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ORIGINAL PAPER

Identifying sensitive periods when changes in parenting and peer factors are associated with changes in adolescent alcohol and marijuana use

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Abstract

Purpose There are well-established associations between parental/peer relationships and adolescent substance use, but few longitudinal studies have examined whether adolescents change their substance use in response to changes in their parents' behavior or peer networks. We employ a within-person change approach to address two key questions: Are changes in parenting and peer factors associated with changes in adolescent marijuana and alcohol use? Are there sensitive periods when changes in parenting and peer factors are more strongly associated with changes in adolescent marijuana and alcohol use?

Methods We analyzed longitudinal data collected annually on 503 boys, ages 13–19, recruited from Pittsburgh public schools. Questionnaires regarding parental supervision, negative parenting practices, parental stress, physical punishment, peer delinquency, and peer drug use were administered to adolescents and their caretakers. Alcohol and marijuana use were assessed by a substance use scale adapted from the National Youth Survey.

Results Reductions in parental supervision and increases in peer drug use and peer delinquency were associated with increases in marijuana frequency, alcohol frequency, and alcohol quantity. Increases in parental stress were associated with increases in marijuana and alcohol frequency. The magnitudes of these relationships were strongest at ages 14–15 and systematically decreased across adolescence. These associations were not due to unmeasured stable confounders or measured time-varying confounders.

Conclusions Reducing or mitigating changes in parenting and peer risk factors in early adolescence may be particularly important for preventing substance use problems as adolescents transition into young adulthood.

Keywords Peer influence · Parental influence · Substance use · Adolescence · Transition to adulthood · Fixed effects

Introduction

Social context is central to the development of substance use problems. For adolescents, interactions with parents and peers are key socio-contextual factors that influence the formation of conventional norms and values and provide opportunities for normative vs. non-normative activities and behaviors [1, 2]. There are well-established associations between parent and peer behaviors and youth substance use across adolescence [3–7]. Specifically, the magnitude of the association between parenting factors and adolescent substance use tends to decline over the course of adolescence, whereas the magnitude of the association with peers factors tends to increase over that period [8, 9].

Extant research, however, typically examines substance use among adolescents with high levels of parenting or peer risk factors vs. adolescents with low levels of these factors.

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As a result, much prior research is subject to potential confounding and selection effects that may produce spurious, rather than causal, associations between parenting and peer factors and adolescent substance use. In contrast to this between-person approach, few longitudinal studies have taken a within-person approach: examining whether adolescents change their substance use in response to changes in parenting or peer networks [10, 11]. This within-person approach, which compares each adolescent to themselves over time, can enhance causal inference by ruling out potential confounding and selection effects of stable differences between individuals, such as prenatal complications, family history of substance use, and early childhood trauma.

In the present study, we employ a within-person change approach to address two questions: Are changes in parenting and peer factors associated with changes in adolescent marijuana and alcohol use? Are there sensitive periods when changes in parenting and peer factors are more strongly associated with changes in adolescent marijuana and alcohol use?

Parenting and adolescent substance use

Parenting practices are associated with adolescent substance use. Parental monitoring and supervision, characterized by parents knowing about and exerting control over their child's activities, whereabouts, and affiliates, is consistently associated with lower substance use [1, 9, 12]. Adolescents' accurate perceptions of parental expectations about substance use, parental disapproval of heavy drinking, open communication, and parental warmth are associated with lower levels of substance use, whereas parental permissiveness and adolescents' inaccurate perceptions of parental expectations are associated with higher levels of substance use [8, 12–16]. Excessive parental punishment and strictness may increase frequency of adolescent alcohol use behaviors [9]. Finally, parental stress is a driver of parenting style and adolescent health behaviors [17, 18], as well as a potential mediator through which parental substance use may influence adolescent substance use [9, 19].

The influence of parenting practices on adolescent substance use, however, tends to decrease as children get older [1, 12], likely due to the emergence of more direct opportunities for substance use as adolescents develop greater independence from their caregivers and engage in unmonitored activities with peers [1, 14]. Indeed, the role of parental monitoring and parenting style seems to be partially mediated by peer affiliation; i.e., the extent to which parenting practices influence adolescent substance use is partially due to parents' influence on the sorts of peers that adolescents select [12].

Parenting practices occur within a broader family context, characterized by, e.g., socioeconomic status and stressful events. These contextual factors influence adolescent substance use via their effects on parenting practices, but also have direct effects on adolescent substance use [20, 21]. What remains unclear, however, is the extent to which associations between family context, parenting practices, and adolescent substance use reflect underlying stable, potentially unmeasured confounding and selection factors [10]. A within-person approach that compares an adolescent to themself over time can isolate changes in parenting practices from the broader family context.

Peers and adolescent substance use

Affiliation with peers who engage in delinquent behaviors, particularly substance use, is one of the strongest and most consistent predictors of adolescent substance use [16, 22–25], and may be more important than parenting practices [1, 16]. Peer interactions provide a context for acquiring new social skills and learning social roles and norms, which can be supportive of, or protective against, substance use [26, 27]. Adolescence is a developmental period during which peer behaviors play a highly influential role through social learning, peer pressure, and peer reinforcement [16].

The influence of peers on substance use increases during adolescence, as youth spend less time with parents, involvement with family decreases, and peer interactions become unstructured and unsupervised [28, 29]. Crawford and Novak [1] identified early high school as a sensitive period when the influence of peers on substance use matters most. The effect of peers on substance use begins to increase around age 15 [8] and may last until age 20 [30]. However, the extent to which the effect of peers on adolescent substance use is causal or the result of homophilic selection remains uncertain [24, 27, 30].

Psychiatric symptomatology

There is a consistent link between externalizing and internalizing psychopathology and adolescent alcohol and marijuana use [31–38]. Specifically, conduct disorder, depression, and anxiety predict adolescent initiation of alcohol and marijuana use, frequency of use, and development of substance use disorders [31, 33, 35–38]. Given the well-established associations between parenting factors, peer factors, and externalizing and internalizing symptoms [39–42], analyses of parenting/peer factors on adolescent substance use must account for variations in psychiatric symptomatology.

Methodological considerations and the present study

Most research on the role of parenting and peer influences on adolescent substance use employs a between-person

approach. This approach estimates the average level of substance use expected in adolescents with a low level of parenting or peer risk factors had they been exposed to a high level of those risk factors. However, unmeasured time-invariant factors (described above), or contextual factors that contribute to homophilic selection of peer groups, may explain both why certain adolescents have higher levels of parental and peer risk factors and also why they are more likely to engage in substance use. Thus, this between-person approach presents limits for casual inference.

In the present study, we employ fixed effects, or within-person change models, to address these limitations. Within-person change models determine whether, within an individual, changes in parenting and peer factors predict subsequent changes in substance use. Within-person change models are underutilized in research on adolescent substance use: we are aware of few studies that use fixed effects to examine the relationship between changes in individual-level risk factors and changes in adolescent substance use [10, 11, 31, 43–45]. In conjunction with existing evidence from traditional approaches, if changes in parenting and peer factors predict changes in substance use, we can be more confident that these effects are causal and not spurious.

Beardslee et al. [10] recently employed a within-person approach to estimate the associations between changes in parent-son conflict, peer substance use/criminal offending, and subsequent changes in substance use and criminal offending among the oldest cohort of the Pittsburgh Youth Study (PYS) (ages 17–26). They found that increased peer delinquency and offending were associated with increased substance use and offending, and associations were strongest for substance use during adolescence. We build upon this research by applying a similar approach to study adolescents ages 13–19, reflecting a developmental period during which parenting and peer factors may play a stronger role in shaping adolescent substance use.

Methods

Sample

Data are from the youngest cohort of the PYS, which has been described in depth elsewhere [31, 46–49]. First-grade boys enrolled in Pittsburgh (PA) public schools between 1987 and 1988 were randomly sampled from school enrollment lists for initial screening. Boys were rated for conduct problems (e.g., fighting, stealing) by parents, teachers, and the boys themselves. Those with composite conduct problem scores in the upper 30th percentile, together with an approximately equal number of participants randomly selected from the remaining distribution, were selected for longitudinal follow-up (total $N = 503$). The sample is predominantly black (56%) and white (41%) with 3% Asian, Hispanic, and mixed-race.

Participants were assessed every 6 months for the initial 8 assessments and then annually for 9 consecutive assessments, totalling17 assessments. Caretakers provided informed consent and adolescents provided assent until age 17 and consent thereafter. Substance use was rare among boys during ages 7–12: 93.9% and 84.5% did not use marijuana or alcohol, respectively, on any occasion during those ages. Thus, we restricted analysis to adolescents ages 13–19, resulting in 7 annual assessments for each participant and a total of 3,521 units (participant-years) for analysis.

Measures

Outcome variables

Alcohol and marijuana use Alcohol and marijuana use were assessed by a 16-item Substance Use Scale [50, 51] adapted from the National Youth Survey. Adolescents self-reported the frequency and quantity of alcohol consumption and the frequency of marijuana use. We defined "marijuana frequency" and "alcohol frequency" as the count of the number of days of marijuana or alcohol use in the past year, respectively. "Alcohol quantity" is the average number of drinks per drinking occasion in the past year, ranging from 1 = less than one drink to 5 = six or more drinks. Missingness ranged from 15.6% for alcohol frequency to 15.7% for marijuana frequency; we excluded participants with missing outcome data from analyses.

Exposure variables

Parenting factors All parenting factors except parental stress were assessed using identical items administered to parents and youths. For parenting factors assessed by two informants, ratings were summed to create composite scores. Parental supervision was assessed with four items about caretakers' knowledge of adolescents' activities (α of 0.66) [52, 53], drawn from the Supervision/Involvement Scale [54–56]. Negative parenting, measured with an adaptation of the Positive Parenting Scale [49], assessed frequency of negative responses to adolescent behavior (α between 0.8 and 0.82 across study years). Physical punishment was indexed by one item drawn from the Discipline Scale [49]. Parental stress, measured with the parent-report Perceived Stress Scale, is a 14-item scale assessing caretakers' stress levels and abilities to cope with stress in the previous month (α between 0.85 and 0.88) [49, 57]. Higher scores indicate lower supervision, more negative parenting, more parental stress, and more use of physical punishment. Correlation among parenting factors was low, suggesting distinct factors; the highest correlation was between super-

vision and negative parenting (Pearson's correlation coefficient = 0.37). Parenting factors were only available for both informants from ages 13–16 (2,012 participant-years). Thus, analysis of parenting factors was limited to adolescents ages 13–16. Missingness ranged from 6.1% for parental stress to 6.4% for parental supervision. For more detail regarding the psychometric properties of these measures, see Loeber and colleagues [52, 58].

Peer factors Peer factors were drawn from the Peer Delinquency Scale, which contains 15 items corresponding to those on the Self-Reported Delinquency Scale and the Substance Use Scale [58]. Participants were asked to report the behavior of their peers. Peer factors consisted of adolescent peer delinquency, e.g., proportion of peers who hit someone or destroyed property (α between 0.89 and 0.93), and peer drug use, e.g., proportion of peers who used marijuana or alcohol (α between 0.68 and 0.74) [50]. The Pearson's correlation coefficient for these two variables was 0.57, suggesting overlapping but distinct factors. Peer factors were available for adolescents from ages 13–19. Peer delinquency and peer drug use had 0.8% and 0.5% missingness, respectively.

We regressed missingness (participant-years with any missing data vs. none) on the three outcomes of interest, age, and race. The only significant difference between missing and non-missing participant years was a small difference in age. In the analytic sample for parenting factors (adolescents ages 13–16), the mean age for those with complete data was 14.4 vs. 15.0 for those with missing data. In the analytic sample for peer factors (adolescents ages 13–19), the mean age for those with complete data was 15.8 vs. 16.8 for those with missing data.

Potential confounders

Socioeconomic status Participants' socioeconomic status (SES) was assessed annually by applying the Hollingshead Index of Social Status to data provided by the primary caretaker or the adolescent if no longer living with family beginning at age 16 [59].

Psychiatric symptoms Depression symptoms were measured using the 13-item Recent Mood and Feelings Questionnaire (RMFQ), administered to boys annually [60]. Each item is rated on 3-point Likert scale (0 = "not true" to 2 = "true"). The scale has adequate reliability (α between 0.81 and 0.87) and a strong association with a diagnosis of depression [61]. We operationalized depression symptoms as the count of symptoms in the prior year.

Anxiety was measured with six items from the Achenbach scales rated as consistent with anxiety disorders by a group of mental health professionals [49, 62–64]. They were administered to adolescents, caretakers, and teachers. If any of the three informants answered "sometimes" or "often" for a given item, the adolescent was coded as positive for that item and the items were summed to form a total anxiety score [49]. α coefficients varied from 0.67 to 0.73. The scale discriminates between clinic-referred adolescents with anxiety disorders and non-referred adolescents [65]. We operationalized anxiety symptoms as the count of symptoms in the prior year.

Conduct disorder symptoms were measured with nine items from the Self-Reported Antisocial Behavior scale, the Self-Reported Delinquency scale [47, 50], and the Child Report of the Achenbach scales [62–64]. α coefficients were 0.92 and 0.83, respectively [66, 67]. We operationalized conduct disorder symptoms as the count of symptoms in the prior year.

Analyses

Because substance use outcomes are counts, we fit quasi-Poisson regression models to assess the within-person effects of changes in parenting (ages 13–16) and peer factors (ages 13–19) on changes in alcohol and marijuana use. Quasi-Poisson models are an approach to dealing with over-dispersion, which we found in initial Poisson models. Quasi-Poisson models leave the dispersion parameter unrestricted and estimate it from the data [68]. This leads to the same coefficient estimates as Poisson models, but adjusts standard errors for over-dispersion [69]. We followed Allison's "dummy variable method" for estimating Poisson fixed effects, by including $k-1$ dummy variables to represent the k sample participants [70]. This removes all between-person variance, leaving only within-person variance to account for any observed association. In essence, this approach uses each individual as their own control, thereby eliminating any potential stable confounding or selection factors.

Modeling strategy

First, we fit separate models for each of the parenting and peer variables and each substance use outcome. We regressed each substance use outcome on the exposure of interest and age. We modeled age as a 4-level categorical variable for parenting exposures (ages 13–16), and as a 7-level categorical variable for peer exposures (ages 13–19). We included measures of parenting and peer factors from the same survey year as the substance use outcomes, as exposure values from the prior year were very weakly associated with substance use, likely due to dissipation of exposure effects at such a wide temporal resolution. Next, we additionally adjusted significant effects obtained from the first set of models by prior year psychiatric symptoms and SES. We used covariate data

from the prior year to ensure the correct temporal ordering, i.e., to ensure that potential confounders preceded the exposure rather than being consequences of the exposure. This was important given that the association of interest may be mediated through psychiatric symptoms and SES. In a third and fourth set of models, we controlled for combinations of all parenting and peer factors simultaneously. Finally, we tested for multiplicative effect modification between age and parenting and peer variables that showed significant main effects, by including a cross-product term between the exposure and the categorical age variable. Post hoc interaction contrasts were obtained with R package 'phia' [71]. We plotted predicted substance use counts for a hypothetical adolescent whose magnitude of change in parenting and peer exposures fell at the mean, mean plus one standard deviation, and mean plus two standard deviations at each time point.

Sensitivity analysis

To account for the possibility that past-year substance use confounded the relationship between parenting/peer factors and current year substance use, we repeated the analyses above but included the substance use outcome lagged by one year [72, 73] as a covariate in all models. Results of these models did not differ appreciably from the findings reported below, and are available upon request.

Results

Table 1 shows descriptive statistics for all outcomes, exposures, and covariates over the study period.

Table 2 presents rate ratios for a one unit increase in the crude (inclusion of only age as a covariate) and adjusted (additional adjustment by prior-year psychiatric symptoms and SES) effects of each parenting and peer factor

Table 1 Descriptive statistics of the sample, Pittsburgh Youth Study ($N=503$)

	Possible scores	Mean (SD)						
		Age 13	Age 14	Age 15	Age 16	Age 17	Age 18	Age 19
Negative parenting	14–42	22.20 (4.57)	22.52 (4.56)	23.23 (4.60)	23.09 (4.92)	–	–	–
Low supervision	8–24	11.51 (2.63)	11.71 (2.58)	12.12 (2.94)	12.31 (2.99)	–	–	–
Physical punishment	2–6	2.38 (0.62)	2.29 (0.59)	2.24 (0.53)	2.25 (0.56)	–	–	–
Parental stress	14–42	23.36 (5.15)	23.58 (5.16)	23.70 (5.34)	23.51 (4.93)	–	–	–
Peer delinquency	0–14	4.48 (6.52)	5.03 (6.78)	4.92 (6.47)	5.33 (6.70)	4.23 (6.28)	3.90 (5.76)	2.93 (4.75)
Peer drug use	0–12	1.40 (2.27)	2.17 (2.58)	2.69 (2.68)	3.18 (2.76)	3.14 (2.81)	3.53 (2.96)	3.89 (2.79)
Depression	0–26	2.17 (3.12)	2.11 (3.03)	2.17 (3.23)	2.20 (3.46)	1.77 (2.96)	1.75 (3.18)	1.43 (2.38)
Anxiety	0–12	2.50 (2.01)	2.28 (1.99)	1.93 (1.83)	1.61 (1.69)	1.32 (1.85)	1.27 (1.86)	1.04 (1.66)
Conduct disorder	0–13	0.57 (1.16)	0.68 (1.23)	0.61 (1.05)	0.53 (0.99)	0.29 (0.76)	0.19 (0.60)	0.14 (0.53)
Marijuana frequency	0–365[a]	6.55 (38.08)	18.67 (64.79)	29.23 (81.42)	39.53 (97.18)	39.43 (94.79)	58.61 (117.39)	49.95 (108.48)
Alcohol frequency	0–365[a]	5.60 (29.85)	13.30 (49.31)	12.75 (38.24)	18.28 (52.18)	25.47 (62.34)	40.33 (81.35)	45.02 (78.78)
Alcohol quantity	0–5[b]	1.19 (2.43)	1.85 (3.09)	2.20 (3.38)	2.68 (3.56)	3.04 (3.80)	4.04 (4.25)	4.23 (4.03)
SES	*N* (%)							
	Age 13	Age 14	Age 15	Age 16	Age 17	Age 18	Age 19	
1st quartile	44 (8.7)	48 (9.5)	45 (8.9)	84 (16.7)	215 (42.7)	193 (38.4)	114 (22.7)	
2nd quartile	117 (23.3)	101 (20.1)	98 (19.5)	100 (19.9)	107 (21.3)	125 (24.9)	117 (23.3)	
3rd quartile	161 (32.0)	154 (30.6)	147 (29.2)	101 (20.1)	57 (11.3)	71 (14.1)	58 (11.5)	
4th quartile	140 (27.8)	148 (29.4)	154 (30.6)	149 (29.6)	48 (9.5)	33 (6.6)	29 (5.8)	
Missing	41 (8.2)	52 (10.3)	59 (11.7)	69 (13.7)	76 (15.1)	81 (16.1)	185 (36.8)	
Race/ethnicity								
Black	280 (55.7)							
White/Other	223 (44.3)							

[a]Days

[b]Drinks per occasion

Table 2 Rate ratios of the fixed effects of the association between each parenting factor and substance use and each peer factor and substance use

	Marijuana Frequency			Alcohol frequency			Alcohol quantity		
	RR	95% CI		RR	95% CI		RR	95% CI	
Parenting (ages 13–16)									
Crude[a]									
Negative parenting	1.01	0.99	1.03	0.99	0.97	1.02	1.02	1.00	1.04
Low supervision	**1.06**	**1.02**	**1.10**	**1.12**	**1.08**	**1.17**	**1.04**	**1.01**	**1.07**
Physical punishment	0.95	0.81	1.12	1.11	0.95	1.28	0.99	0.87	1.13
Parental stress	**1.05**	**1.03**	**1.08**	**1.04**	**1.02**	**1.06**	0.99	0.98	1.01
Adjusted[b]									
Low supervision	**1.07**	**1.03**	**1.11**	**1.08**	**1.04**	**1.13**	**1.04**	**1.01**	**1.07**
Parental stress	**1.04**	**1.02**	**1.06**	**1.03**	**1.01**	**1.05**	0.99	0.97	1.01
Peer (ages 13–19)									
Crude[a]									
Peer drug use	**1.25**	**1.22**	**1.28**	**1.27**	**1.24**	**1.3**	**1.17**	**1.15**	**1.18**
Peer delinquency	**1.05**	**1.04**	**1.06**	**1.06**	**1.05**	**1.07**	**1.04**	**1.03**	**1.05**
Adjusted[b]									
Peer drug use	**1.25**	**1.22**	**1.28**	**1.28**	**1.25**	**1.31**	**1.17**	**1.15**	**1.19**
Peer delinquency	**1.05**	**1.04**	**1.06**	**1.06**	**1.05**	**1.07**	**1.04**	**1.03**	**1.05**

Bold values are statistically significant

[a]Crude models regress each substance use outcome on each parenting and peer variable, respectively, in addition to age

[b]We adjusted crude models that showed significant main effects by lagged psychiatric symptoms and SES

on substance use. To aid in interpretation, we report rate ratios for a standard deviation increase in exposures. Regarding parenting factors, there was no significant relationship between changes in negative parenting or physical punishment and changes in substance use outcomes. Adolescents who experienced a standard deviation change in parental supervision (lower supervision) experienced a 1.06-fold (95% CI 1.02, 1.10) increase in their rate of marijuana frequency, a 1.12-fold (95% CI 1.08, 1.17) increase in their rate of alcohol frequency, and a 1.04-fold (95% CI 1.01, 1.07) increase in their rate of alcohol quantity. Adolescents whose parents experienced a standard deviation increase in stress exhibited a 1.05-fold (95% CI 1.03, 1.08) increase in their rate of marijuana frequency and a 1.04-fold (95% CI 1.02, 1.06) increase in their rate of alcohol frequency. Adjusting for prior-year depression, anxiety, conduct disorder, and SES did not appreciably reduce the effects of these parenting variables on substance use outcomes.

Regarding peer factors, Table 2 shows that when adolescents experienced a standard deviation increase in peer drug use, their predicted rates of marijuana frequency, alcohol frequency, and alcohol quantity increased by 1.25 (95% CI 1.22, 1.28), 1.27 (95% CI 1.24, 1.30), and 1.17 (95% CI 1.15, 1.18), respectively. Similarly, when adolescents experienced a standard deviation increase in peer delinquency, their predicted rates of marijuana frequency, alcohol frequency, and alcohol quantity increased by 1.05 (95% CI 1.04, 1.06), 1.06 (95% CI 1.05, 1.07), and 1.04 (95% CI 1.03, 1.05), respectively. Results did not change appreciably after adjusting for prior-year depression, anxiety, conduct disorder, and SES.

Table 3 presents results from two sets of models. The first set of models regress each substance use outcome on all four parenting variables simultaneously, plus prior-year psychiatric symptoms and SES. These models show that after adjusting for other parenting factors, prior-year psychiatric symptoms, and SES, only changes in parental supervision are consistently associated with changes in substance use outcomes. When adolescents experience a standard deviation change in parental supervision (lower supervision), their predicted rates of marijuana frequency, alcohol frequency, and alcohol quantity increased by 1.08 (95% CI 1.04, 1.13), 1.10 (95% CI 1.06, 1.15), and 1.04 (95% CI 1.01, 1.07), respectively.

The second set of models in Table 3 regress each substance use outcome on both peer variables simultaneously, plus prior-year psychiatric symptoms and SES. After adjusting for peer delinquency and other covariates, when adolescents experienced a standard deviation increase in peer drug use, their predicted rates of marijuana frequency, alcohol frequency, and alcohol quantity increased by 1.23 (95% CI 1.20, 1.26), 1.25 (95% CI 1.22, 1.28), and 1.16 (95% CI 1.14, 1.18), respectively. After controlling for peer drug use and other covariates, when adolescents experienced a standard deviation increase in peer delinquency, their predicted rate of alcohol frequency increased by 1.02 (95% CI 1.01, 1.03).

Table 3 Rate ratios of the fixed effects of the association between all parenting factors and substance use and all peer factors and substance use

	Marijuana frequency			Alcohol frequency			Alcohol quantity		
	RR	95% CI		RR	95% CI		RR	95% CI	
Parenting (ages 13–16)[a]									
Negative parenting	0.97	0.95	1.00	0.99	0.97	1.01	1.01	0.99	1.03
Low supervision	**1.08**	**1.04**	**1.13**	**1.10**	**1.06**	**1.15**	**1.04**	**1.01**	**1.07**
Physical punishment	0.90	0.77	1.07	1.02	0.89	1.17	0.92	0.81	1.05
Parental stress	**1.05**	**1.02**	**1.07**	**1.03**	**1.01**	**1.05**	0.99	0.97	1.00
Peer (ages 13–19)[b]									
Peer drug use	**1.23**	**1.20**	**1.26**	**1.25**	**1.22**	**1.28**	**1.16**	**1.14**	**1.18**
Peer delinquency	1.01	1.00	1.02	**1.02**	**1.01**	**1.03**	1.01	1.00	1.02

Bold values are statistically significant

[a]Each substance use outcome is regressed on all four parenting variables simultaneously, plus psychiatric symptoms and SES

[b]Each substance use outcome is regressed on both peer variables simultaneously, plus psychiatric symptoms and SES

In Table 4, we regressed each substance use outcome on the peer and parenting factors, simultaneously that were significant in Table 2. These factors were parental stress, low supervision, peer delinquency, and peer drug use. In the models adjusted for prior-year psychiatric symptoms and SES, when adolescents' parents experienced a standard deviation increase in stress, their rate of marijuana frequency increased by 1.05 (95% CI 1.02, 1.07). Parental stress and low supervision were no longer associated with alcohol frequency or alcohol quantity after adjusting for peer factors. When adolescents experienced a standard deviation increase in peer drug use, their predicted rates of marijuana frequency, alcohol frequency, and alcohol quantity increased by 1.30 (95% CI 1.25, 1.36), 1.30 (95% CI 1.25, 1.35), and 1.18 (95% CI 1.14, 1.21), respectively.

In a final set of models, we tested whether age modified the associations between changes in parenting and peer factors and changes in substance use. The results of these models are shown in Supplemental Table 1. We plotted predicted substance use counts over time for a hypothetical individual whose parenting and peer exposures changed at each time point, with all other variables held constant (Fig. 1). Substance use tends to increase over the course of adolescence, but the magnitude of the associations of parenting and peer factors with increases in substance use is not consistent over time. To explore this multiplicative effect modification, we conducted post-hoc interaction contrasts, available in Supplemental Table 2. These contrasts allowed us to better visualize, in Fig. 2, the modifying effect of age on the associations between parenting

Table 4 Rate ratios of the fixed effects of the association between all parenting and peer factors and substance use

	Marijuana frequency			Alcohol frequency			Alcohol quantity		
	RR	95% CI		RR	95% CI		RR	95% CI	
Crude[a]									
Parental stress	**1.04**	**1.03**	**1.07**	**1.03**	**1.01**	**1.05**	0.99	0.97	1.00
Low supervision	0.98	0.95	1.02	1.01	0.97	1.05	1.01	0.98	1.03
Peer delinquency	1.01	1.00	1.03	1.01	1.00	1.02	1.01	1.00	1.02
Peer drug use	**1.31**	**1.26**	**1.36**	**1.35**	**1.30**	**1.41**	**1.19**	**1.16**	**1.23**
Adjusted[b]									
Parental stress	**1.05**	**1.02**	**1.07**	1.01	0.99	1.03	0.98	0.97	1.00
Low supervision	0.97	0.94	1.01	0.98	0.95	1.02	1.00	0.98	1.03
Peer delinquency	1.01	1.00	1.02	1.00	0.99	1.02	1.00	0.99	1.01
Peer drug use	**1.30**	**1.25**	**1.36**	**1.30**	**1.25**	**1.35**	**1.18**	**1.14**	**1.21**

Bold values are statistically significant

[a]In the crude models, each substance use outcome is regressed on the peer and parenting factors, simultaneously, that were significant in Table 2. These factors were parental stress, low supervision, peer delinquency, and peer drug use

[b]In the adjusted models, we additionally adjust for psychiatric symptoms and SES

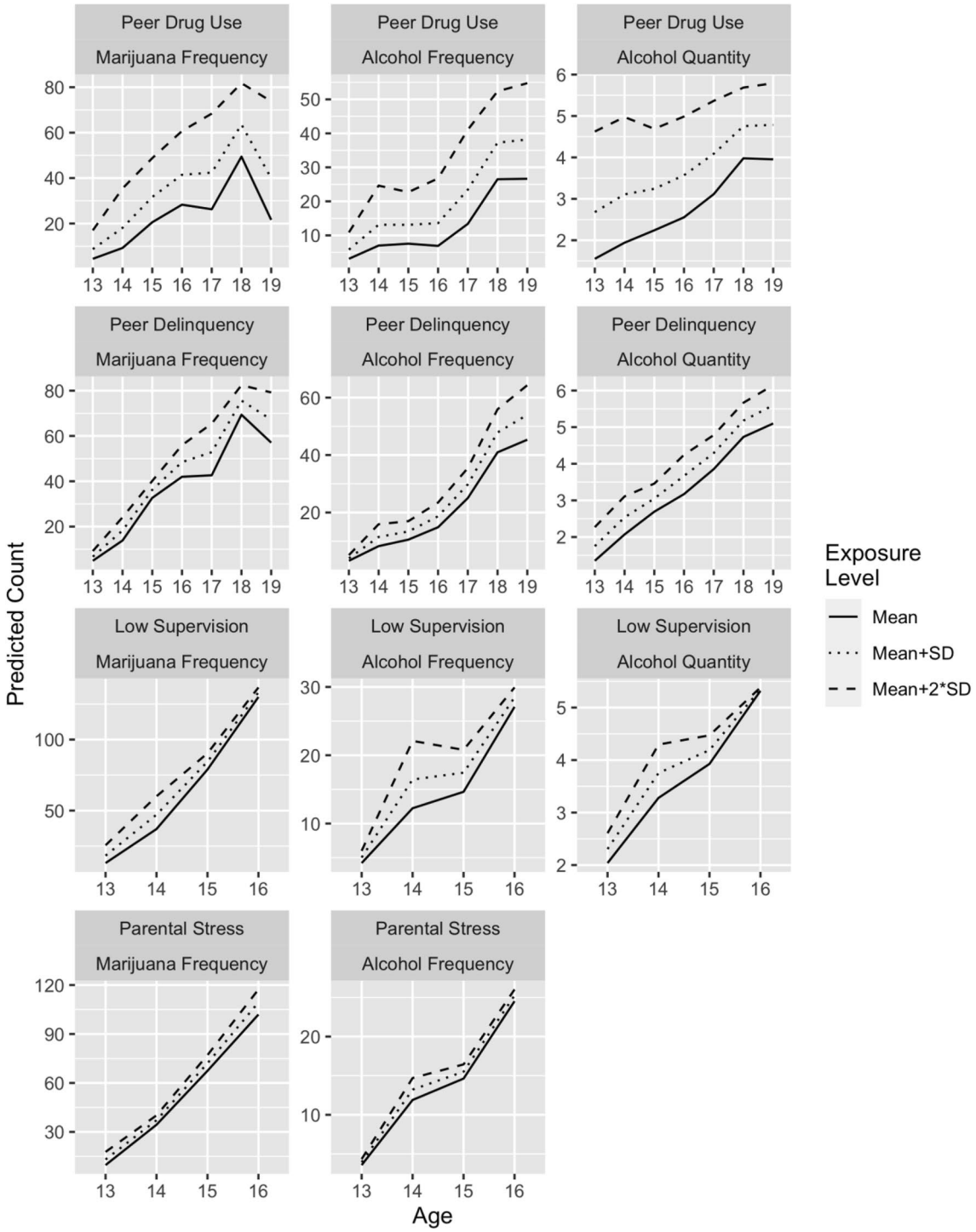

Fig. 1 Predicted change in substance use counts for a hypothetical adolescent whose parenting and peer exposures changed at the within-person mean level (solid line) at each time point, changed by the mean plus a standard deviation at each time point (dotted line), and changed at the mean plus two standard deviations each time point. Note: Only those parenting and peer exposures that predicted substance use are included

and peer factors and substance use. Based on Fig. 2 and Supplemental Table 2, the magnitude of the association between increases in low parental supervision and changes in substance use appears to decrease as adolescents get older. The magnitude of the association between parental stress and adolescent marijuana use seems most

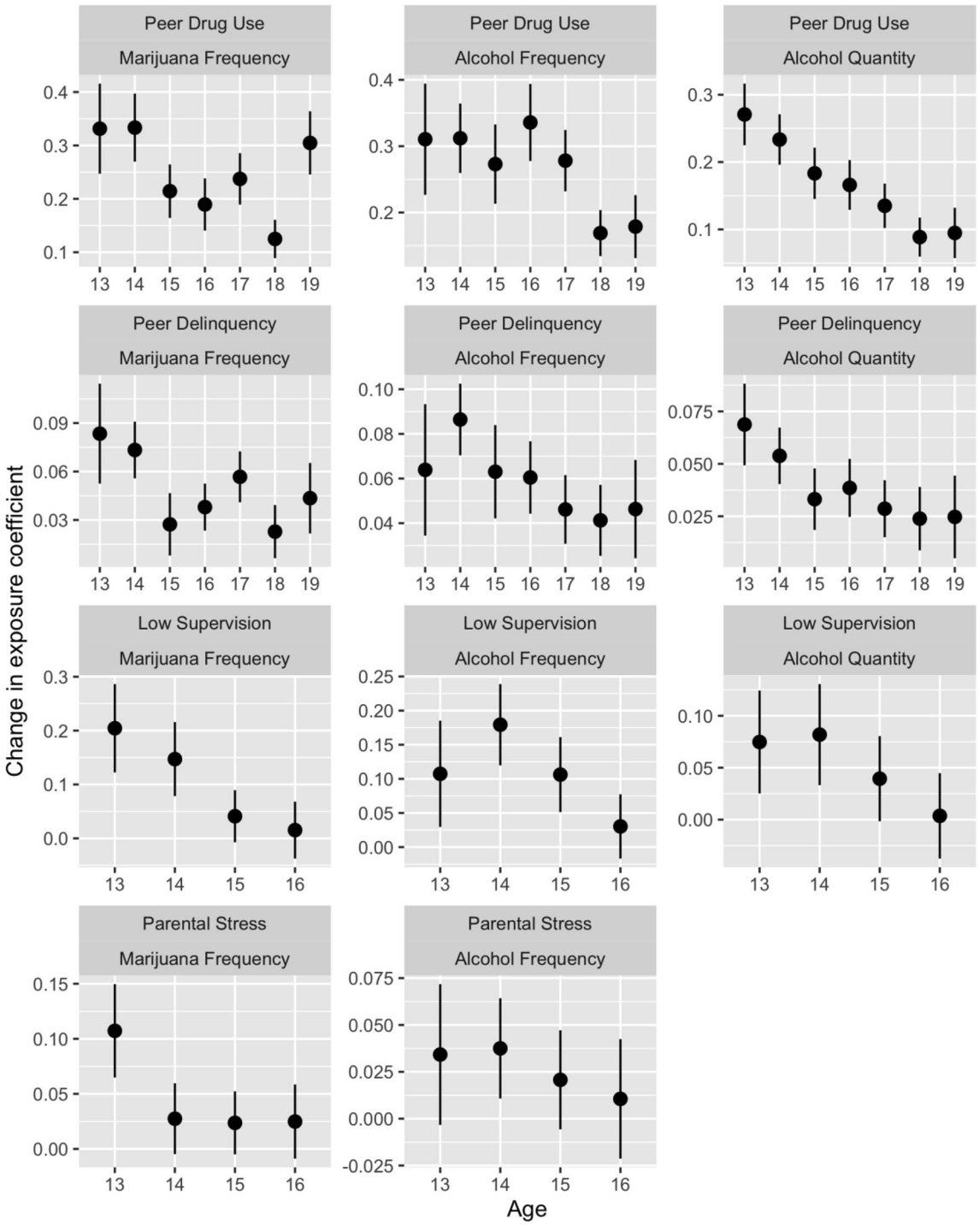

Fig. 2 Multiplicative modification of the effects of exposures on outcomes by age. Each point (with 95% confidence interval) is the value of the change in the exposure coefficient due to the modifying effect of age

pronounced at age 13. For peer delinquency, the pattern is less clear, but generally the magnitude of the association is most pronounced at ages 13–14 for marijuana frequency, at age 14 for alcohol frequency, and at ages 13–14 for alcohol quantity. For peer drug use, the magnitude of the association with marijuana frequency is most pronounced at ages 13–14 and 19. For alcohol frequency and quantity, the magnitude of the association with peer drug use decreases as adolescents get older, and is most pronounced around ages 13–14.

Discussion

We investigated whether adolescents exhibit increases in substance use when exposed to increased levels of parenting and peer risk factors and identified ages when these associations may be particularly important. Regarding parenting factors, we found that when adolescents experienced a reduction in parental supervision, they increased their frequency of marijuana and alcohol use, as well as their quantity of alcohol consumption. Increases in exposure to parental stress were associated with increases in adolescents' frequency of marijuana and alcohol use. Changes in negative parenting and physical punishment were not associated with increases in substance use. Regarding peer factors, we found that when adolescents increased their affiliation with peers who used drugs and engaged in delinquent behaviors, they increased their frequency of marijuana and alcohol use as well as alcohol quantity.

Although it is well-established that parenting practices and peer affiliations are risk factors for adolescent substance use, few studies have examined whether adolescents increase their substance use in response to increases in their parenting and peer exposures. The present study utilized a within-person change approach to rule out the possibility that these associations are due to confounding and selection bias from stable individual differences between adolescents with different levels of baseline parenting and peer factors. We also controlled for confounding from time-varying covariates, including changes in psychiatric problems and SES.

The magnitudes of the associations between changes in low parental supervision, parental stress, and peer delinquency, respectively, with changes in adolescent substance use were modest. This is consistent with extant research on changes in substance use over time [74, 75], and with the idea that adolescent substance use is shaped by an "ecology of development" [20] involving multiple, correlated risk factors. Thus, we would expect the contribution of any one risk factor to be smaller when measured in isolation vs. measuring the joint effects of multiple factors acting in concert. The magnitude of the associations between changes in peer drug use and changes in marijuana and alcohol outcomes were moderately strong, even after adjusting for potentially antecedent and mediating parenting and peer covariates (effect sizes between 18 and 30% for a standard deviation increase). This is consistent with prior research that peer drug use may be particularly important relative to parenting factors [1, 16].

Our finding that the influence of changes in parenting factors on substance use is more pronounced in early adolescence, and dissipates as adolescents get older, is consistent with findings from longitudinal studies of between-person differences [1, 12]. Our findings are also consistent with the developmental perspective that as adolescents transition to young adulthood, they gain independence and autonomy from their parents and have greater opportunity for unstructured and unsupervised activities with peers, including substance use. Our finding that changes in peer affiliations also had a stronger impact on substance use in early adolescence is less consistent with prior research. That research, based primarily on between-person approaches, finds that the impact of peers increases over the course of adolescence but begins to decline in early adulthood, as young adults develop resistance to peer influences [30]. In contrast, the results of our within-person approach suggest that *changes* in peer affiliations may be more important at ages 13–14, but that such changes may not have as great an impact in later teenage years. This may reflect the role of stress from life transitions that occurred during the study period, such as transitioning from middle school to high school, which can affect peer affiliations and influence substance use [76, 77]. Such transitions may also provide a new context for homophilic peer selection. It is also possible that findings from prior research using between-person approaches captured spurious stable effects of selection into peer affiliations in later adolescence.

Our findings should be considered in light of the following limitations. First, because the data were collected annually and a one-year lag between exposure and outcome was too large for meaningful inference, we included exposure and outcome measures from the same survey year. This introduces a potential lack of clarity in temporal ordering. However, we mitigated concerns of reverse causation through sensitivity analyses in which we included prior-year substance use as a covariate and found no notable differences. Second, all participants in the Pittsburgh Youth Study are male; hence, we could not examine parenting, peer factors, and substance use among girls. Third, half of the sample comprised high-risk boys; therefore findings may not be generalizable to population distributions of risk among adolescent boys given the disproportionate prevalence of risk factors for substance use in the sample. Fourth, other sources of social influence, such as adolescents' changes in romantic partners, were not available, and may confound or mediate the relationship between peers and substance use, or have direct effects on substance use. Parental substance use or illegal behavior might also confound these relationships, but these data were not available.

We found that when adolescent boys experience a reduction in parental supervision or an increase in peer drug use and peer delinquency, they also experience an increase in the frequency of marijuana and alcohol use and the quantity of alcohol consumption. Additionally, increases in parental

stress are associated with increases in marijuana and alcohol frequency. These associations are not due to unmeasured stable confounders or confounding by psychiatric symptoms or SES. Reducing or mitigating changes in these parenting and peer factors in early adolescence, potentially at key transitional periods such as matriculating from middle to high school, may be particularly important for preventing substance use problems as adolescents transition into young adulthood.

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Compliance with ethical standards

Conflict of interest None of the authors declare any conflicts of interest.

Ethics statement This secondary analysis was approved by the Columbia University Institutional Review Board. All analyses were performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

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