	65	5.20 (4.48)	5.86 (6.15)	1.16 (0.93 to 1.45)	0.184	1.06 (0.89 to 1.25)	0.514
CBCL Externalizing Problems							
Unexposed	5546	3.62 (5.23)	3.67 (5.22)	1.00 (ref)	-	1.00 (ref)	-
Persistent exposure, smoked	827	4.62 (5.90)	5.00 (6.06)	1.16 (1.08 to 1.24)	<0.001	1.10 (1.04 to 1.16)	<0.001
Persistent exposure, smokeless	66	3.70 (4.27)	4.05 (4.68)	1.13 (0.90 to 1.42)	0.277	1.08 (0.92 to 1.27)	0.332
Ceased exposure, smoked	373	4.68 (5.40)	4.52 (6.06)	1.08 (0.98 to 1.20)	0.118	0.99 (0.92 to 1.06)	0.738
Ceased exposure, smokeless	65	3.46 (4.69)	3.43 (4.49)	1.07 (0.85 to 1.34)	0.575	1.05 (0.89 to 1.23)	0.567
PQ-BC Distress Score							
Unexposed	5546	3.20 (7.01)	2.59 (6.19)	1.00 (ref)	-	1.00 (ref)	-
Persistent exposure, smoked	827	3.97 (8.67)	3.71 (7.55)	1.12 (1.04 to 1.21)	0.003	1.11 (1.04 to 1.19)	0.002
Persistent exposure, smokeless	66	1.45 (3.22)	1.58 (3.58)	1.00 (0.80 to 1.26)	1.000	1.10 (0.89 to 1.34)	0.377
Ceased exposure, smoked	373	4.97 (10.18)	3.28 (6.99)	1.02 (0.92 to 1.13)	0.681	1.01 (0.92 to 1.10)	0.866
Ceased exposure, smokeless	65	3.43 (8.82)	1.66 (4.82)	0.83 (0.66 to 1.04)	0.106	0.84 (0.69 to 1.03)	0.094

Abbreviations: CBCL, the Child Behavior Checklist; PQ-BC, the Prodromal Questionnaire - Brief Child Version; SD, standard deviation. Note: Model 1 was adjusted for adolescent age, sex, race/ethnicity, lifetime alcohol and tobacco exposure, family annual income, household alcohol and tobacco use, and

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parental history of depression. Model 2 was additionally adjusted for the corresponding psychological variable at wave 2.

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Figure legends

Figure 1. Multivariate **(A)** linear and **(B)** logistic regression models of household cannabis cessation and adolescents' mental health outcomes in the matched sample (N=876).

Abbreviations: CBCL, the Child Behavior Checklist; PQ-BC, the Prodromal Questionnaire - Brief Child Version; SD, standard deviation; OR, odds ratio.

Figure 2. Mediation analyses of family conflict and adolescent sleep problems in the association between household cannabis cessation and **(A, D, G)** internalizing and **(B, E, H)** externalizing problems, and **(C, F, I)** psychotic-like experiences.

Abbreviation: SE, standard error. Note: Path a measures the association between the predictor and the mediator; path b represents the effect of the mediator on the dependent variable; path a*b represents the mediation effect; path c' measures the direct effect, and path c measures the total relationship between the predictor and the dependent variable.

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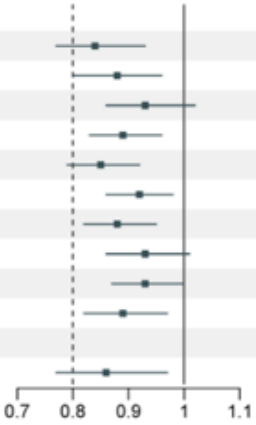
Figure 3. Association between household cannabis cessation and adolescents' psychotic-like experiences in analyses stratified by the CPN-DAN connectivity.

Abbreviations: CPN, cingulo-parietal network; DAN, dorsal attention network; SD, standard deviation; PLEs, psychotic-like experiences. Case/Control refers to the number of adolescents in the ceased and persistent exposure group, respectively.

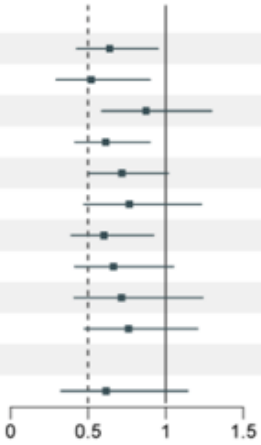
A

Outcome	Persistent Exposure Mean (SD)	Ceased Exposure Mean (SD)	Mean Ratio (95% CI)	P value
CBCL				
Internalizing problems	6.93 (7.20)	5.78 (6.22)	0.84 (0.77 to 0.93)	<0.001
Externalizing problems	5.12 (6.37)	4.36 (5.86)	0.88 (0.80 to 0.96)	0.006
Anxious/depressed	2.96 (3.53)	2.61 (3.09)	0.93 (0.86 to 1.02)	0.111
Withdrawn/depressed	2.13 (2.80)	1.67 (2.27)	0.89 (0.83 to 0.96)	0.004
Somatic complaints	1.83 (2.27)	1.50 (2.08)	0.85 (0.79 to 0.92)	<0.001
Social problems	1.54 (2.37)	1.27 (2.10)	0.92 (0.86 to 0.98)	0.011
Thought problems	1.90 (2.45)	1.41 (2.12)	0.88 (0.82 to 0.95)	0.001
Attention problems	3.58 (3.78)	2.99 (3.34)	0.93 (0.86 to 1.01)	0.069
Rule−breaking behavior	1.51 (2.49)	1.24 (2.08)	0.93 (0.87 to 1.00)	0.049
Aggressive behavior	3.60 (4.33)	3.12 (4.16)	0.89 (0.82 to 0.97)	0.007
PQ−BC				
Distress score	4.15 (8.25)	3.04 (6.74)	0.86 (0.77 to 0.97)	0.012



B

Outcome	Persistent Exposure N (%)	Ceased Exposure N (%)	OR (95% CI)	P value
CBCL				
Internalizing problems	90 (20.5)	74 (16.9)	0.64 (0.43 to 0.95)	0.028
Externalizing problems	49 (11.2)	33 (7.5)	0.52 (0.29 to 0.90)	0.021
Anxious/depressed	77 (17.6)	68 (15.5)	0.87 (0.59 to 1.29)	0.502
Withdrawn/depressed	105 (24.0)	79 (18.0)	0.61 (0.42 to 0.90)	0.013
Somatic complaints	100 (22.8)	83 (18.9)	0.72 (0.51 to 1.02)	0.063
Social problems	51 (11.6)	46 (10.5)	0.77 (0.47 to 1.23)	0.271
Thought problems	85 (19.4)	54 (12.3)	0.60 (0.39 to 0.92)	0.020
Attention problems	78 (17.8)	56 (12.8)	0.66 (0.41 to 1.05)	0.081
Rule−breaking behavior	40 (9.1)	31 (7.1)	0.72 (0.41 to 1.24)	0.235
Aggressive behavior	55 (12.6)	46 (10.5)	0.76 (0.48 to 1.21)	0.246
PQ−BC				
Distress score	28 (6.4)	21 (4.8)	0.62 (0.33 to 1.14)	0.129



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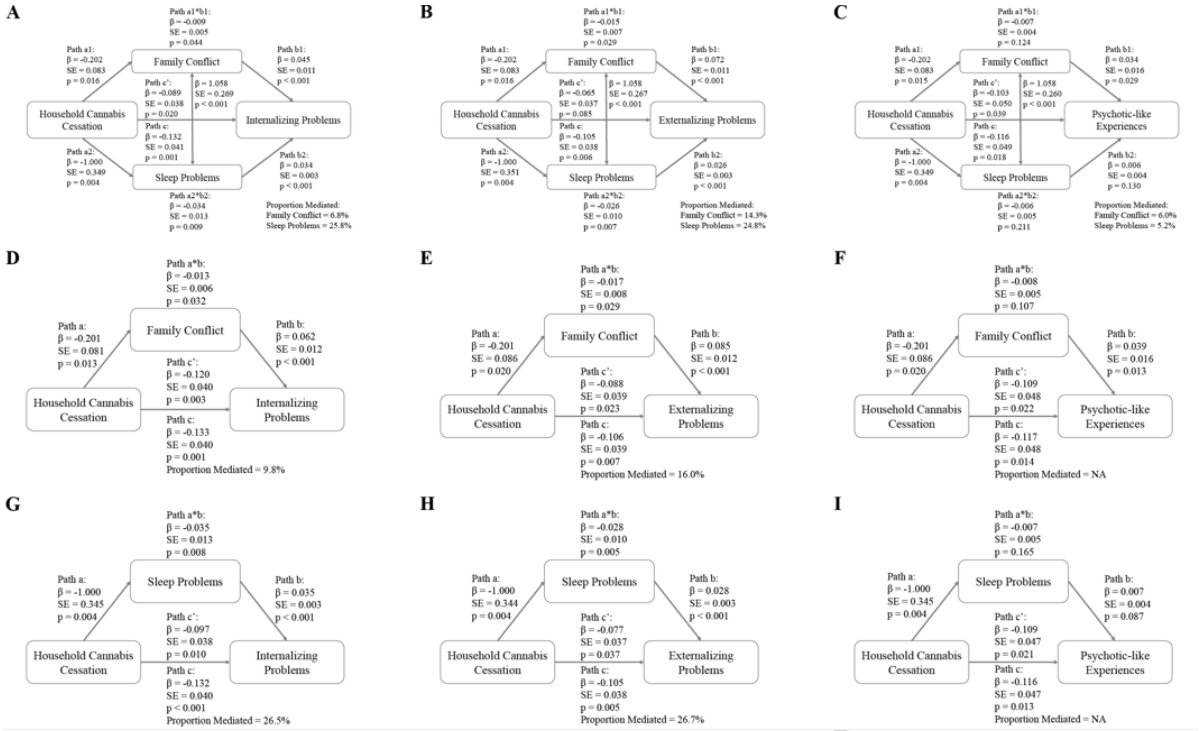

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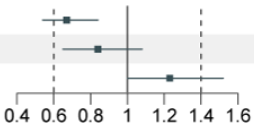
Average correlation between CPN and DAN	Total N (Case/Control)	Mean (SD) for PLEs	Mean Ratio (95% CI)	P value
The lowest tertile	268 (88/180)	3.29 (7.78)	0.67 (0.54 to 0.84)	0.001
The middle tertile	268 (77/191)	3.49 (6.54)	0.84 (0.65 to 1.08)	0.176
The highest tertile	276 (93/183)	2.88 (6.45)	1.23 (1.00 to 1.52)	0.055



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