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Trajectories of criteria of nicotine dependence from adolescence to early adulthood[☆]

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Abstract

Background—To identify patterns and correlates of developmental trajectories of DSM-IV nicotine dependence criteria from adolescence to early adulthood.

Methods—The analytical sample of lifetime smokers ($N = 877$) is from a longitudinal cohort of 6th–10th graders drawn from an urban school system. Subjects were interviewed 5 times at 6-month intervals and once 4.5 years later. Growth mixture models were estimated to identify trajectories of DSM-IV nicotine dependence criteria over ages 12–23.

Results—A four-class solution fitted the data best: No dependence criteria (Class 1, 32.0%); Early onset/Chronic course (Class 2, 26.1%); Early onset/Remission (Class 3, 15.4%); Late onset (Class 4, 26.5%). There appeared to be three critical periods. At ages 12–15, symptoms increased rapidly. As of age 16, the Early onset/Chronic class stabilized at high levels of symptoms, the Early onset/Remission class started its symptomatic decline, and the Late onset class experienced a sharp increase in symptoms. At age 20, there was a convergence in the prevalence of symptoms experienced at high (Classes 2 and 4) and low levels (Classes 1 and 3). Extensiveness of smoking and marijuana use were associated with higher baseline levels of nicotine dependence criteria. Anxiety disorders were associated with all three symptomatic trajectories. Parental smoking and nicotine dependence were associated specifically with the Early/Chronic class, while pleasant initial sensitivity and earlier onset ages of cigarette and marijuana use characterized the two early onset classes (2 and 3).

Conclusions—Trajectories of dependence criteria constitute an advantageous phenotype for research and intervention over static summaries of smoking behaviors.

[☆]Supplementary material can be found by accessing the online version of this paper at <http://dx.doi.org>. Please see Appendix Table A.

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Contributors

Denise B. Kandel and Mei-Chen Hu contributed to the study design and wrote the manuscript. Mei-Chen Hu undertook the statistical analysis. Christine Schaffran, Pamela Griesler and Melanie Wall contributed to data analysis. All authors revised the manuscript and approved the final version for submission.

Conflict of interest No conflict declared.

Keywords

Nicotine dependence criteria; Developmental trajectories; Growth mixture modeling; Adolescence

1. Introduction

Nicotine is a most addictive drug, second only to heroin. Understanding the natural history of nicotine dependence (ND) has great public health importance. ND develops in adolescence, with 22–40% of adolescent smokers meeting criteria for full ND (DiFranza et al., 2007; Gervais et al., 2006; Kandel et al., 2005, 2007). Cross-sectional studies document that rates increase rapidly throughout adolescence to age 18 (Kandel, 2003; Nelson and Wittchen, 1998). Earlier age of smoking onset increases ND risk (Audrain-McGovern et al., 2007; Breslau et al., 1994; Hu et al., 2006).

Recently some understanding has been gained regarding the latency between onset of smoking and the first dependence symptom (DiFranza et al., 2007; Gervais et al., 2006; Kandel et al., 2007). Latency can be as short as 30 days (DiFranza et al., 2007 – Hooked on Nicotine Checklist) or extend to five months for the first criterion and 23 months for the full syndrome (Kandel et al., 2007 – DSM-IV), or 11 and 41 months, respectively (Gervais et al., 2006 – ICD-10), depending upon the dependence measure. Little is known about the development, chronicity and remission of nicotine dependence and the risk and protective factors that underlie different developmental courses. Three studies besides our own (Hu et al., 2008), investigated developmental courses of ND symptoms. Each identified a single class of increasing symptoms: Audrain-McGovern et al. (2007; Rodriguez et al., 2008) examined the FTND from 9th grade to age 21; Mermelstein and colleagues examined the mFTQ from 9th–10th to 11th–12th grades (Heinz et al., 2010); Iacono and colleagues DSM-III-R based measures from ages 12 to 18 (Walden et al., 2007). In a prior analysis, we identified four trajectories of DSM-IV ND criteria among new smokers 12–17 years old followed over three years after smoking onset: Class 1 – No DSM criteria; Class 2 – Early onset of full DSM dependence/Chronic course; Class 3 – Early onset/Remission; Class 4 – Late onset (Hu et al., 2008).

Smoking and substance use history and other individual and family characteristics predict different developmental patterns of ND symptoms. In the single class model of increasing ND, factors related to baseline ND levels included pleasant initial sensitivity to cigarettes, marijuana use, peer smoking, the expectancy that smoking would relieve negative affect, and being male. Escalation of ND symptoms was predicted by baseline smoking level, smoking expectancy, parental ND, nicotine metabolism, ADHD symptoms and being male. We found that blunt use prior to smoking initiation was strongly associated with each symptomatic class. Pleasant initial sensitivity predicted those who experienced symptoms of DSM-IV dependence early (Classes 2 and 3). Parental ND, conduct disorder and extensiveness of smoking prior to the first symptom predicted early onset with chronic course (Class 2), while novelty seeking and being female predicted the Early onset/Remission trajectory (Class 3) (Hu et al., 2008). Despite differences in methodology and resulting trajectories, the studies converge in documenting the importance of parental ND, pleasant initial sensitivity, smoking extensiveness, marijuana use and gender in predicting ND course in adolescence. We also documented the role of adolescent conduct problems in predicting early onset with chronic course. We did not examine expectancies or beliefs about smoking.

This report extends our earlier analysis using a new wave of data collected 4.5 years later, which allowed us to follow smokers to age 23 and extend the follow-up from three to seven

years. Rather than symptoms following smoking onset, we investigate trajectories by age among smokers from adolescence to early adulthood. By including all smokers, not only new smokers, we can better investigate persistence and remission in symptoms in a larger group of youths in a crucial developmental period for onset of nicotine dependence symptoms. Our aims are to identify (1) trajectories of ND symptoms over seven years from adolescence to early adulthood and (2) psychosocial factors that characterize different trajectories.

2. Methods

2.1. Sample

Analyses are based on six waves of interviews with a multi-ethnic cohort of Chicago Public Schools 6th–10th graders, and three waves with one parent, mostly mothers. A two-stage design was implemented to select the target sample for follow-up. In Phase I (1/03–5/03), 15,763 students from 43 schools were surveyed (completion rate 83.1%). The sample was designed to provide approximately equal numbers of non-Hispanic whites, non-Hispanic African-Americans, and Hispanics. Responses were used to select a target sample of 1236 youths: 1106 tobacco users who reported having started to use within 12 months and 130 non-tobacco users susceptible of starting to smoke (Pierce et al., 1996). All whites and African-Americans who started tobacco use 0–12 months earlier and Hispanics who started 0–6 months earlier were selected; 25% of Hispanics who started 7–12 months earlier were sampled, because of the larger number of Hispanics than other racial/ethnic groups.

In Phase II (2/03–10/05), on average 9 weeks after each survey, 1039 (84.1%) of the 1236 youths and one parent agreed to participate in the longitudinal follow-up. We conducted three annual computerized household interviews with youths and parents (87% biological mother, 5% biological father, 8% other parental figures), each about 90 min long (Wave 1, W3, W5), and two short bi-annual interviews (20 min) with youths six months after W1 and W3 (W2, W4). The average interval between waves was 6.0–6.3 months, range = 3–10. Completion rates at W2–W5 were 96% of the W1 sample. In Phase III (11/09–08/10), on average 4.5 years after W5, 934 (90.6%) of 1031 W1 respondents (8 had died) were re-interviewed (80 min) (W6). The field work was conducted by the National Opinion Research Center (NORC).

The analytical sample included 908 lifetime cigarette smokers (255 white, 281 African-American, 372 Hispanic; 46.9% male, 53.1% female). Smoking only one or two puffs qualified individuals for inclusion. Twenty-four percent initiated smoking before age 12; 33.7% at ages 12–13; 37.6% at 14–17; 4.4% at 18 or over.

2.2. Human subjects procedures

Passive parental consent was obtained for the school surveys, active consent for the household interviews; adolescent assent or consent was also obtained. Interviewers emphasized all answers would be completely confidential. Procedures were approved by Institutional Review Boards of the New York State Psychiatric Institute, Columbia University, and NORC.

2.3. Variable definitions

Except for dependence, variables were time-constant. Dependence was time-varying and was linked to respondent's age at each wave. Most variables were not timed to onset of the first dependence criterion and were considered correlates rather than predictors of dependence. Predictive variables are highlighted below.

2.3.1. Nicotine dependence criteria (ND)—Measured per Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) (American Psychiatric Association, 1994), with an instrument for adolescents and young adults (Dierker et al., 2007) that we modified to measure symptoms experienced with the specific tobacco products used. The 11-item scale has high internal reliability, concurrent and predictive validity (Sledjeski et al., 2007), and defines the seven DSM-IV dependence criteria: tolerance, withdrawal, impaired control, unsuccessful quit attempts, great deal of time spent using tobacco, neglect important activities, use despite physical or psychological problems ($\alpha = .85$) (Kandel et al., 2005, 2007). Full dependence = 3+ criteria within a 12-month period. At W1 and W6, adolescents reported symptoms experienced the last 12 months; at W2–W5, symptoms since the prior interview six months earlier. Responses at W2–W3 and W4–W5 were aggregated separately to provide measures of last-twelve months symptoms. At W6, adolescents also reported symptoms between W5 and 12 months before W6, timed at the midpoint of the 3.5 year interval. The total number of ND criteria was treated as a count variable and was coded zero before smoking onset and during non-smoking periods.

2.3.2. Smoking and other drug use. Onset age of smoking—Month/year first smoked cigarette minus birth date (Predictor).

Pleasant initial sensitivity to tobacco use (modified Pomerleau et al., 1998): Dizziness and rush/buzz symptoms were differentiated into pleasurable and unpleasurable experiences. Only the *Pleasant Symptoms* scale was considered. It averaged scores of pleasant sensations, relaxation, pleasurable dizziness, pleasurable rush or buzz ($\alpha = .77$), coded 1 = none to 4 = intense experience (Predictor).

Maximum number cigarettes smoked per month by W6: Product of days smoked per month (frequency) and cigarettes per day on days smoked (quantity), recoded to mid-point values and transformed into packs per month. Based on a monthly tobacco-use history chart for 24 months before W1 and intervals between each interview at W2–W5. At W6, data were obtained for the last 12 months and the interval between W5 and 12 months before W6. **Frequency:** 0 days = 0; 1–2 days = 1.5; 3–5 days = 4; 6–9 days = 7.5; 10–19 days = 15; 20–29 days = 25; 30 days = 30. **Quantity:** one or two puffs = 0.5; 1 = 1; 2–5 = 3; 6–15 = 10; 16–25 = 20; 26–35 = 30; 35 = 40 cigarettes. Five packs or more (75th percentile) = 1; 4 packs or less = 0.

Maximum number alcohol drinks per month by W6: Logged maximum number of drinks last month or most recent month drank either at W1, W3, W5, or W6: product of days drank (frequency) and drinks per day on days drank (quantity), recoded to mid-point values. **Frequency:** 0 days = 0; 1–2 days = 1.5; 3–5 days = 4; 6–9 days = 7.5; 10–19 days = 15; 20–29 days = 25; 30 days = 30. **Quantity:** <1 drink = 0.5; 1 = 1; 2 = 2;...; 5 = 5; 6–8 = 7; 9–11 = 10; 12 = 12 drinks.

Ever used marijuana by W6. Yes = 1; no = 0.

Onset age of marijuana use: Month/year first used marijuana minus birth date.

2.3.3. Psychosocial variables. Psychiatric disorders by W5—Assessed by DISC-IV-Y/P (Shaffer et al., 2000a). Anxiety, mood and disruptive disorders were ascertained from parents and youths. Last year and whole life modules assessed mood disorders at W1, W3, W5; anxiety and disruptive disorders at W3, W5. Youths were assigned a diagnosis if met criteria on the parent, youth, or combined informant scores without impairment. Impairment algorithms were unavailable for combined diagnosis (Shaffer et al., 2000b).

Novelty seeking by W5: Based on Cloninger's Tridimensional Personality Questionnaire (Wills et al., 1998). Highest average score of nine 5-point items at W1, W3, or W5 ($\alpha = 0.87$).

Parent's lifetime DSM-IV ND (same assessment as youth): Defined as full dependence = 3+ criteria within a 12-month period. Self-reported by interviewed parent at W1, W3 or W5: never smoked; smoked, never nicotine dependent; lifetime nicotine dependent (Predictor).

Parental education (W1): Highest level reported by parents for themselves or spouses/partners: high school = 0; some college or more = 1 (Predictor).

Race/ethnicity: Non-Hispanic white; non-Hispanic African-American; Hispanic (Predictor).

Gender: Male; female (Predictor).

2.4. Statistical analysis

Growth mixture models (GMM) were estimated to identify trajectories of DSM-IV ND criteria experienced over ages 12–23 (Mplus 6.11, Muthén and Muthén, 1998–2010). GMM estimates the mean of the growth curve for each class and allows individual variation around the mean (Muthén and Asparouhov, 2007). To explore the number of latent classes and test for differences in trajectory shape across classes, GMMs without covariates were estimated by fitting one to five classes, with linear and quadratic parameters, and assuming non-zero versus zero-inflated Poisson distributions, non-random versus random growth factors, and class-equal versus class-varying variances. The optimum number of classes was determined by two fit indices: (a) smaller Bayesian information criterion (BIC), i.e., a high log-likelihood ratio with a small number of free parameters (Sclove, 1987); (b) significant Lo–Mendell–Rubin adjusted likelihood ratio test (LRT) for k versus $k - 1$ classes (Lo et al., 2001). To ensure computational convergence of models, 500 random starting values were generated initially, and 50 optimizations with the highest log-likelihood were used at the final stage.

Predicted mean counts of criteria at each age for each individual within each class, i.e., product of probability of being in the class of individuals who could experience one criterion multiplied by the predicted number of criteria among individuals in that class, were calculated with 95% confidence intervals for comparing classes (Fig. 1). Tests of differences between predicted mean criteria from one age to the next within each class were also performed (Table 2). These tests were conducted directly within the GMM estimation using model constraint commands in Mplus which allow contrasts of nonlinear functions of model parameters to be estimated and tested. Because these difference tests of predicted mean criteria are done within class and thus compare repeated measures over time for the same individuals, they are more powerful than simply comparing the pointwise confidence intervals presented in Fig. 1 which should be used for making between rather than within class comparisons.

To reduce model misspecification and identify significant correlates of trajectories, covariates were included into the best-fitting unconditional GMM as predictors of the probability of class membership and growth factors (Muthén, 2004). To select which covariates to include, we tested mean differences among smokers assigned to each class on the basis of posterior probabilities from unconditional GMM estimation using a Wald test. Significant covariates were then included simultaneously into the conditional GMM. Adjusted odds ratios (AOR) and 95% confidence intervals are presented comparing the odds

of being in each class based on the covariates. Thirty-one smokers missing data on covariates were excluded.

Analyses were based on weighted samples that corrected for undersampling of Hispanics who started tobacco use 7–12 months prior the school survey, and the higher nonresponse rates at W1 of youths reporting in school having smoked the last year and being heavy smokers (≥ 100 cigarettes) (Kandel et al., 2007). To handle missingness on the outcome, the Mplus missing-at-random estimation procedure was implemented.

3. Results

3.1. Descriptive results

Adolescents were on average aged 14.1 years ($SD = 1.4$, range = 11–17) at W1, 20.8 years ($SD = 1.4$, range = 18–23) at W6. Average age at smoking onset was 13.0 years ($SD = 2.7$, range = 7–21). Seventy-eight percent were smoking by W1. The mean interval from smoking onset to W6 was 7.3 years ($SD = 2.7$, range = 0–14). Data were missing for up to seven years following onset for those who initiated smoking 2–8 years before W1 (52.5%).

By W6, 6.3% had only ever smoked one cigarette; 9.1% 2–5 cigarettes; 10.1% 6–15; 7.7% 16–25; 13.9% 26–99 and 52.9% ≥ 100 cigarettes; 41.8% had ever smoked daily; 30.1% had never experienced any DSM-IV ND criterion, 29.9% had experienced one or two criteria, 40.0% three or more. Smoking levels varied greatly across dependence levels. Among smokers without symptoms, 14.6% had ever smoked 100 cigarettes; 6.0% had ever smoked daily. Percentages were 37.5% and 36.1%, respectively, among those reporting 1–2 criteria; 81.1% and 70.0%, among those meeting 3+ criteria (full dependence). Lifetime rates of full dependence were similar among males (42.9%) and females (37.4%), African-Americans (47.4%) and whites (44.7%), but lower among Hispanics (30.0%).

3.2. Growth mixture models of ND criteria

Five GMM models were estimated sequentially, starting with the single class model. The best fitting model was a four-class zero-inflated model with a quadratic growth factor, plus (a) random intercept with class-equal variance for the count part and (b) non-random intercept, slope, and quadratic growth factors allowed to vary across classes for the zero-inflated part. The LRT statistics favored the four-trajectory model (Table 1). For specific parameter estimates, see Table A in Supplementary Material.

The four latent classes of DSM-IV dependence criteria were: (1) No dependence criteria (40.7%); (2) Early onset/Chronic course (21.8%); (3) Early onset/Remission (10.9%); (4) Late onset (26.6%). Fig. 1 shows predicted mean criteria counts and associated 95% confidence intervals by age for each trajectory.

3.2.1. Age-specific patterns—To identify statistically points of change and stabilization of ND symptoms at specific ages, we compared changes in symptom means (with 95% confidence intervals) between two consecutive ages within each of the four trajectories. For Class 2, ND criteria increase from ages 12 to 17, especially at ages 13–14, and stabilize at age 17. For Class 3, ND criteria increase through age 15, especially ages 13–14, decrease as of age 16, and become zero as of age 19. For Class 4, criteria increase from ages 12 to 20, especially between ages 16 and 18, and decrease as of age 20. Overall, ages 12–15 constitute a common period of increase in ND criteria with varying rates across classes. Ages 16–19 constitute a period of diverging patterns. As of age 20, the patterns have solidified, except for a beginning decline in criteria at age 21 for Class 4.

At each age throughout adolescence, the maximum number of cigarettes smoked per month paralleled the trajectories of dependence criteria. The numbers were 0.8 pack per month at age 13, 6 packs at age 16, and 8.5 packs at age 20 for the Early onset/Chronic class. They were 0.5, 2.3, 0.6 packs, respectively, for the Early onset/Remission class; 0.0, 1.3, and 5.1 packs for the Late onset class; and 0.0, 0.2, and 0.4 packs for the No dependence criteria class.

3.3. Models with covariates

The covariates, except gender, novelty seeking and parental education, significantly differentiated the unconditional GMM trajectories (Table 3). The 11 significant covariates and gender were included in conditional models and their impact on trajectories and the intercept growth factor for the count part was examined.

The resulting four trajectories were very similar to those identified without covariates: 32.0% of smokers were assigned to Class 1; 26.1% Class 2; 15.4% Class 3; 26.5% Class 4. Based on the conditional model, 71.0% of Class 1 smokers experienced no criteria. Class 2 smokers started to smoke at an early age (65% by age 13, mean age = 12.1, SD = 1.1); they experienced close to full dependence by age 15, and remained at the same level up to the last observation by age 23. Of Class 3 smokers, 74.0% started to smoke by age 13 (mean age = 11.5 years, SD = 0.9); on average, they experienced 1–2 dependence criteria by age 15, and no criterion after age 18. Among Class 4 smokers, 78.0% started to smoke by age 15 (mean age = 14.0 years, SD = 1.3); on average, they experienced their first symptom around age 17, and close to full dependence by age 18. Those with early onset experienced their first symptom about two years earlier than those with late onset, and almost met criteria for full dependence within three rather than four years of smoking onset.

3.3.1. Correlates of trajectory membership—The correlates of the no-symptom class differed more extensively from those of the two early onset classes than the late onset class (Table 4).

Early onset/Chronic course (Class 2) versus No dependence criteria (Class 1):

Compared with Class 1, adolescents in Class 2 were more likely to have had pleasant experiences at initial tobacco use, smoked over five packs of cigarettes per month, started smoking and using marijuana at an earlier age, been diagnosed with an anxiety disorder, had a parent who had ever smoked or been nicotine dependent, and be white.

Early onset/Remission (Class 3) versus No dependence criteria (Class 1): Compared with Class 1, adolescents in Class 3 were more likely to have had pleasant experiences at initial tobacco use, initiated cigarette and marijuana use at earlier ages, been diagnosed with an anxiety or disruptive disorder, be female and white.

Late onset (Class 4) versus No dependence criteria (Class 1): Compared with Class 1, adolescents in Class 4 were more likely to have smoked over five packs per month, drunk a large amount of alcohol, been diagnosed with an anxiety disorder, and be white rather than Hispanic.

Early onset/Chronic course (Class 2) versus Early onset/Remission (Class 3): Among those with early onset, smoking over five packs per month, having a parent who ever smoked, and being male distinguished chronic course from remission.

Early onset/Chronic course (Class 2) versus Late onset (Class 4): Compared with Class 4, adolescents in Class 2 were more likely to have had pleasant experiences at initial tobacco

use, smoked over five packs per month, started smoking and using marijuana at an earlier age, and had a parent who had ever been nicotine dependent.

Early onset/Remission (Class 3) versus Late onset (Class 4): Compared with Class 4, adolescents in Class 3 were more likely to have had pleasant experiences at initial tobacco use, smoked less than 5 packs per month, started smoking and using marijuana at an earlier age, and been diagnosed with a disruptive disorder, be female and white rather than African American.

3.3.2. Effects of covariates on growth factors—Smoking over five packs of cigarettes per month (AOR = 1.60, 95% CI = 1.38–1.85, $p < .001$) and lifetime marijuana use (AOR = 1.39, 95% CI = 1.09–1.77, $p < .01$) were positively associated with the intercept. No covariates were related to linear or quadratic terms.

4. Comparison of trajectories over different follow-up intervals

The developmental trajectories of ND criteria identified in the first three years following smoking onset (Hu et al., 2008) and those described here for ages 12–23, on average over seven years after smoking onset, were very similar. The current approach, however, made it possible to identify critical developmental periods. Mid-to-late adolescence, spanning approximately five years from ages 15 to 20, is crucial for the differentiation and consolidation of different ND trajectories.

Because this sample included youths who started smoking at a younger age (mean = 13.0, SD = 2.5) than the prior sample (mean = 13.7, SD = 1.3) and the follow-up period increased by four years, the prevalence of the No dependence criterion trajectory decreased from 47.7% to 32.0%, the Early onset/Chronic trajectory increased from 19.8% to 26.1%, and the Late onset trajectory almost doubled from 15.2% to 26.5%. The proportion with early onset who remitted remained almost the same by age 23 (15.4%) as by age 18 (17.3%).

Of the nine common covariates examined in the two analyses, the same five differentiated the trajectories: pleasant initial sensitivity to tobacco; parental smoking/ND; conduct disorder; gender; race/ethnicity. Compared with adolescents without DSM criteria, initial pleasant sensitivity characterized the two early onset classes. Having a nicotine dependent parent was uniquely associated with the Early onset/Chronic course. Females with early onset were more likely to remit than have a chronic course. Whites were more likely than Hispanics to be in the Early onset/Remission or Late onset classes. In both samples, extensiveness of smoking (indexed prior to the first symptom previously, lifetime here) was a significant predictor or correlate of membership in the Early onset/Chronic course trajectory. In this analysis, extensiveness of smoking also differentiated this class from those with early onset who remitted and those with late onset. Parental ND, a significant correlate of Early onset/Chronic course in both samples, characterized 41.5% of the class in this sample compared with 29.2% in the earlier sample. Parental ND may become a stronger predictor over time of persistent dependence in offspring with early ND onset. Age of onset into smoking became a significant predictor of trajectory membership in this analysis due probably to the sample expansion from new smokers at W1–W3 to youths already smoking more than one year before W1. African-Americans were more likely than whites to be in the no dependence or in the late onset rather than early remitting class.

Four covariates measured through late adolescence/early adulthood, but not included in the earlier analysis, were significant. Anxiety disorder was associated positively with all three symptomatic classes but did not differentiate chronic course from remission among those with early onset. Anxiety disorder may be associated with ND onset (Breslau et al., 2004;

Griesler et al., 2011), but not persistence. Lifetime marijuana use was associated with baseline ND level. Earlier onset age of marijuana use differentiated the two Early onset classes from the Late onset and No dependence criteria classes while extensiveness of alcohol use was associated with Late onset.

5. Discussion and conclusion

The findings highlight the importance of developmental course in defining the ND phenotype and may explain partially inconsistent results across studies regarding risk and protective factors in the development of ND. Dependence criteria experienced within a defined time period, whether lifetime, last year or last month, is the outcome analyzed in most existing studies. Yet, four trajectories characterize the development of ND criteria from adolescence to early adulthood: No dependence criteria; Early onset/Chronic course; Early onset/Remission; Late onset. Unless developmental trajectories are differentiated, the results will reflect the weighted average of the proportions of individuals in the sample characterized by each trajectory at the time of the survey. Only when the correlates are invariant across trajectories will the results be consistent across studies. This is the case for initial sensitivity, one factor consistently associated with ND in multiple studies (Audrain-McGovern et al., 2007; DiFranza et al., 2004, 2007; Hu et al., 2006; Kandel et al., 2007; Urbán, 2010). By contrast, parental smoking and full dependence are associated with increased risk of dependence among offspring in some studies (Hu et al., 2008; Lieb et al., 2003; Walden et al., 2007), but not others (Fergusson et al., 1996; Griesler et al., 2008; Rohde et al., 2004). This may be partially explained by the fact that the first group of studies examined younger respondents, who are more likely to be in the Early onset/Chronic trajectory, while the latter studies examined mostly older respondents and did not differentiate smokers with early onset of dependence criteria from those with late onset.

The same overall patterns are observed from ages 12 to 23 and one to three years after smoking onset (Hu et al., 2008). However, the change in focus to age-specific manifestations of ND symptoms allowed us to specify the ages at which acceleration, decline and stabilization in symptoms occur. Ages 12–15 are of particular importance for increases in symptoms, ages 16–19 represent a period of cross-over in the trajectories, and age 20 marks the beginning of consolidation in patterns. The number of cigarettes smoked at different ages by youths in each class parallels the symptom trajectories. Among those who had an early onset of nicotine dependence, the maximum levels of consumption were almost four times higher among those with chronic course (8.5 cigarette packs per month) than among those who remitted (2.3 packs). Those with late onset had consumption levels (5.1 packs) in between the two early classes. It remains to be determined whether consumption drives dependence symptoms or vice versa.

The study has limitations. Since trajectories were investigated to age 23 years, developmental patterns cannot be extended to adulthood. We cannot determine whether the late onset class will continue its downward trend, suggesting that those who develop symptoms late are more likely also to remit sooner than those who develop symptoms early. Because psychiatric disorders were measured only up to W5, associations with trajectories beyond age 18 could not be investigated. Most importantly, time-varying covariates were not available for inclusion in the models since most covariates were not measured prior to onset of dependence symptoms. We can determine that certain factors are associated with different trajectories but not whether they are predictors and/or consequences of ND, except in cases, such as initial pleasant experiences to tobacco or parental dependence, when the factors clearly precede the onset of dependence.

The development of ND symptoms follows alternate paths, which vary by timing of onset, level of escalation, duration, and remission of symptoms. Correlates and predictors of dependence differ according to developmental course. These findings have important implications for research and intervention. Besides providing a deeper understanding of the development of dependence, the identification of trajectories and periods of change in adolescence provides a phenotype that will be advantageous compared with static measures that describe the smoking behaviors of individuals over a well-defined interval. Refining the phenotype will lead to a better identification of the genetic, individual and environmental correlates, predictors and consequences of ND. Improved phenotypes will also facilitate the development of prevention and intervention programs (Audrain-McGovern et al., 2004) tailored to the attributes of the target, the nature of the program, and the period in the life cycle when these programs are to be implemented.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi: 10.1016/j.drugalcdep.2012.03.001.

Fig. 1.

Trajectories of DSM-IV criteria of nicotine dependence in a four-class growth mixture model (lifetime cigarette smokers by Wave 6, $N = 908$). **Note:** Class membership is based on weighted posterior probabilities, without covariates in the model. Each time point represents the estimated number of DSM-IV criteria (mean and 95% confidence interval), i.e., product of probability of being in the class of individuals who could experience one criterion multiplied by the predicted number of criteria among individuals in that class.

Test statistics for trajectories of DSM-IV criteria of nicotine dependence in unconditional and conditional growth mixture models (lifetime cigarette smokers, $N = 908$).

Table 1

Trajectories	Log-likelihood	Free parameters	BIC ^a	Entropy	LRT ^b (p)	Class size ^c
<i>Unconditional</i>						
1	-5503.94	7	11055.56			908
2	-5301.18	14	10697.72	0.69	0.0000	477, 431
3	-5217.85	21	10578.74	0.67	0.0000	371, 269, 268
4	-5177.47	28	10545.65	0.65	0.0000	369, 198, 99, 242
5	-5153.16	35	10544.71	0.63	0.1700	284, 216, 185, 172, 51
<i>Conditional</i>						
4 classes with 12 covariates ^d	-4722.16	84	10013.55	0.73		281, 229, 135, 232

^aBIC: Bayesian information criterion.

^bLRT = Lo-Mendell–Rubin adjusted likelihood ratio.

^cRespondents assigned to a class on the basis of weighted posterior probabilities.

^dExcludes 31 cases with missing data.

Table 2

Estimated individual mean changes in DSM-IV nicotine dependence criteria between two consecutive ages from ages 12 to 23 in a four-class unconditional GMM model (lifetime cigarette smokers, $N = 908$).

Age comparisons	Class 1		Class 2		Class 3		Class 4	
	No dependence criteria		Early onset/Chronic		Early onset/Remission		Late onset	
	Mean change	95% CI	Mean change	95% CI	Mean change	95% CI	Mean change	95% CI
Ages 12–13	–0.01	–0.02 to 0.01	0.60***	0.49 to 0.71	0.23**	0.07 to 0.39	0.02**	0.01 to 0.02
Ages 13–14	0.00	–0.01 to 0.01	0.96***	0.84 to 1.08	0.64***	0.50 to 0.79	0.06***	0.04 to 0.08
Ages 14–15	0.00	–0.01 to 0.01	0.59***	0.48 to 0.69	0.41***	0.21 to 0.61	0.18***	0.13 to 0.24
Ages 15–16	0.00	0.00 to 0.01	0.24***	0.14 to 0.34	0.05	–0.13 to 0.22	0.45***	0.33 to 0.56
Ages 16–17	0.01*	0.00 to 0.01	0.10*	0.02 to 0.17	–0.37**	–0.63 to –0.11	0.70***	0.60 to 0.80
Ages 17–18	0.01**	0.00 to 0.02	0.03	–0.03 to 0.09	–0.70***	–0.87 to –0.53	0.66***	0.54 to 0.77
Ages 18–19	0.02***	0.01 to 0.03	–0.01	–0.07 to 0.05	–0.26*	–0.48 to –0.04	0.39**	0.29 to 0.49
Ages 19–20	0.02***	0.01 to 0.04	–0.05	–0.13 to 0.03	–0.03	–0.06 to 0.01	0.14**	0.05 to 0.23
Ages 20–21	0.04*	0.00 to 0.07	–0.12	–0.25 to 0.01	0.00	0.00 to 0.00	–0.04	–0.14 to 0.07
Ages 21–22	0.05	0.00 to 0.11	–0.26	–0.54 to 0.03	0.00	0.00 to 0.00	–0.16*	–0.29 to –0.03
Ages 22–23	0.08	–0.02 to 0.18	–0.59	–1.19 to 0.02	0.00	0.00 to 0.00	–0.24***	–0.37 to –0.11

* $p < .05$.

** $p < .01$.

*** $p < .001$.

Table 3

Distributions of percentages or means of covariates across latent trajectories of DSM-IV nicotine dependence criteria using posterior probability-based multiple imputations in a four-class unconditional growth mixture model (lifetime cigarette smokers, $N = 908$).

Covariates	Class 1 No dependence criteria $N = 369$ % or mean (SD)	Class 2 Early onset/Chronic $N = 198$ % or mean (SD)	Class 3 Early onset/Remission $N = 99$ % or mean (SD)	Class 4 Late onset $N = 242$ % or mean (SD)	Wald test (p value)
Male (vs. female)	42.6 ^a	50.9 ^{ab}	39.0 ^a	53.5 ^b	0.068
Race/ethnicity					
White	28.5 ^a	43.0 ^{bc}	31.9 ^{ac}	38.3 ^{bc}	0.019
African-American	27.7	28.6	25.7	29.5	0.916
Hispanic	43.7 ^a	28.4 ^{bc}	42.4 ^{ac}	32.2 ^{bc}	0.004
Onset age of smoking	13.2 (1.7) ^{ab}	12.3 (0.9) ^c	12.6 (0.8) ^{ac}	13.4 (1.4) ^b	<0.001
Smoked 5+ packs per month by W6	5.6 ^a	56.5 ^b	20.2 ^c	35.6 ^d	<0.001
Max no. of drinks per month by W6	2.1 (1.0) ^a	3.0 (0.7) ^b	2.4 (0.5) ^a	2.9 (0.8) ^b	<0.001
Used marijuana by W6	67.3 ^a	88.3 ^b	79.2 ^b	80.2 ^b	<0.001
Onset age of marijuana use	14.7 (1.1) ^a	13.4 (0.7) ^b	14.2 (0.5) ^a	14.5 (0.9) ^a	<0.001
Pleasant initial sensitivity to tobacco	1.2 (0.2) ^a	1.6 (0.3) ^b	1.5 (0.2) ^{bc}	1.4 (0.3) ^c	<0.001
Parental nicotine dependence					
Never smoked	31.4 ^a	15.7 ^b	29.7 ^a	26.6 ^a	<0.001
Smoked, not dependent	44.1	42.8	44.8	43.9	0.986
Ever dependent	24.5 ^a	41.5 ^b	25.4 ^a	29.4 ^a	0.001
Parental education level (vs. high school)					
Some college	54.3	62.1	56.0	56.6	0.356
Disruptive disorder by W5	19.1 ^a	39.5 ^b	33.0 ^{bc}	28.5 ^c	<0.001
Mood disorder by W5	13.4 ^a	23.6 ^b	23.0 ^{ab}	18.4 ^{ab}	0.044
Anxiety disorder by W5	11.4 ^a	21.7 ^{bc}	22.4 ^c	18.1 ^{ac}	0.039
Novelty seeking by W5	3.0 (0.5)	3.1 (0.4)	3.2 (0.3)	3.1 (0.4)	0.260

^{abc}Classes with different superscripts in the same row are significantly different at $p < .05$.

Table 4

Correlates of developmental trajectories of DSM-IV criteria of nicotine dependence over ages 12–23 in a four-class conditional growth mixture model (lifetime cigarette smokers, $N = 877^a$).

Covariates	Class 2 (Early/Chronic) vs. Class 1 (None)			Class 3 (Early/Remit) vs. Class 1 (None)			Class 4 (Late) vs. Class 1 (None)			Class 2 (Early/Chronic) vs. Class 3 (Early/ Remit)			Class 2 (Early/ Chronic) vs. Class 4 (Late)			Class 3 (Early/Remit) vs. Class 4 (Late)		
	AOR	95% CI		AOR	95% CI		AOR	95% CI		AOR	95% CI		AOR	95% CI		AOR	95% CI	
Male (vs. female)	0.66	0.28–1.52		0.14 ^{**}	0.04–0.52		1.26	0.67–2.35		4.77 [*]	1.44–15.9		0.52	0.23–1.18		0.11 ^{**}	0.03–0.38	
Race/ethnicity (vs. white)																		
African-American	0.32 [*]	0.12–0.87		0.17 [*]	0.04–0.68		0.62	0.28–1.36		1.82	0.59–5.58		0.51	0.21–1.26		0.28 [*]	0.09–0.91	
Hispanic	0.28 [*]	0.10–0.80		0.24 [*]	0.06–0.97		0.39 [*]	0.17–0.91		1.18	0.42–3.37		0.72	0.30–1.75		0.61	0.20–1.87	
Onset age of smoking	0.72 [*]	0.55–0.95		0.58 ^{**}	0.41–0.83		1.12	0.93–1.35		1.23	0.99–1.54		0.64 [*]	0.46–0.90		0.52 ^{**}	0.34–0.79	
Smoked 5+ packs per month by W6	22.97 ^{***}	6.54–80.67		1.47	0.21–10.22		8.42 ^{**}	2.52–28.12		15.63 ^{***}	4.11–59.4		2.73 [*]	1.21–6.16		0.17 [*]	0.04–0.81	
Max no. of drinks per month by W6	1.22	0.93–1.60		1.26	0.88–1.81		1.41 ^{**}	1.15–1.74		0.96	0.68–1.35		0.86	0.66–1.12		0.89	0.64–1.25	
Used marijuana by W6	1.94	0.75–5.01		1.68	0.44–6.43		1.42	0.61–3.29		1.15	0.37–3.59		1.36	0.51–3.62		1.18	0.39–3.57	
Onset age of marijuana use	0.49 ^{***}	0.34–0.70		0.54 ^{**}	0.36–0.82		0.87	0.72–1.05		0.90	0.67–1.21		0.56 ^{***}	0.41–0.76		0.62 [*]	0.43–0.89	
Pleasant initial sensitivity to tobacco	10.25 ^{***}	3.56–29.53		10.70 ^{***}	3.03–37.80		2.45	0.97–6.19		0.96	0.40–2.31		4.17 ^{**}	1.84–9.49		4.36 ^{**}	1.47–12.88	
Parental nicotine dependence (vs. never smoked)																		
Smoked, not dependent	3.92 [*]	1.22–12.6		1.14	0.30–4.36		1.28	0.61–2.69		3.45 [*]	1.04–11.4		3.07	0.88–10.7		0.89	0.25–3.16	
Ever dependent	4.58 [*]	1.42–14.8		2.03	0.46–8.99		1.61	0.71–3.65		2.25	0.68–7.42		2.85 [*]	1.00–8.11		1.26	0.38–4.26	
Disruptive disorder by W5	2.11	0.82–5.42		4.09 [*]	1.21–13.83		1.27	0.58–2.75		0.52	0.21–1.25		1.67	0.67–4.14		3.23 [*]	1.13–9.21	
Mood disorder by W5	1.12	0.36–3.53		0.48	0.09–2.55		0.73	0.28–1.91		2.34	0.74–7.44		1.53	0.54–4.34		0.65	0.17–2.49	
Anxiety disorder by W5	4.55 [*]	1.26–16.49		4.36 [*]	1.11–17.05		3.65 [*]	1.19–11.16		1.04	0.34–3.18		1.25	0.23–6.90		1.19	0.29–4.96	

^aExcludes 31 cases with missing data.

^{*} $p < .05$.

^{**} $p < .01$.

^{***} $p < .001$.