Identifying and Characterizing Adolescent Smoking Trajectories

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Abstract

Our understanding of longitudinal patterns of adolescent smoking development and the determinants of these patterns is limited. The present study evaluated adolescent smoking trajectories and characterized these trajectories with social, psychological, and behavioral factors in a cohort of adolescents assessed annually from grades 9 to 12. Complete data (smoking practices, novelty seeking, academic performance, substance use, peer smoking, physical activity and sports participation, and tobacco ad receptivity) were available on 968 participants; data were analyzed using latent class growth modeling. Four adolescent smoking trajectories emerged: never smokers, experimenters, earlier/faster smoking adopters, and later/slower smoking adopters. Early adopters were characterized by their high novelty seeking personality, depressive symptoms, poorer academic performance, and receptivity to tobacco advertising, as well as their exposure to other smokers, and use of other substances. Later adopters were characterized quite similarly to the early adopters, although they tended to perform better in school and to be more involved in sports. Experimenters also shared many of these same risk characteristics but to a lesser degree. Overall, never smokers were the most conventional in their profile. These data suggest that there is significant heterogeneity in the timing, rate, and intensity of smoking progression. Adolescent smoking prevention and intervention programs will need to consider this heterogeneity and tailor or enhance attention to risk and protective factors depending on the subpopulation. (Cancer Epidemiol Biomarkers Prev 2004;13(12):2023–34)

Introduction

As the majority of adult smokers report initiating smoking sometime during adolescence (1), adolescence represents an important developmental period in which to study smoking acquisition (2). Despite the public health significance of smoking among adolescents, our understanding of the longitudinal patterns of adolescent smoking behavior and the determinants of these patterns remains limited. Research has identified several stages of adolescent smoking, spanning nonsmoking to established smoking, as well as common and distinct predictors of these stages (3). However, inconsistencies in the definitions researchers apply to the stages have contributed to inconsistent findings regarding smoking determinants and outcomes. Whereas it is obvious that not all adolescents initiate smoking at the same time, with the same frequency, or with the same intensity, this heterogeneity has been largely ignored. Given this heterogeneity in adolescent smoking behavior, more sophisticated developmental models are necessary to understand the longitudinal pathways (i.e., trajectories) of smoking acquisition during adolescence.

Empirically identifying smoking trajectories based on multiple time points is one way to address the arbitrary and inconsistent nature of smoking stage definitions. This approach also allows researchers to extend beyond a description of the average smoking behavior of the sample and to analyze interindividual change in the smoking paths across time. In addition, characterizing trajectories with key variables defines the adolescents who comprise a particular developmental smoking path. Information on smoking trajectories and the characteristics of trajectory membership are critical to effectively target adolescents for smoking prevention and intervention programs. By utilizing this type of approach, it is possible to inform which adolescents should be targeted, what type of programs may be most helpful (e.g., primary or secondary prevention, intervention), factors that may need to be addressed within the program, and when adolescents should be targeted.

Two studies have investigated and characterized developmental smoking trajectories from adolescence to adulthood (4, 5). In a sequential cohort study, Chassin et al. (4) measured smoking behavior at three time points across 14 years and identified four smoking trajectory groups, including early stable smokers, late stable smokers, experimenters, and quitters (4). Groups whose smoking trajectories indicated an early onset and a persistence of smoking into adulthood had the most friends who smoked during adolescence and greater tolerance for deviance. Similarly, a recent study assessed smoking behavior at five time points across 18 years and identified three trajectory groups, which included

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heavy/regular use, occasional use/maturing out, and nonsmokers/experimental smokers (5). Higher levels of disinhibition, poorer school performance, and more frequent use of alcohol and other drugs, increased the likelihood of being in a smoking trajectory over a nonsmoking trajectory. None of the risk factors distinguished between occasional and regular smokers.

The findings of these two studies are important; however, transitions in smoking behavior were measured across long time intervals (3-5 years), which tends to oversimplify growth curves (6). Only two measurement points would have occurred during adolescence, which does not provide sufficient information about transitions in adolescent smoking behavior. In addition, in order to accurately account for how a time-varying determinant may influence smoking behavior across time, it is necessary to assess it across time. By doing so, changes in the determinant will be captured as will changes in the relationship between the determinant and smoking behavior (6-8).

Only two studies have specifically investigated adolescent smoking trajectories. Colder et al. (9) identified five longitudinal smoking patterns in adolescents assessed annually from ages 12 to 16 years old. These smoking trajectories included early rapid escalators, late moderate escalators, late slow escalators, stable light smokers, and stable puffers (9). However, these trajectories were not characterized.

A recent study examined the longitudinal patterns of smoking among adolescents assessed on an annual basis from grades 6 to 12 (10). The following six cluster groups were identified: nonsmokers, quitters, experimenters, early escalators, late escalators, and continuous smokers. Adolescents in smoking clusters, especially continuous smokers, tended to maintain or increase their already elevated baseline levels of risk factors (e.g., alcohol and marijuana use, poorer school performance, truancy, and low levels of church attendance) compared with nonsmokers. Adolescents whose smoking escalated later in high school tended to show declines in life satisfaction. A strength of this particular study is the longitudinal evaluation of predictor variables with respect to smoking patterns across time. However, the assumption that there is no classification error in the clusters precludes the use of certain statistics (e.g., *F* tests) to make intercluster comparisons (11). Finally, many of the constructs were assessed by single items or scales that have not been used in previous research.

These recent studies represent initial efforts to identify important variations in adolescent smoking patterns over time. The current study set out to replicate findings related to adolescent smoking trajectories. In addition, we sought to expand upon previous efforts by (a) including data from annual assessments, (b) including more refined predictors, (c) utilizing multivariate methodology that allowed for the identification and characterization of trajectories in a parsimonious fashion, and (d) longitudinal analysis of the effects of predictor variables. We did so by empirically identifying smoking trajectories in adolescents ages 14 to 18 years. We hypothesized that there would be several smoking trajectories, and that these trajectories would vary in features such as smoking frequency, intensity, and rate of progression. We also sought to characterize adolescent smoking trajectories in a longitudinal fashion based on social, psychological, and behavioral determinants shown to be associated with smoking in previous research (3, 12-14). Here, we hypothesized that these variables would discriminate between nonsmoking and smoking trajectories and between smoking trajectories. The results of this investigation may translate into a more comprehensive model of smoking progression and persistence in adolescence as well as in the optimization of adolescent smoking prevention and intervention efforts.

Materials and Methods

Participants. Participants were high school students participating in a longitudinal cohort study of the biobehavioral predictors of adolescent smoking adoption. Participants were enrolled in five public high schools in northern Virginia. About half (52%) of the sample was female, 63% Caucasian, 12% Hispanic, 11% Asian, 8% African American, and 6% other. The cohort was formed in the 9th grade and followed through the end of the 12th grade. Data collection took place in five waves: 9th grade, spring of 2000; 10th grade, fall of 2000 and spring of 2001; 11th grade, spring of 2002; 12th grade, spring 2003. The data analyzed in this study includes the four spring waves in order to retain equal time spacing between waves (1 year).

A total of 2,120 (89%) students were eligible to participate in this study. Of the 2,120 eligible students, 1,533 (72%) parents provided a response, and of these 1,151 (75%) parents consented to their teen's participation in the study, which yielded an overall consent rate of 54%. Analysis for differences between students whose parents consented and those whose parents did not consent to participation in the study revealed a race by education interaction. The interaction indicated that the likelihood of consent was over twice as high for Caucasian parents with greater than a high school education than for Caucasian parents with a high school education or less (15). Although these overall differences were small, some caution in generalization is suggested.

Participation in the study required student assent as well as parental consent. Fifteen students declined participation in the study. Thirteen students provided assent, although they failed to participate in either the baseline administration or the make-up due to absence. The final baseline sample size was 1,123 of the 2,120 eligible students. The University Institutional Review Board approval of the study protocol was obtained.

Procedures. Data were collected on-site inside a classroom common to all students (e.g., health, and science). A member of the research team distributed the self-report survey. The completed survey contained only an identification number. A member of the research team read aloud a set of instructions, emphasizing confidentiality to promote honest responding, and encouraged questions if survey items were not clear. Surveys took ~30 minutes to complete. Make-up sessions were held in the library for students absent during survey administration.

As this is a longitudinal study, students were resurveyed in the fall and spring of the 10th, and in the springs of 11th and 12th grades, for a total of five data collection waves. The rates of participation at the three spring follow-ups in the 10th, 11th, and 12th grades were ~96% (1,081), 93% (1,043), and 89% (1,005), respectively. The primary variables of interest were 9th to 12th grade smoking behaviors (dependent variable), the time invariant covariates of gender, race, and novelty seeking, and the time varying covariates of depressive symptoms, tobacco advertising receptivity, peer smoking, grade point average, alcohol and marijuana use, team sport participation, and physical activity. The data presented in the following analyses are based on 968 participants with complete data for the independent and dependent variables at each time point.

Measures

Dependent Variable

Smoking Behavior. Adolescent smoking behavior was summarized in an ordered-categorical variable with five categories representing increasing levels of smoking. The variable was generated from responses to a series of standard epidemiologic questions regarding smoking such as, ''Have you ever tried or experimented with cigarette smoking, even a few puffs?'' and ''Have you smoked a cigarette in the past 30 days?'' (16). The five ordered categories are 0, Never smoker; 1, Puffer (not ever having smoked a whole cigarette); 2, experimenter (having smoked a whole cigarette but ≤100 cigarettes total in a lifetime); 3, current smoker (smoked <20 days in the last 30 days and >100 cigarettes in a lifetime); 4, frequent smoker (≥20 days smoked in the last 30 days and >100 cigarettes in a lifetime). Adolescents who smoked >100 cigarettes in a lifetime but who have not smoked in the last 30 days were classified as experimenters (n = 4). Research supports the reliability of Youth Risk Behavior Survey (YRBS) items assessing smoking practices with coefficients in the substantial or higher range (≥61%; refs. 17, 18). Research also supports the validity of self-report measures of smoking behavior in adolescents, particularly in nontreatment contexts where confidentiality is emphasized (19, 20).

Time-Invariant Covariates. The following time invariant covariates were used to characterize trajectories of smoking. Time-invariant covariates were assessed at baseline only, as they are not subject to change.

Demographics. Race (0 = Caucasian and 1 = non-Caucasian) and gender (1 = male, 2 = female) were measured.

Novelty-Seeking Personality. A 20-item version of the Temperament and Character Inventory was used to measure novelty seeking (21). The True/False novelty-seeking scale included items such as ''I often try new things just for fun or thrills...'' and ''I like to think about things for a long time before I make a decision.'' In the present study, the Kuder-Richardson coefficient of reliability was satisfactory (0.74).

Time-Varying Covariates. The following time-varying covariates were used to characterize smoking trajectories. Time-varying covariates are variables that are modeled across time because they are subject to change (22).

Academic Performance. Academic performance each wave was assessed with a four-point self-reported grade point average (GPA).

Alcohol Use. An item from the YRBS was used to measure lifetime alcohol use at each wave (16). The item asked, ''During your life, on how many days have you had at least *one drink* (not just a sip) of alcohol?'' Participants responded on a seven-point scale, with response choices ranging from 0 to ≥100 days. The item was dichotomized in the present analysis (0 = zero days, 1 = else) to facilitate interpretation.

Marijuana Use. An item from the YRBS was used to measure lifetime marijuana use (16). Participants responded on a seven-point scale, with response choices ranging from 0 to ≥100 times having used marijuana. The item was dichotomized for the present analysis to facilitate interpretation (0 = zero times, 1 = else).

Peer Smoking. Peer smoking was assessed with a dichotomous item (0 = does not have peers who smoke, 1 = has peers who smoke,) generated from responses to items asking whether adolescents have any friends who currently smoke: ''Does your best friend smoke?'' ''Do any of your best *male* friends currently smoke?'' and ''Do any of your best *female* friends currently smoke?'' (23, 24).

Physical Activity. Physical activity was assessed with three items from the YRBS. The items assessed intensity, duration, and frequency of physical activity, asking how many of the past 7 days the individual participated in (a) 20 minutes of physical activity ''...that made you sweat or breathe hard, such as basketball, soccer...; (b) ...physical activity for at least 30 minutes that did not make you sweat and breath hard, such as fast walking, slow bicycling...; (c) ...exercise to strengthen or tone your muscles, such as push-ups, sit-ups or weight lifting?'' These three items were summed to create a physical activity score. Research has shown that physical activity is inversely related to smoking progression (25).

Team Sport Participation. Team sport participation was assessed with a single four-point scale YRBS item that requested the number of teams played during the past 12 months, including those run by the ''...school or community group'' (''0 teams'' = 1, ''1 team'' = 2, ''2 teams'' = 3, ''3 or more teams'' = 4). Team sport participation has been shown to be related to smoking in adolescents (26).

Tobacco Advertising Receptivity. A five-item scale was used to assess the purchase, receipt, and use of tobacco promotional items (e.g., t-shirts that advertise a tobacco brand or promotional items distributed by a tobacco company), as well as the recall of brands advertised most often, brands of ads that attracted the most attention, and brands of favorite ads (27). Receptivity was evaluated based on affirmative responses to a sequence of items reflecting progressive levels of receptivity. A dichotomous item was generated (1 = high receptivity, 0 = low receptivity; ref. 28). Adolescents able to name no more than a frequently advertised brand but who did not have a favorite brand or had never received or used promotional items were classified as having low receptivity. Those who had a favorite brand or were willing to use promotional items were labeled as having high receptivity. Research has shown that tobacco advertising receptivity is related to smoking status (14).

Statistical Analysis. Data analysis was conducted with latent class growth modeling (LCGM). LCGM is a factor mixture modeling technique that models repeated measures of categorical indicator variables (22, 29). Similar to other longitudinal mixture modeling techniques (e.g., growth mixture modeling), LCGM aims to identify homogenous classes represented by developmental trajectories corresponding to repeated measures on a single construct (29, 30). LCGM allows class-specific growth trajectories that can vary in shape and sign (30-32) and evaluates developmental heterogeneity between rather than within classes.

There are several steps in LCGM. These steps are outlined as they were applied in the current study. First, the single-class smoking progression model, representing individualized growth, was fit to the data with the appropriate growth curve. To maximize fit, we allowed the trend coefficients for waves three and four to be freely estimated, instead of fitting a linear, quadratic, or two piece models (see ref. 25 for an explanation of LGM with ordered categorical variables). Next, analysis of the number of latent growth classes (trajectories) was assessed. Determination of the optimal number of trajectories was accomplished by assessing selected fit indices, along with substantive theory. Although there is no ''gold standard'' fit index for selection of the optimal number of trajectories, the Bayesian information criterion (BIC) is suggested (30, 33). Low BIC values reflect model parsimony, favoring a high log likelihood estimate along with a low number of parameters. According to this criterion, trajectories are added so long as the BIC continues to decrease.

A second indicator of the optimal number of trajectories is correct participant classification into their most likely trajectories. Trajectory membership is accompanied by posterior probabilities, which refers to the probability a participant belongs to each possible trajectory (30, 31, 34). When a given number of trajectories are estimated, individuals are classified into the trajectory for which their posterior probability is highest. A $K \times K$ classification table is generated for the K estimated trajectories, based on the posterior probabilities. Classification is considered acceptable for diagonal values close to 1 (all or almost all individuals belonging to trajectory K have been classified in trajectory K) and off-diagonal values are closer to 0 (little or no incorrect classification). An *entropy* summary statistic is available to assess classification quality, with *entropy* values ranging from 0 to 1, and values closer to 1 representing good classification quality (22, 35, 36).

A third indicator of optimization is the Lo-Mendell-Rubin likelihood ratio test that tests for significance in the $-2 \times$ *log likelihood* difference between the model with K and $K - 1$ (H0) classes (22, 37). The suggestion is to stop modeling when the difference is no longer significant, selecting the model with $K - 1$ classes. A final consideration is the utility of each class. Utility is assessed by the number of individuals in each trajectory, the similarity between trajectories, and the number of estimated parameters (35). All four indicators were employed in the smoking trajectories optimization process. Model estimation was conducted with Mplus software, version 3.01 (38).

After the number of trajectories was decided upon, the next step involved characterizing trajectories of smoking by social, psychological, and behavioral determinants (covariates) measured at baseline. Characterization in mixture modeling is a multinomial logistic regression approach that involves comparing the odds of belonging to a specific trajectory versus a criterion trajectory for a unit increase in a covariate, holding the remaining covariates constant (30, 33). In essence, the latent class variable is regressed on a set of empirically selected covariates for purpose of characterization. To facilitate this process, the criterion class (trajectory) is changeable to refine characterization. The final outcome is a profile of typical trajectory membership.

We recentered the overall model (the smoking measurement LGM) to assess the effects of covariates on smoking at the final wave (12th grade). In structural equation modeling, centering refers to fixing the level to a specific wave. Generally, level is centered at the first wave (baseline) by fixing its factor loading from the latent trajectory variable to zero. Briefly, in LGM, development is modeled on two or more latent variables (factors) representing baseline status (level) and rate of change (trend), depending on the trajectory shape. Centering level to the first wave allows researchers to assess the effects of baseline covariates on development. With a four-wave latent growth model, this would result in the following trend factor loadings 0, 1, 2, and 3, indicating a linear growth trend. Often, it is of interest to researchers to recenter level to future waves and explore the effects of covariates at different time points. Recentering allows this possibility without requiring additional cross-sectional analyses that could inflate error rate (39). To recenter, therefore, the factor loading from trend to the new baseline indicator would be fixed at zero. However, to maintain the correct growth form (e.g., linear), and not alter model fit, the remaining factor loadings must be adjusted accordingly (39). Recentering the level to the fourth wave for instance, whereas maintaining a linear growth form, the new factor loadings would be -3, -2, -1, and 0. After recentering, level can be regressed on the time invariant and appropriate time varying covariates.

It is important to note that the pattern of factor loadings from the level factor to the repeated measures of smoking remains the same regardless of centering (i.e., 1). This ensures that the effect of baseline level does not change with time and allows for interpretation of the effects of covariates on level regardless of where baseline is centered. Therefore, in the present analysis recentering baseline at 12th grade allowed us to assess the impact of the covariates on smoking level at 12th grade to determine stability in the effects of covariates across time (see ref. 39 for a thorough discussion of centering with LGM).

Results

Descriptive Statistics. The frequency distributions for smoking level in grades 9 to 12 are presented in Table 1. All differences between waves are significant ($P < 0.001$). The LGM for smoking fit the data well, χ^2 [(8, 968) = 15.21, $P < 0.05$], CFI = 1.00, RMSEA = 0.03. Trend was nonlinear, with factor loadings 0, 1, 1.859, and 2.461, representing the best relationship between the trend factor and observed variables in grades 9 to 12,

Table 1. Frequency distributions for smoking, grades 9 to 12

Status	Grade			
	9th grade	10th grade	11th grade	12th grade
	Frequency (%)	Frequency (%)	Frequency (%)	Frequency (%)
Never	678 (60.75)	582 (54.44)	528 (50.57)	458 (45.66)
Puffer	152 (13.62)	144 (13.47)	139 (13.31)	130 (12.96)
Experimenter	232 (20.79)	257 (24.04)	266 (25.48)	276 (27.52)
Current	25 (2.24)	30 (2.81)	41 (3.93)	48 (4.79)
Frequent	29 (2.60)	56 (5.24)	70 (6.70)	91 (9.07)

respectively. Mean trend (η_1) was significantly different from zero ($\eta_1 = 0.17$, $z = 11.44$, $P < 0.0001$). Variances in smoking trend and level were both significantly different from zero ($P < 0.0001$), indicating that there was individual difference in both baseline smoking status and the odds of progression over time.

Missing Data. The current analysis is based on the 968 participants with complete data on the four repeated measures of smoking. Complete case modeling (listwise deletion) is based on the assumption that the complete cases are a random sample of the entire sample. Essentially, data are missing completely at random (ref. 40). We tested the assumption of missing completely at random with a likelihood ratio χ^2 test under the unrestricted latent class indicator model, a feature in Mplus software, version 3.01. The results provided support for the missing data being completely at random, $\chi^2(628, n = 1{,}135) = 202.50$, $P = 1.00$, which indicated that the data can be considered a random sample of the entire sample. In addition, the results using complete cases did not differ from analyses where all available data were used.

Smoking Trajectories. A total of six models were tested, beginning with a two-trajectory model, to determine the optimal number of trajectories of smoking across the four waves; one trajectory was added in each subsequent trial. The statistics for determining the optimal number of trajectories are presented in Table 2. BIC values dropped from [sample size adjusted BIC (SSABIC) = 9,304.52] in the single-trajectory model to (SSABIC = 6,370.29) in the five-trajectory model. Excluding the single-trajectory model in which all subjects are assigned to the same trajectory, *entropy* value was highest for the two-trajectory model (Entropy = 0.93) and settled at 0.88 for the five-trajectory model. These data would favor the five-trajectory model. However, the Lo-Mendell-Rubin likelihood ratio test was not significant for the five- versus four-trajectory model, indicating the best representation of the overall population represented by this sample is the mixture model with four trajectories (SSABIC = 6,427.41, *entropy* = 0.89).

Inclusion of the covariates in the four-trajectory model resulted in an additional improvement in overall fit (SSABIC = 5,567.84, *entropy* = 0.91). Inspection of the $K \times K$ classification matrix for the four-trajectory model with covariates revealed acceptable classification quality consistent with the *entropy* value (median diagonal probability = 0.93). The proportion of adolescents in each smoking status from 9th to 12th grade by trajectory is presented in Table 3. Means, SDs, and zero-order correlations for the covariates are presented in Table 4.

Characteristics of the Four Trajectories

The Four Trajectories of Smoking Progression. The four trajectories are labeled based on baseline levels and the change in smoking level over time: Trajectory 1, *early/fast adopters* ($n = 76$, 8%); Trajectory 2, *late/slow adopters* ($n = 236$, 24%); Trajectory 3, *experimenters* ($n = 222$, 23%); Trajectory 4, *never smokers* ($n = 434$, 45%). Figure 1 depicts the average smoking level at each time point for each trajectory, along with 95% confidence interval (95% CI). This model is provided for illustrative purposes, as it involves the interpretation of our ordered categorical smoking data as continuous.

Figure 2 depicts the odds of adolescent smoking progression from 9th to 12th grade by trajectory. Briefly, LCGM with ordered-categorical outcome variables employs a proportional odds logit model for estimating the slopes of each trajectory (22). Exponentiation of the

Table 2. Optimal number of trajectories: assessment statistics

Trajectories	Log likelihood	BIC	SSABIC	Free parameters	Entropy	LRT
1	−4,643.01	9,320.40	9,304.52	5	NA	NA
2	−3,549.32	7,153.65	7,128.24	8	0.93	$P < 0.0001$
3	−3,332.38	6,740.38	6,705.44	11	0.88	$P < 0.0001$
4	−3,187.81	6,471.88	6,427.41	14	0.89	$P < 0.0001$
5	−3,153.70	6,424.28	6,370.29	17	0.88	$P = 0.0689$
Model with covariates	−2,698.46	5,717.11	5,567.84	47	0.91	$P < 0.0001$

NOTE: BIC ($-2\log L + r \ln n$), where r is the number of free model parameters; SSABIC (n in BIC formula is replaced by $n^* = (n + 2)/24$); Vuong-Lo-Mendell-Rubin likelihood ratio test for k (H0) versus $k - 1$ classes.

Table 3. Proportion of participants in each smoking status by trajectory, grades 9 to 12

Level	Adolescent smoking trajectory (n = 968)			
	Never (n = 434)	Experiment (n = 222)	Late (n = 236)	Early (n = 76)
9th grade				
Never	1	0.630	0.113	0.003
Puffer	0	0.287	0.339	0.014
Experimenter	0	0.082	0.535	0.576
Current	0	0.001	0.009	0.220
Frequent	0	0	0.005	0.188
10th grade				
Never	1	0.453	0.034	0.001
Puffer	0	0.390	0.153	0.004
Experimenter	0	0.155	0.766	0.293
Current	0	0.001	0.031	0.261
Frequent	0	0.001	0.016	0.441
11th grade				
Never	0.994	0.308	0.012	0
Puffer	0.005	0.435	0.060	0.001
Experimenter	0.001	0.254	0.800	0.127
Current	0	0.003	0.081	0.177
Frequent	0	0.000	0.047	0.695
12th grade				
Never	0.933	0.124	0.006	0
Puffer	0.056	0.528	0.029	0.001
Experimenter	0.011	0.343	0.726	0.065
Current	0	0.004	0.144	0.108
Frequent	0	0.001	0.095	0.826

log odds results in the odds of progression for each unit change. The figure indicates that the adolescents in the experimenter trajectory were over five times more likely to progress from 9th to 12th grade [odds ratio (OR), 5.60; 95% CI, 3.54-8.82] versus remaining at baseline smoking status. Adolescents in the earlier/faster trajectory were over 15 times more likely to progress from 9th grade to the 12th grade (OR, 15.23; 95% CI, 6.36-36.38) versus remaining at baseline smoking status. Adolescents in the later/slower trajectory were over 17 times more likely to progress from 9th grade to 12th grade (OR, 17.48; 95% CI, 9.22-33.22) versus remaining at baseline smoking status. We assessed the difference in these slopes (log odds) with a likelihood ratio χ^2 difference test, comparing a less restricted model allowing different slopes to a more restricted model in which the four slopes were constrained to equality. The difference was significant, $G = -2[(-3{,}659.382) - (-3{,}654.327)] = 10.11$, $P\,[\chi^2(3) > 10.11] = 0.017$, indicating that the slopes were indeed significantly different. Model estimation was conducted with Mplus software, version 3.01 (38).

Table 4. Correlation matrix for baseline covariates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) Gender	1.0										
(2) Race	0.01	1.0									
(3) Novelty	−0.05	−0.06*	1.0								
(4) DS	0.14†	0.06*	0.15†	1.0							
(5) Peers	0.04	0.13†	0.19†	0.15†	1.0						
(6) Alcohol	−0.03	−0.04	0.29†	0.13†	0.27†	1.0					
(7) MJ	−0.12†	0.02	0.18†	0.06	0.24†	0.51†	1.0				
(8) PA	−0.15†	−0.14‡	0.04	−0.11‡	0.06	0.16†	0.09‡	1.0			
(9) Teams	−0.13†	−0.28†	0.11‡	−0.11‡	−0.04	0.08‡	−0.00	0.34†	1.0		
(10) Grades	0.16†	0.19†	−0.27†	−0.10‡	−0.21†	−0.17†	−0.23†	0.08‡	0.17†	1.0	
(11) TAR	−0.10‡	−0.01	0.22†	0.13†	0.17†	0.26†	0.22†	0.08‡	0.07‡	−0.13†	1.0
Mean	1.52	0.37	10.78	13.80	0.54	2.15	1.44	10.51	1.59	3.01	0.46
SD	0.50	0.48	3.86	9.08	0.50	1.55	1.14	5.06	1.18	0.78	0.50

NOTE: Gender: 0 = male, 1 = female; Race: 0 = Caucasian, 1 = non-Caucasian; Novelty, novelty seeking; DS, depressive symptoms (score range, 0-60); Peers: 1 = peers smoking, 0 = else; Alcohol: 1 = had at least one drink, 0 = else; MJ: 1 = smoked marijuana at least once, 0 = else; PA, hours of physical activity per week; Teams, number of teams in the past 12 months; Grades: self-reported grade point average on a four-point scale (4 = A, 3 = B, 2 = C, 1 = Mostly Ds and Fs); TAR: 1 = receptive to tobacco advertising, 0 = else.

*$P < 0.05$.

†$P < 0.0001$.

‡$P < 0.01$.

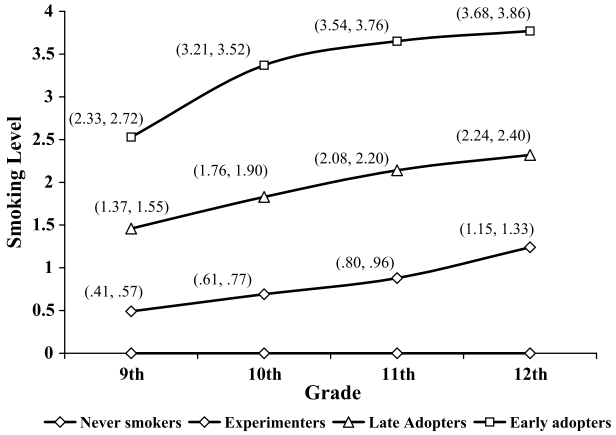

Figure 1. An illustration of the adolescent smoking trajectories from 9th to 12th grade.

To estimate the impact of the covariates on trajectory membership relative to a comparison trajectory and to facilitate trajectory characterization, we regressed the latent trajectory variable on the baseline covariates, varying the comparison trajectory. This is a multinomial logistic regression model with the comparison trajectory coefficients set to zero (30, 33, 41). The significant findings are reviewed below for each comparison. To assess the stability of covariate effects across time, we evaluated time varying covariates on the smoking trajectories from 9th grade (baseline) to 12th grade (last follow-up). The pattern of significant covariate effects over time is presented in Table 5.

Ninth Grade

Early Adopters versus Never Smokers. Adolescents higher in novelty seeking (OR, 1.12; 95% CI, 1.02-1.24), depressive symptoms (OR, 2.69; 95% CI, 1.16-6.23), and with high tobacco advertising receptivity (OR, 2.97; 95% CI, 1.34-6.58) were more likely to be early/fast adopters than never smokers. Adolescents who drank at least one alcoholic beverage (OR, 2.84; 95% CI, 1.17-6.90), used marijuana at least once by 9th grade (OR, 155.87; 95% CI, 30.75-789.18), and who had peers who smoked (OR, 7.95; 95% CI, 2.91-21.71), were also more likely to be early/fast adopters. By contrast, adolescents with higher GPAs (OR, 0.22; 95% CI, 0.13-0.37) were less likely to be early/fast adopters than never smokers.

Early Adopters versus Experimenters. Adolescents higher in depressive symptoms (OR, 3.28; 95% CI, 1.36-7.88), who used marijuana by 9th grade (OR, 17.41; 95% CI, 7.12-42.56), and had peers who smoke (OR, 4.94; 95% CI, 1.80-13.53), were more likely to be early/fast adopters than experimenters. By contrast, adolescents with higher GPAs (OR, 0.46; 95% CI, 0.28-0.76) were less likely to be early/fast adopters than experimenters.

Early versus Late Adopters. Adolescents using marijuana at least once by 9th grade (OR, 6.24; 95% CI, 2.81-13.89) were more likely to be early/fast than late/slow adopters. However, adolescents with higher GPAs (OR, 0.53; 95% CI, 0.33-0.86) and team sport participation (OR, 0.63; 95% CI, 0.45-0.87) were less likely to be early/fast than late/slow adopters.

Late Adopters versus Never Smokers. Adolescents higher in novelty seeking (OR, 1.11; 95% CI, 1.04-1.17) and high in tobacco advertising receptivity (OR, 1.93; 95% CI, 1.24-3.01) were more likely to be late/slow adopters than never smokers. Adolescents who consumed at least one alcoholic beverage (OR, 5.48; 95% CI, 3.46-8.68) and used marijuana at least once by 9th grade (OR, 24.95; 95% CI, 5.63-110.50) were also more likely to be late/slow adopters. Furthermore, adolescents higher in team sport participation (OR, 1.31; 95% CI, 1.06-1.62), and with peers who smoke (OR, 3.51; 95% CI, 2.21-5.58) were more likely to be late/slow adopters. By contrast, adolescents with higher GPAs (OR, 0.42; 95% CI, 0.31-0.58) were less likely to be late/slow adopters than never smokers.

Late Adopters versus Experimenters. Adolescents who drank at least one alcoholic beverage (OR, 3.89; 95% CI, 2.27-6.69) and used marijuana at least once by 9th grade (OR, 2.79; 95% CI, 1.29-6.01) were more likely to be late/slow adopters than experimenters. Furthermore, adolescents higher in team sport participation (OR, 1.38; 95% CI, 1.09-1.76), and with smoking peers (OR, 2.18; 95% CI, 1.30-3.67) were more likely to be late/slow adopters. By contrast, non-Caucasian adolescents (OR, 0.56; 95% CI, 0.32-0.98) were less likely to be late/slow adopters than experimenters.

Experimenters versus Never Smokers. Non-Caucasians (OR, 1.73; 95% CI, 1.13-2.66) were more likely to be experimenters than never smokers. Adolescents who used marijuana at least once by 9th grade (OR, 8.95; 95% CI, 1.87-42.82) were also more likely to be experimenters. Furthermore, adolescents with higher levels of physical activity (OR, 1.05; 95% CI, 1.01-1.10), and with smoking peers (OR, 1.61; 95% CI, 1.06-2.43) were more likely to be experimenters than never smokers. By contrast, adolescents with higher GPAs (OR, 0.49; 95% CI, 0.37-0.65) were less likely to be experimenters than never smokers.

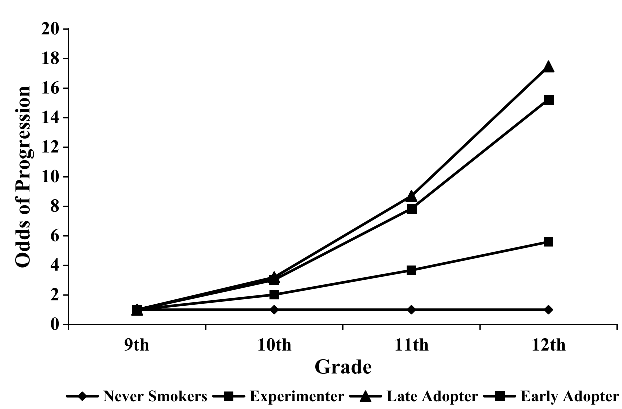

Figure 2. The odds of adolescent smoking progression from 9th to 12th grade by trajectory.

Table 5. Characteristics of smoking trajectories over time

Comparison	Grade	
	9th grade	12th grade
Early adopters versus never smokers	Novelty seeking Depressive symptoms Peer smoking Alcohol use Marijuana use GPA Tobacco ad receptivity	Novelty seeking Peer smoking Alcohol use Marijuana use GPA Team sport Tobacco ad receptivity
Early adopters versus experimenters	Depressive symptoms Peer smoking Marijuana use GPA	Novelty seeking Marijuana use GPA Team sport Tobacco ad receptivity
Early adopters versus late adopters	Marijuana use GPA Team sport	GPA Team sport
Late adopters versus never smokers	Novelty seeking Peer smoking Alcohol use Marijuana use GPA Team sport Tobacco ad receptivity	Novelty seeking Peer smoking Alcohol use Marijuana use GPA Tobacco ad receptivity
Late adopters versus experimenters	Race Peer smoking Alcohol use Marijuana use Team sport	Novelty seeking Alcohol use Marijuana use
Experimenters versus never smokers	Race Peer smoking Marijuana use GPA Physical Activity	Race Peer smoking Alcohol use Marijuana use GPA

Twelfth Grade

Early Adopters versus Never Smokers. Adolescents higher in tobacco advertising receptivity (OR, 3.83; 95% CI, 1.55-9.48) and novelty seeking (OR, 1.22; 95% CI, 1.09-1.36) were more likely to be early/fast adopters than never smokers. Adolescents using marijuana at least once by 12th grade (OR, 227.01; 95% CI, 29.34-1,756.36) and who had peers who smoked (OR, 5.40; 95% CI, 1.75-16.66) were also more likely to be early/fast adopters. By contrast, adolescents with higher GPAs (OR, 0.14; 95% CI, 0.07-0.29) and greater team sport participation (OR, 0.54; 95% CI, 0.37-0.81) were less likely to be early/fast adopters than never smokers.

Early Adopters versus Experimenters. Adolescents higher in tobacco advertising receptivity (OR, 2.85; 95% CI, 1.18-6.92) and novelty seeking (OR, 1.22; 95% CI, 1.05-1.30) were more likely to be early/fast adopters than experimenters. Adolescents who used marijuana at least once by 12th grade (OR, 68.99; 95% CI, 9.31-511.32) were also more likely to be early/fast adopters. However, adolescents with higher GPAs (OR, 0.36; 95% CI, 0.18-0.72) and greater levels of team sport participation (OR, 0.50; 95% CI, 0.34-0.74) were less likely to be early/fast adopters than experimenters.

Early versus Late Adopters. Adolescents with higher GPAs (OR, 0.44; 95% CI, 0.25-0.77) and team sport participation (OR, 0.62; 95% CI, 0.43-0.88) were less likely to be early/fast than late/slow adopters.

Late Adopters versus Never Smokers. Adolescents with high tobacco advertising receptivity (OR, 2.08; 95% CI, 1.22-3.53) and novelty-seeking (OR, 1.14; 95% CI, 1.07-1.22) were more likely to be late/slow adopters than never smokers. Adolescents who drank at least one alcoholic beverage (OR, 5.42; 95% CI, 2.34-12.53) and used marijuana at least once by 12th grade (OR, 37.41; 95% CI, 19.77-70.88), and had peers who smoked (OR, 2.27; 95% CI, 1.30-3.94) were also more likely to be late/slow adopters. In contrast, adolescents with higher GPAs (OR, 0.33; 95% CI, 0.19-0.55) were less likely to be late adopters than never smokers.

Late Adopters versus Experimenters. Adolescents higher in novelty-seeking (OR, 1.09; 95% CI, 1.03-1.17) were more likely to be late/slow adopters than experimenters.

In addition, adolescents who drank at least one alcoholic beverage (OR, 3.10; 95% CI, 1.27-7.60) and used marijuana by 12th grade (OR, 11.37; 95% CI, 5.94-21.78) were more likely to be late/slow adopters than experimenters.

Experimentation versus Never Smoker. Non-Caucasians were over twice (OR, 2.12; 95% CI, 1.36-3.29) more likely to be experimenters than never smokers. Adolescents who drank at least one alcoholic beverage (OR, 1.74; 95% CI, 1.09-2.78) and used marijuana at least once by 12th grade (OR, 3.29; 95% CI, 1.91-5.66) were more likely to be experimenters than never smokers. Adolescents with peers who smoked (OR, 2.22; 95% CI, 1.44-3.43) were more likely to be experimenters, whereas adolescents with higher GPAs (OR, 0.40; 95% CI, 0.26-0.62) were less likely to be experimenters than never smokers.

Discussion

The present study sought to empirically identify adolescent smoking trajectories and to define these trajectories by social, psychological, and behavioral variables. We found evidence of four subpopulations of adolescents with respect to their smoking behavior, which included never smokers, experimenters, earlier/faster smoking adopters, and later/slower smoking adopters. Whereas most previous research has defined smoking stages inconsistently and subjectively based on one or two time points, the present study empirically identified subgroups of adolescent smoking based on smoking behavior measured at four time points over a 4-year period. As anticipated, these trajectories differed on several features such as the magnitude of smoking progression, and the rate at which, or the point in time when, a regular smoking habit was adopted. The identified trajectories are similar to those adolescent smoking trajectories found in a recent study (10). Thus, it seems that there are distinct longitudinal patterns of adolescent smoking reflecting adolescents who never smoke, adolescents who do not progress past experimentation, and adolescents who progress to regular smoking with some progressing earlier and faster than others. These findings provide a richer understanding of adolescent smoking behavior to inform intervention timing as well as intervention type for different subpopulations of adolescents. This could be especially beneficial because research has shown that ''one size fits all'' approaches to youth smoking interventions is largely ineffective (42).

With respect to characterizing the smoking trajectories, the profile of social, psychological, and behavioral variables that define the distinct longitudinal smoking patterns assist in clarifying the similarities and the differences in trajectory membership. As expected, these variables discriminated among the nonsmoking and smoking trajectories and among the smoking trajectories. This is important because previous investigations were not able to delineate similarities and differences among smoking trajectories (e.g., ref. 5). In addition, the present study defined these adolescent smoking trajectories with variables that have been found to individually relate to smoking stages in previous cross-sectional and/or longitudinal investigations (3). This permits a fuller description of trajectory membership as it highlights stable smoking influences across time and delineates factors that concurrently influence adolescent smoking behavior.

Based upon the analysis, there seems to be two subpopulations of adolescents who are more vulnerable to progress to a regular smoking habit. These subpopulations are adolescents in the earlier and later smoking adoption trajectories. Adolescents in the earlier smoking adoption trajectory tended to have numerous risk factors for adolescent smoking. These risk factors, found individually to relate to smoking in previous studies, coexist in an overall high-risk smoking profile (10, 43). Adolescents who tend to start smoking earlier (many by 9th grade) and progress quickly, have higher levels of novelty-seeking and depressive symptoms and are more receptive to tobacco advertising. In addition, they tend to have peers who smoke, to have used alcohol and marijuana, and to perform less well academically. Given that depressive symptoms were only significantly higher at baseline (9th grade) when compared with the never smoking and experimenter trajectories, these adolescents may represent a subgroup who derive mood-related benefits from smoking (44-47). If this is the case, then screening and treatment for depression could be initiated early (e.g., before 9th grade) to possibly prevent the onset of smoking during adolescence. Depressed mood management may also need to be a component in smoking cessation programs for these youth. In addition, antitobacco media campaigns may need to be tailored to the novelty-seeking personality traits of those in smoking adopters trajectories to be effective (14). This approach has been shown to be effective with antidrug use campaigns targeting marijuana (48).

The later smoking adopters (i.e., adolescents who have progressed to or are approaching a regular habit) have many of the same characteristics as the earlier adopters, although their progression to regular smoking tends to occur later. For example, they tend to be novelty seekers, have peers who smoke, use alcohol, and marijuana, and to have lower grades than never smokers. These adolescents also are more receptive to tobacco advertising. Similar to the earlier smoking adopters, this may reflect later adopters attentiveness to smoking advertisements and their willingness to use promotional items (27, 49). However, later adopters consistently perform better academically than early adopters and are consistently more involved in sports teams. Thus, adolescents in this trajectory have a few factors in their profile that have been shown to be protective against smoking (13, 23, 26), which may help to explain the later onset of a more regular smoking habit.

In addition, later adopters are less likely to use marijuana compared with earlier adopters, yet this difference becomes smaller across time and is nonsignifcant by 12th grade; adolescents in this trajectory have finally adopted or are approaching a regular smoking habit and have become more involved in marijuana use. Like their early adopter counterparts, this group is of high concern given that many of its members have already reached a harmful smoking outcome during adolescence, albeit in a somewhat delayed fashion. Given that this subgroup acquires a smoking habit later (many in the 11th and 12th grade), yet are greater in number than early adopters (24% versus 8% of the sample), smoking prevention initiatives throughout the high school years have the potential to reduce the likelihood of smoking progression for a significant number of adolescents. This is a critical point because prevention initiatives typically occur in middle school. Moreover, smoking prevention interventions may need to go beyond social influence-based approaches that have been met with limited success (42) and incorporate strategies to promote better school performance and participation in sports and other activities as these may have a protective effect against smoking progression (13, 25, 26).

Adolescents in the experimenter trajectory represent a very interesting subgroup. They experiment with cigarettes, yet do not go on to develop a regular habit. Although adolescents in this trajectory have similar smoking influences as adolescents in the earlier and later smoking trajectories (e.g., peers who smoke, marijuana, alcohol, and lower academic performance compared with never smokers) these influences are lesser in degree. In fact, there seems to be somewhat of a dose-response relationship between these risk factors and smoking adoption. Chassin et al. (4) also noted that experimenters resembled individuals in more regular smoking trajectories, although a key difference was that experimenters also had more conventional aspects to their profile, such as higher rates of college attendance and parental support. Soldz and Cui (10) found that adolescents in an experimenter trajectory initiated smoking later and scored midrange between smokers and nonsmokers on psychosocial variables. The notion that experimenters may be more conventional than those who progress to a regular habit is supported in the present study in that adolescents in this trajectory were not characterized by novelty-seeking behavior.

Of note, non-Caucasian adolescents were more likely to be in the experimenter smoking trajectory than in the late adopter trajectory at 9th grade, although this difference disappeared by the 12th grade. This finding is consistent with previous research indicating that some non-Caucasian adolescents, specifically African American adolescents, initiate smoking experimentation and adoption later than Caucasian adolescents (50, 51). Although race seems to discriminate between experimenter and smoking trajectories at baseline, we are not able to draw conclusions about specific racial groups or comment on gender differences in smoking among non-Caucasian adolescents.

Never smokers represent the largest trajectory. In comparison with the other three trajectories, adolescent never smokers were more conventional and distinct from the smoking trajectories on most of the social and psychological variables assessed. Adolescents in this trajectory tended to perform well academically, tended not to consume alcohol or use marijuana, and tended to have peers who are nonsmokers. In addition, their risk profile tended to be more conservative and within normal limits in that they are not characterized by novelty-seeking or thrill-seeking behavior and had a relative absence of depressive symptoms. Thus, this trajectory represents a relatively stable and low risk for smoking subgroup of adolescents. To the extent that this group represents an important achievement with respect to tobacco control, their smoking abstinence should not go unnoticed. Public health campaigns such as the Centers for Disease Control and Prevention's Sports Initiatives (52) that congratulate adolescents for remaining tobacco and substance free help serve this function, but parents, teachers, and other adults who are more closely involved with adolescents should continue to do so as well.

The limitations of the current study should be acknowledged. Seventy-five percent of those parents who responded did provide consent. The differences between those who provided consent and those who declined were relatively small and few (15) although, caution is warranted in generalizing the results of this study, especially in light of the study's consent rate (54%). However, it is important to point out that our sample was nationally and locally representative on basic demographic characteristics (53-55). In addition, the smoking rates in our sample are fairly comparable to those found in national surveys. For example, 2001 data from Monitoring the Future (MTF) and from the YRBS survey for the geographic area of our sample are comparable to our figures (55-57). Data from our 2003 survey indicated that 10% are daily smokers compared with 9% in the 2001 YRBS survey and15% in the 2001 MTF Survey. In addition, 15% of the adolescents in our sample were current smokers compared with 13% in the 2001 YRBS survey and 26% in the 2001 MTF Survey. Although the smoking rates of our sample may not be completely representative of all adolescents nationwide, they are representative of the region and the population of high school students in the county from which the sample was drawn. Importantly, the goal of this research is not to quantify rates of smoking, but to elucidate risk and protective factors in the natural history of smoking progression. In addition, our low attrition rate contributes to a sample less biased by loss than several large nationwide surveys of high school students.

A second limitation of the current investigation is that it is not possible with LCGM to identify temporal precedence. We can only characterize which individuals are more likely to belong to a given trajectory with respect to a comparison group based on the covariates. However, we cannot conclude whether the covariates influence changes in smoking or whether smoking behavior drives the changes in the covariates.

In summary, the present study empirically identified four distinct adolescent smoking trajectories, which included never smokers, experimenters, earlier smoking adopters, and later smoking adopters. In addition, the current investigation characterized these trajectories by social, psychological, and behavioral variables. These variables discriminated between nonsmoking and smoking trajectories as well as between smoking trajectories. These findings may assist in the identification of those adolescents who should be targeted for a specific smoking prevention or intervention program, as discussed throughout. The optimal timing of the smoking prevention or intervention program, and what other factors may need to be considered as part of these programs can be informed by this work as well. Although no single program can be effective for all adolescents, multiple programs that reach out to, and are specifically tailored for, these special subpopulations may be better able to reduce the overall smoking rates.

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