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Salivary cotinine concentration versus self-reported cigarette smoking: Three patterns of inconsistency in adolescence

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Abstract

The present study examined the extent and sources of discrepancies between self-reported cigarette smoking and salivary cotinine concentration among adolescents. The data are from household interviews with a cohort of 1,024 adolescents from an urban school system. Histories of tobacco use in the last 7 days and saliva samples were obtained. Logistic regressions identified correlates of three inconsistent patterns: (a) Pattern 1—self-reported nonsmoking among adolescents with cotinine concentration above the 11.4 ng/mg cutpoint ($n=176$), (b) Pattern 2—low cotinine concentration (below cutpoint) among adolescents reporting having smoked within the last 3 days ($n=155$), and (c) Pattern 3—high cotinine concentration (above cutpoint) among adolescents reporting not having smoked within the last 3 days ($n=869$). Rates of inconsistency were high among smokers defined by cotinine levels or self-reports (Pattern 1=49.1%; Pattern 2=42.0%). Controlling for other covariates, we found that reports of nonsmoking among those with high cotinine (Pattern 1) were associated with younger age, having few friends smoking, little recent exposure to smokers, and being interviewed by the same interviewer as the parent and on the same day. Low cotinine concentration among self-reported smokers (Pattern 2) was negatively associated with older age, being African American, number of cigarettes smoked, depth of inhalation, and exposure to passive smoke but positively associated with less recent smoking and depressive symptoms. High cotinine concentrations among self-reported nonsmokers was positively associated with exposure to passive smoke (Pattern 3). The data are consonant with laboratory findings regarding ethnic differences in nicotine metabolism rate. The inverse relationship of cotinine concentration with depressive symptoms has not previously been reported. Depressed adolescent smokers may take in smaller doses of nicotine than nondepressed smokers; alternatively, depressed adolescents may metabolize nicotine more rapidly.

Introduction

Epidemiological studies of smoking patterns define the phenotypes of interest on the basis of respondents' self-reports. The validity of these reports, especially among adolescents, has been questioned. Setting and degree of privacy influence the extent to which cigarette smokers are willing to report their behavior. Household interviews typically elicit lower reported rates of

smoking than school surveys (Kann, Brener, Warren, Collins, & Giovino, 2002); anonymous school surveys elicit higher rates than surveys identified by name or code number (Harrison, 2001).

Biological indicators, such as levels of cotinine or carbon monoxide, are assumed to be more valid indicators of a person's current smoking status than are self-reports. A general discussion of the utility of biomarkers of tobacco use among adults is provided by the Society for Research on Nicotine and Tobacco (2002). From an epidemiological perspective, biological indicators offer a limited window on smoking behavior inasmuch as they reflect smoking during a very short recent period and provide no information on other aspects of a person's smoking history, such as age at onset, lifetime experience, or extensiveness of consumption. To the extent that biological assays reflect current smoking, however, it is important to determine their congruence with self-reports of smoking and to identify the correlates of discrepancy.

This issue has been explored in community and clinical samples (Bauman & Ennett, 1984; Caraballo, Giovino, Pechacek, & Mowery, 2001; Caraballo et al., 1998; Dolcini, Adler, & Ginsberg, 1996; Dolcini, Adler, Lee, & Bauman, 2003; Mowery et al., 2003; R. P. Murray, Connett, Istvan, Nides, & Rempel-Rossum, 2002; Patrick et al., 1994; Pérez-Stable, Benowitz, & Marín, 1995; Slattery, Hunt, French, Ford, & Williams, 1989), including a national adolescent sample aged 12–17 years from the Third National Health and Nutrition Examination Survey (NHANES III; Caraballo, Giovino, & Pechacek, 2004). Using biochemical assay of salivary cotinine as the criterion, Patrick et al. (1994) found sensitivity estimates for adolescents that ranged from 77% to 100% in 10 studies conducted through 1989 (*Mdn*=93%). In a study based on a household probability adolescent sample in the southeastern United States, Dolcini et al. (2003) reported sensitivity of 70.8% and specificity of 92.7%, unadjusted for smokeless tobacco use, among those reporting having smoked within the past 3 days. The cutpoint defining a positive cotinine was 10 ng/ml. Sensitivity decreased with length of time since consumption of the last cigarette and was 88.9% among those reporting having smoked the day of the interview. Caraballo et al. (2004) reported sensitivity of 81.3% and specificity of 96.9% using cutpoints of 11.4 ng/ml for cotinine and smoking within the last 5 days for self-reported consumption.

Discrepancies may be higher among adolescents than adults. In NHANES III, Caraballo et al. (2004) found that 18.7% of adolescents with cotinine above 11.4 ng/ml reported not having smoked in the prior 5 days; 21.1% of those who reported having smoked in the prior 5 days had cotinine values below the cutpoint. Among respondents aged 17 years or older from the same NHANES III study, but based on a higher cutpoint of 15 ng/ml, the respective percentages were 1.4% and 7.5% (Caraballo et al., 2001).

Two major discrepant groups exist among those defined as active smokers by either self-report or biological indicator: Those who report to be non-smoking but have cotinine levels above a specified cutpoint, and those with cotinine levels below the cutpoint who report current smoking. The two nondiscrepant groups include those consistently identified as smokers or nonsmokers by both indicators. Three comparisons between inconsistent and consistent groups have been examined in the literature, yielding three patterns of inconsistency. We label these as Pattern 1, nonsmoking among all respondents above a cutpoint; Pattern 2, cotinine below a cutpoint among all self-reported smokers; and Pattern 3, cotinine above a cutpoint among all self-reported current nonsmokers.

Studies that examine Pattern 1 are mostly descriptive and focus on rates of sensitivity and specificity (Bauman & Ennett, 1984; Dolcini et al., 1996). Among adults, lower education, higher income, being married, active church membership, and being a former smoker increase this pattern of discrepancy (Slattery et al., 1989). Pattern 2 has been examined by Caraballo et

al. (2001, 2004), who also examined Pattern 3 and considered a large number of covariates within a multivariate framework among adolescents and adults. Regarding Pattern 2, among adolescents and adults, number of cigarettes smoked per day is the most significant (negative) correlate of low cotinine among self-reported smokers; additional negative correlates for adults include age and ethnicity (being African American). Regarding Pattern 3 (Caraballo et al., 2001, 2004; R. P. Murray et al., 2002), being Mexican American is associated with reduced inconsistency among adolescents and adults. Among adults, education is associated with reduced discrepancy, while older age, recent and extensive prior smoking, and less exposure to smokers in the household are associated with increased discrepancy. In a review of 28 articles comparing adolescent self-reported smoking with various biological indicators, Dolcini et al. (1996) pointed to other sources of discrepancy, such as limitations of biological markers, format of questions, social desirability, fear of disclosure, and analytic and statistical issues.

We examined the extent and correlates of the three patterns of discrepancy between self-reports and salivary cotinine among adolescents. To the extent that it was appropriate, the same covariates were included in all the models. The common covariates included demographic characteristics, role models for smoking, exposure to passive smoke, and social and personal characteristics. The behavioral and psychological attributes of delinquency and depressive symptoms were included to explain Pattern 1 inconsistency, because they have consistently been found to correlate with and predict smoking (e.g., Johnson, Rhee, Chase, & Breslau, 2004; Kandel, Kiros, Schaffran, & Hu, 2004). These two variables were retained in the other two models to establish the comparability of models across outcomes. For Pattern 1, we also considered the setting of the data collection procedure. This may affect perceived confidentiality, which in turn affects willingness to report cigarette use, a behavior that is illegal for adolescents and socially disapproved more generally. Fear of disclosure and social desirability are considered only indirectly in this article. For Pattern 2 inconsistency, we also included factors related to patterns and topography of smoking, such as depth of inhalation, and factors potentially related to nicotine metabolism, such as body mass index, which are expected to be related to low-level cotinine among self-reported smokers. For Pattern 3 inconsistency, we considered the same covariates as for Pattern 1, with the exception of interview setting. The data are from a longitudinal study of the transition to nicotine dependence in adolescence.

The present study differs from prior studies in two significant ways. We examined the three patterns of inconsistency in the same sample. In addition, we considered a more extensive set of factors than in most prior studies and included variables, such as parental smoking, perceived smoking by peers, delinquency, and depressive symptoms, which have not been examined previously. The results suggest novel and speculative hypotheses about the relationship between depressive symptoms and nicotine intake or cotinine metabolism.

Method

Sample

The data are from the first two waves of a prospective five-wave longitudinal panel of adolescents aged 11–16 years ($M=14.1$) when first interviewed in the spring of 2003 ($N=1,039$) and of the first wave of interviews with mothers. A cohort of 1,236 non-Hispanic White, non-Hispanic African American, and Hispanic 6th–10th graders and their mothers were selected from the Chicago Public Schools (CPS) for five waves of household interviews to be conducted over a 2-year period. A two-stage sampling design was implemented. In Phase I, 15,763 students in grades 6–10 were sampled from 43 middle and senior high schools in the CPS. The sample was designed to provide approximately equal numbers of adolescents among the three major ethnic groups: Non-Hispanic White, non-Hispanic African American, and Hispanic. Because of the ethnic distribution in the CPS, largely Hispanic high schools were excluded

and schools with large numbers of non-Hispanic White students were oversampled. In the spring of 2003, students were administered a brief survey, with the schools staggered over a 4-month interval (83.1% participation rate). Responses were used to select a target sample of 1,236 youths: 1,110 tobacco users who started to use tobacco within the prior 12 months and 126 susceptible nonsmokers, divided as evenly as possible among the three ethnic groups. Whites and African Americans who started to use tobacco up to 12 months earlier and Hispanics who started up to 6 months earlier were selected with certainty; Hispanics who started using tobacco 7–12 months earlier were subsampled at a 25% rate. In Phase II, on average 9 weeks after each school survey, 1,236 youths and their mothers were recruited for participation in a 2-year longitudinal follow-up consisting of three annual household interviews with youths and their mothers (waves 1, 3, and 5) and two short biannual interviews with youths 6 months after the first and second annual interviews (waves 2 and 4).

Data collection

The data were collected by the National Opinion Research Center. Data were obtained in respondents' homes through computerized interviews. The adolescent interviews took on average 1 hr and 27 min at wave 1, and 20 min at wave 2. The interviews were administered by interviewers, with the exception of a self-administered module containing questions on delinquency, physical development, and sexual experiences at wave 1, and on depressive symptoms at waves 1 and 2. Adolescents were asked very detailed questions about their use of various tobacco products, including use of cigarettes on each of the preceding 7 days and use of other tobacco products on each of the prior 3 days. Two saliva samples were collected at the end of each interview to assess cotinine levels. Because 70%–80% of nicotine is metabolized to cotinine (Benowitz & Jacob, 1994), cotinine levels are an excellent index of cotinine intake and tobacco use. All samples were frozen and shipped on dry ice to Salimetrics LLC (State College, Pennsylvania).

Interviews with parents took on average 1 hr and 21 min. In 86.8% of families, mothers were the participating parent (83.7% biological, 2.0% adoptive, 1.1% step or foster). Wave 1 interviews were completed with 1,039 parent-child dyads (84.1% participation rate of target $N=1,236$), and 1,000 sets of saliva samples (96.2%) were collected. Wave 2 interviews were completed with 1,000 adolescents (96.2% of wave 1 sample), and 970 sets of saliva samples (97.0%) were collected. A total of 1,024 youths provided a saliva sample at either wave 1 or 2. At wave 1, to maximize participants' trust in the confidentiality of their responses, attempts were made to interview parent and child simultaneously by two different interviewers on the same day. In 87.2% of families, adolescent and parent were interviewed on the same day; of those interviewed on the same day, however, only 62.5% were interviewed simultaneously by different interviewers. The average interval between waves 1 and 2 was 6.1 months.

Hispanics who had started to use tobacco 7–12 months earlier were given a weight of 4. All Hispanic tobacco users were rescaled to the unweighted number who were interviewed.

Human subject procedures

Passive parental consent was obtained for the school survey and active consent for the household interviews and saliva collections; adolescent assent was obtained for the school and household interviews and saliva collections. At the beginning of the interview, the interviewers informed the adolescents that, if they agreed, two saliva samples would be collected to determine exposure to nicotine and cotinine, biochemical products in tobacco, either because they had smoked or were exposed to tobacco smoke. It was emphasized that the samples would not be tested for any other drugs. The interviewers also stressed that all answers and the results of the saliva samples would be kept completely confidential and would not be communicated to anyone, including the adolescents' parents or teachers. All procedures for obtaining parental

consent and youth assent were approved by the institutional review boards of the New York State Psychiatric Institute, Columbia University, and the National Opinion Research Center.

Saliva assays

The saliva samples were tested for salivary cotinine in duplicate by Salimetrics using a highly sensitive enzyme immunoassay. Method accuracy, determined by spike recovery and linearity, averaged 99.4% and 95.9%, respectively (cotinine technical performance characteristics, Salimetrics, September 10, 2004). The test was performed on 50 μ l of saliva (for singlet determinations). It had a lower limit of sensitivity of 2 ng/ml and a range of 3–300 ng/ml. The average intra- and interassay coefficients of variation were 4.0% and 7.2%, respectively (Salimetrics, September 21 and October 4, 2004). Based on a receiver operating analysis (described in the Results section) and the value used in the national adolescent sample from the NHANES III (Caraballo et al., 2004), we used a value of 11.4 ng/ml as a cutpoint to define active smoking. Cotinine has a half-life of 16–20 hr (Hukkanen, Jacob, & Benowitz, 2005).

Analytic sample

Three groups of adolescents were identified among the 1,024 youths: (a) With cotinine as the criterion, adolescents who had cotinine levels above the cutpoint (≥ 11.4 ng/ml) at either the wave 1 or wave 2 interview ($n=176$), (b) with self-report as the criterion, those who reported smoking within the 3 days preceding either interview ($n=155$), the limit at which cotinine can be detected, and (c) with self-report as the criterion, those who reported not having smoked within the 3 days preceding both interviews ($n=869$). These criteria were selected on the basis of receiver operating characteristic analyses described below. If a respondent met both criteria or the same single criterion at both waves, the wave 1 responses were selected since the wave 2 interview included very few variables other than smoking history. If a respondent met both criteria or only one criterion at a single wave, that wave was selected. If a respondent met a different criterion at each wave ($n=4$), the cotinine above the cutpoint determined selection of the wave.

We identified consistent and inconsistent response patterns and different contrasts. Adolescents with cotinine above the cutpoint were subdivided into those who reported having smoked in the last 3 days ($n=94$) and those who did not report having done so ($n=82$; Pattern 1 inconsistency). Adolescents who reported smoking within the last 3 days were subdivided into those with cotinine above the cutpoint ($n=94$) and those with cotinine below the cutpoint ($n=61$; Pattern 2 inconsistency). Adolescents who reported not smoking within the last 3 days were subdivided into those with cotinine below the cutpoint ($n=787$) and those with cotinine above the cutpoint ($n=82$; Pattern 3 inconsistency).

Analytic strategies

Two receiver operating characteristic analyses were implemented to assess specificity and sensitivity of self-reported smoking and salivary cotinine and to determine the optimum cutpoints for each variable. In a second step, three logistic regressions identified the correlates of the three inconsistent responses. Model 1 estimated self-reported nonsmoking among those with cotinine above the cutpoint, model 2 estimated cotinine below the cutpoint among those who reported having smoked within the last 3 days, and model 3 estimated cotinine above the cutpoint among those who reported not having smoked within the prior 3 days. A common set of variables was included in the three models plus covariates unique to each outcome in models 1 and 2. The common variables included demographic characteristics, role models for smoking, exposure to passive smoke, and psychosocial variables related to smoking specifically (depression) and to nonconforming behavior more generally (delinquency). Characteristics of the interview situation was a variable unique to model 1. Specific variables in model 2 included those related to patterns and topography of smoking and the metabolism of nicotine. Variables

pertaining to patterns and topography of smoking could not be included in models 1 and 3 because inconsistent respondents in model 1 and all respondents in model 3 reported not having smoked recently and could not logically be asked the relevant questions.

Definition of covariates

All covariates were measured at wave 1 and were based on adolescents' reports, with several exceptions. Cigarette smoking, other tobacco use, one of the two items measuring exposure to passive smoke, depressive symptoms, and interview setting were selected from the wave at which adolescents reported smoking within the last 3 days. One variable, parental smoking, was based on the parental interviews.

The following variables were included in all three models.

- *Age* (wave 1): 11 to 16 years.
- *Gender* (wave 1): 1=male, 2=female.
- *Race/ethnicity* (wave 1): 1=non-Hispanic White, 2=non-Hispanic African American, 3=Hispanic.
- *At least one residential parent reported smoking in the last 12 months* (wave 1, parent self-report): Based on focal parent's report of her or his own smoking and the smoking of spouse or partner. 0=did not smoke, 1=smoked.
- *How many friends perceived to smoke currently* (wave 1): 0=none or one, 1=some, 2=most or all.
- *Number of days in a room or a car with a smoker in the last 3 days* (wave 1 or 2): 0, 1, 2, 3.
- *Number of people in household who smoked last 12 months* (wave 1): 0, 1, 2, 3, or more.
- *Lifetime delinquency scale* (wave 1): Measures lifetime involvement in 15 delinquent activities including graffiti, physically damaging property or persons, lying, shoplifting, stealing something worth less or more than \$50 dollars, breaking/entering, threatening with a weapon, individual or group fighting, running away, driving another's car without permission, selling marijuana or other drugs, and trouble with the police (Resnick, 1997). Each item was coded 0=no, 1=yes. Summed count ranged from 0 to 14 ($\alpha=.79$).
- *Depressive symptoms scale* (wave 1 or 2): Measures *DSM-IV* criteria for major depressive disorder and dysthymia in the last 30 days (American Psychiatric Association, 1994; Gadow et al., 2002). The suicide ideation item was removed from the 13-item scale because of human subject concerns. For each of 12 items, youths rated their behaviors (trouble falling or staying asleep, trouble concentrating, tired/no energy, eating a lot, sleeping a lot, skipped meals/ate little) and feelings (grouchy/cranky, unhappy/sad, did not feel like doing anything, did not like self, felt things never work out right, felt could not do things as well as others) in the last 30 days on a four-point scale (0=never, 1=sometimes, 2=often, 3=very often). Summed average scores ranged from 0 to 3 ($\alpha=.88$).

The following variable was added to model 1:

- *Interview setting* (wave 1 or 2): Indirect measure of fear of disclosure, based on whether the data came from wave 2 when only the adolescent was interviewed or from wave 1 when the parent also was interviewed. In the latter case, the variable indicated whether parent and child were interviewed on the same day and by the same

interviewer or simultaneously by different interviewers. The categories were as follows: Adolescent solo interview (wave 2), adolescent interviewed on same day as parent and simultaneously by different interviewers (wave 1), adolescent interviewed on same day as parent and sequentially by same interviewer (wave 1), and adolescent interviewed on different day than parent (wave 1).

The following variables were added to model 2.

- *Most recent day smoked* (wave 1 or 2): 0=today, 1=yesterday, 2=2 days ago. Based on a question that asked adolescents how many cigarettes they had smoked on each of the last 7 days: "Tell me how many cigarettes you smoked today, yesterday, 2, 3, 4, 5, 6 days ago." To aid recall, a customized day-of-the-week text was plugged in for the 2–6 days ago probes. Positive responses defined the most recent day on which the respondent had smoked a cigarette.
- *Number of cigarettes smoked last 3 days* (wave 1 or 2): Sum of cigarettes smoked the day of the survey, yesterday, and 2 days ago. Based on question above. Range=less than 1 to 30 cigarettes.
- *Depth of inhalation* (wave 1 or 2): 0=does not inhale, 1=just in mouth, 2=back in the throat, 3=in the lungs shallow, 4=in the lungs deep, 5=in the lungs very deep.
- Usual brand of cigarettes mentholated (wave 1): 0=no, 1=yes.
- *Used other tobacco products last 3 days (i.e., cigars, smokeless tobacco, pipe, kreteks, bidis)* (wave 1 or 2): Based on questions asked about each tobacco product parallel to question about cigarettes (see above).
- *Body mass index* (wave 1): Ratio of weight to height squared.

Results

Smoking rates and cotinine values

In the total sample, 72.4% had ever smoked by the second interview; 15.8% had smoked within the last 3 days at either wave 1 or 2. These adolescents were very light smokers. Of those who reported having ever smoked, 47.2% had ever smoked only a puff or less than one cigarette, 11.4% had smoked 1 cigarette, 16.6% 2–5 cigarettes, 9.4% 6–15 cigarettes, 3.4% 16–25 cigarettes, 5.4% 26–99 cigarettes, and 6.6% had ever smoked at least 100 cigarettes. Besides cigarettes, 31.5% of the cigarette smokers had ever used another tobacco product: 29.3% had ever used cigars, 3.5% a pipe, 0.8% kreteks, 0.8% bidis, and 2.8% smokeless tobacco.

The range of cotinine values was skewed toward low values. Since cotinine has a half-life of 16–20 hr (Hukkanen et al., 2005), youths who reported smoking the day of the interview at either wave 1 or wave 2 would be expected to have the highest cotinine values. Even these active smokers had low values. The distribution of cotinine levels were as follows: 0 ng/ml (21.2%), above 0 ng/ml to less than 11 ng/ml (5.7%), 11 ng/ml to less than 100 ng/ml (44.0%), 100 ng/ml to less than 200 ng/ml (21.6%), and 200 ng/ml or higher (7.5%). As reflected in means and medians, cotinine was highest among adolescents who reported smoking the day of the interview and declined significantly between those reporting having smoked today versus yesterday (Table 1). A further decline occurred between those reporting having smoked 2 versus 3 days earlier. Smoking 3 days earlier (excluding today) for the last time was associated with a mean of 3.7 ng/ml and a median of 2.1 ng/ml, values far below the cutpoints of 11–15 ng/ml used to identify active smokers.

Receiver operating characteristic analysis

Two receiver operating analyses were estimated. One analysis was estimated using self-reports as the gold standard to determine the optimum cutpoint on the cotinine values that defined a youth as an active smoker. Sensitivity and specificity were similar for cotinine values ranging among 10.2 ng/ml (58.0%, 89.3%), 11.4 ng/ml (58.0%, 90.0%), 13.7 ng/ml (55.2%, 91.8%), and 15.2 ng/ml (54.1%, 92.8%). Caraballo et al. (2004) reported a substantially better combination of sensitivity (78.9%) and specificity (97.3%) for the value of 11.4 ng/ml in the national adolescent NHANES III sample. Because we found little difference in values between 10.2 ng/ml and 15.2 ng/ml, we selected 11.4 ng/ml as a cutpoint, the value chosen by Caraballo et al. (2004) for a national adolescent sample.

Another analysis was estimated using a cotinine value of 11.4 ng/ml as the gold standard to determine the most appropriate definition of recency of smoking and to maximize the sample size in the regression analyses. Sensitivity and specificity were 29.9% and 97.7% for those reporting having smoked today, 44.5% and 94.5% for those reporting having last smoked yesterday, 50.9% and 92.3% for those reporting having last smoked 2 days ago. The values did not vary greatly for subsequent intervals and ranged from 51.4% to 53.1% for sensitivity and 91.5% to 90.6% for specificity among those reporting having smoked 3–6 days ago. Having smoked within the last 3 days was selected as the criterion for self-reported smoking, based on the half-life of cotinine and the goal of having as large an analytic sample as possible. Thus sensitivity of the self-reports, and especially the saliva, were low.

In the cohort, 176 youth had cotinine values above the 11.4 ng/ml cutpoint (i.e., positive cotinine) at one of the two interviews. A total of 155 youths reported having recently smoked cigarettes, or 21.8% of those who acknowledged having ever smoked; 11 youths had also consumed another tobacco product in the last 3-day period (10 had smoked a cigar and 1 had smoked a bidi). A total of 869 youths reported not having smoked in the last 3 days.

Distribution of patterns of consistent and inconsistent cases

Of youths with cotinine values above the cutpoint of 11.4 ng/ml, 50.9% reported smoking within the last 3 days, 33.5% reported smoking but not within the last 3 days, and 15.6% reported never having smoked. Thus 49.1% provided reports discrepant with the salivary cotinine (Table 2a). Of those below the cutpoint for cotinine, 7.7% reported having smoked in the last 3 days (Table 2a). Of youths who reported smoking within the last 3 days, 42.0% had levels below the cutpoint that were discrepant with self-reports (Table 2b). Of all those who reported not smoking within the last 3 days, 10.0% had cotinines above the cutpoint (Table 2b).

Adolescents with cotinine above the cutpoint who reported not having smoked within the past 3 days (Pattern 1 inconsistency), self-reported smokers with cotinine below the cutpoint (Pattern 2 inconsistency), and self-reported nonsmokers with cotinine above the cutpoint (Pattern 3 inconsistency) constituted the groups of interest. Among youths with cotinine above the cutpoint, self-reported smokers had much higher cotinine values than did self-reported nonsmokers ($Mdn=70.7$ ng/ml vs. 20.9 ng/ml, respectively; Table 3).

The mean values on the covariates for all four groups are presented in the appendix table.

Correlates of self-reported nonsmoking among youths with high cotinine: Pattern 1 inconsistency

Four factors—age, setting of the interview, number of days spent with a smoker in a room or a car, and especially the proportion of friends perceived to be smoking—had a significant adjusted effect on whether youths with positive cotinines reported having smoked recently

(Table 4). Older youths and those with friends perceived to be smoking, and with more recent exposure to smokers had lower rates of under-reporting. The association with friends appeared even when youths perceived only some friends to be smoking compared with none. Being interviewed on the same day as the parent and by the same interviewer increased nonsmoking reports. Delinquency had significant negative unadjusted odds ratios that became nonsignificant when adjusted for other covariates.

Correlates of low cotinine among self-reported smokers: Pattern 2 inconsistency

The most significant adjusted correlates of low cotinine were being African American, depth of inhalation, and depressive symptoms. Other significant correlates included age, number of days with a smoker in a room or a car, last smoked 2 days ago, and number of cigarettes smoked in the last 3 days (Table 5). Except for depressive symptoms and last smoked 2 days ago, these factors were associated with reduced odds of low cotinine. Thus African American smokers were much less likely than Whites to have cotinines below the cutpoint. Similarly, older youths, youths who smoked more recently and more extensively, inhaled deeply, and spent more days in the last 3 days in a room or a car with a smoker were less likely to have low cotinine. By contrast, youths with elevated depressive symptoms had increased odds of low cotinine. Gender, parental smoking, perceived smoking by friends, number of people in the household who smoked in the last 12 months, smoking mentholated cigarettes, the use of other tobacco products, body mass index, and delinquency had no significant effects.

Correlates of high cotinine among self-reported nonsmokers: Pattern 3 inconsistency

Controlling for other covariates, we found that the only significant correlates of positive cotinine among nonsmokers were passive exposure to smoke in a room or a car within the last 3 days and number of people in the household who smoked in the last 12 months (Table 6).

Discussion

Sensitivity and specificity in this sample were low and much lower than in other adolescent studies; sensitivity of the salivary cotinine was especially low. A large percentage of self-reports of smoking were inconsistent. About 49% of adolescents with salivary cotinine above the cutpoint reported not having smoked within the last 3 days, whereas 42% of those who reported smoking in the last 3 days had salivary cotinine concentrations below the cutpoint; 9.4% of those who reported not having smoked in the last 3 days had cotinine above the cutpoint. These discrepancies occurred despite interview procedures designed to emphasize the confidentiality of the interview and the knowledge on the part of adolescents that they would provide a biological sample to be assayed for the presence of tobacco products. The low sensitivity of self-reports in this study is especially striking because prior studies have documented that adolescents are more likely to report smoking when they are told in advance that biological measures will be taken to verify their answers (e.g., see review by Aguinis, Pierce, & Quigley, 1993; Dolcini et al., 1996; D. M. Murray, O'Connell, Schmid, & Perry, 1987). Neither self-reports nor biological measures can be considered the gold standard; and both measures, like others, contain error.

We considered three patterns of inconsistency: (a) Youths with cotinine above a cutpoint who reported not having smoked, (b) self-reported smokers with cotinine values below the cutpoint, and (c) self-reported nonsmokers with cotinine above the cutpoint. We could not take into account sources of inconsistencies that might have arisen because of errors in the assays themselves. The correlates of inconsistency that we examined included sociodemographics, role models for smoking as indexed by self-reported parental smoking and perceived smoking by peers, exposure to passive smoke, psychosocial variables (delinquency, depressive

symptoms), variables related to extensiveness and topography of smoking, body mass index, and the conditions of the interview setting.

The unique factors associated with self-reported nonsmoking among young people whose cotinine reach levels that would indicate active smoking (Pattern 1 inconsistency) are the same factors usually found to be related to self-reported smoking: Older age, perceived smoking by peers, being in the presence of people who smoke, and the setting of the interview (i.e., whether a parent is also interviewed and by the same person that interviews the child). These significant factors demonstrate indirectly the role of perceived norms and threat to confidentiality in response patterns. The perception of norms favorable to smoking, as indexed by perceived friends' smoking (but not parental smoking), reduces nonsmoking reports. By contrast, when the same person interviews parent and adolescent, the inferred perceived fear of disclosure, lack of confidentiality, and resulting threat of violating (implied) parental norms against smoking increase reports of nonsmoking. The effect of the child being interviewed by the same person that interviews the parent demonstrates the social constraints imposed by the interview setting on the quality of responses. The finding that perceived smoking by friends is a significant correlate of smoking reports whereas parental smoking is not significant emphasizes that peer norms are much more important than parental norms in adolescents' acknowledgment of their smoking behavior.

The finding that African American adolescent smokers are less likely than Whites to have cotinine levels below the cutpoint (Pattern 2 inconsistency) is consonant with ethnic differences in nicotine metabolism observed among adults in the laboratory. African Americans metabolize cotinine slower than do Whites (Benowitz et al., 1999; Pérez-Stable, Herrera, Jacob, & Benowitz, 1998), resulting in higher blood cotinine levels for any given level of nicotine intake. Variables related to patterns and topography of smoking, such as recency and extensiveness of smoking, and depth of inhalation, similarly reduce the likelihood of low cotinine values, as does exposure to passive smoke. Thus we confirmed the association between extensiveness of smoking and cotinine values above the cutpoint among self-reported smokers, reported previously for adolescents and adults (Caraballo et al., 2001, 2004). Depressive symptoms, however, greatly increase the likelihood of low cotinine. Although biological assays are traditionally considered to be the gold standard for assessing smoking, the present study provides another illustration of the limitations of such assessment among adolescents, who smoke very few cigarettes per day (Caraballo et al., 2004; Dolcini et al., 2003).

Regarding Pattern 3 inconsistency, exposures to sources of passive smoke were the only significant correlates of cotinine above the cutpoint among self-reported nonsmokers. This relatively uncommon discrepancy may not reflect misreporting of smoking status as much as the impact of exposure to environmental smoke. We did not replicate the effect of minority ethnicity on this pattern of inconsistency observed among adolescents and adults by Caraballo et al. (2001, 2004).

Depressive symptoms and cotinine levels

The negative association between depressive symptoms and low cotinine levels is a most intriguing finding. It contrasts with the well-documented positive association of depression with rates and extensiveness of smoking observed in cross-sectional and longitudinal epidemiological studies (Breslau, Kilbey, & Andreski, 1991; Glassman et al., 1990; Lasser et al., 2000). The negative association of depressive symptoms and salivary cotinine observed in the present study has not been noted previously in the literature. To the best of our knowledge, Pérez-Stable et al. (1995) are the only investigators to have explicitly examined this relationship. They found no association between mean scores on a scale of depressive symptoms (the Center for Epidemiologic Studies–Depression [CES-D] scale) and serum cotinine in a national sample of Mexican American men and women. Rojas, Killen, Haydel,

and Robinson (1998) did not discuss the significant negative association between cotinine levels and the CES-D in their data from an adolescent sample (Rojas et al., 1998, Table 2).

This negative cross-sectional association is open to several interpretations. We propose two. In one interpretation, the lower cotinine levels observed among smokers with higher depression compared with those with lower depression reflects less intensive smoking of cigarettes. Depressed smokers may inhale less smoke and take in less nicotine per cigarette than do nondepressed smokers. Perhaps nicotine needs are different in depressed than nondepressed young smokers, such that depressed smokers take in smaller doses. Depressed smokers may be smoking more for the behavior itself than for the pharmacological effect of nicotine.

In the other interpretation, depressive symptoms are associated with faster rate of cotinine metabolism. Because the present analysis controlled for number of cigarettes smoked, the low cotinine values among depressed adolescents could reflect a lower percentage of nicotine converted to cotinine or more rapid metabolism of cotinine (Benowitz & Jacob, 1994). The rates of metabolism of nicotine and cotinine are correlated, so if cotinine metabolism is rapid, nicotine metabolism would be expected to be rapid as well. According to this view, depressed individuals would metabolize nicotine more rapidly than those not depressed because of their heightened stress. One might consider a linkage between depression and genes that influence the metabolism of nicotine. The most important genes for nicotine and cotinine metabolism are CYP2A6 (Hukkanen et al., 2005; Tyndale & Sellers, 2002), found mainly in the liver, as well as CYP2B6, found in the brain (Miksys, Lerman, Shields, Mash, & Tyndale, 2003; Tyndale, Schoedel, Mash, & Miksys, 2001). This latter enzyme plays a less important role than CYP2A6, except in individuals deficient in CYP2A6 (Ring et al., 2005). It is also of interest that Kawanishi, Lundgren, Ågren, and Bertilsson (2004) reported that a very high percentage (88.9%) of persistently depressed individuals who did not respond to antidepressant medication expressed an allelic variation of the enzyme CYP2D6, another variant of cytochrome P-450, that results in more rapid metabolism of many antidepressant drugs. Thus if depressed individuals metabolize nicotine more rapidly than those who are not depressed, a self-reinforcing cycle of tobacco consumption may be established. The faster metabolism induced by depressive symptoms would lead to higher consumption of tobacco to meet the needs of smokers to obtain a satisfactory level of nicotine. Depressed individuals may smoke not necessarily to relieve symptoms of depression but to sustain levels of nicotine that would be depleted more rapidly by the depressive state itself and to avert symptoms of nicotine withdrawal. Perhaps these processes occur in adolescence but not in adulthood. In the absence of data, these hypotheses are purely speculative and need to be tested further among adolescents and adults.

Findings from the present study illustrate that the setting and conditions under which data are collected are important determinants of accurate reporting. Efforts need to be made to maximize objective and perceived confidentiality of the data collection procedure. In particular, in a household context, self-administered computerized interviews with an audio component (ACASI) or without (CASI) might be preferable to traditional personal interviews, although this may not be practical given the age of respondents and the complexity of the interviews.

Furthermore, there are no substitutable measures for self-reports of smoking in epidemiological studies. Most epidemiological information of interest regarding the history and patterns of smoking can be obtained only from self-reports, because information is required for a longer historical period of time than the very short interval when the biological metabolites are active. Biases in self-reports, however, lead to decreased overall observed prevalence rates; and unreliability leads to decreased relationships observed between the covariates of interest and smoking behavior.

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Table 1Salivary cotinine levels by most recent day smoked (wave 1/wave 2; $n=1,024$).

When last smoked	Sample size	Salivary cotinine level (ng/ml)		
		Mean	Median	SD
Today	75	78.4	63.8	93.9
Yesterday	52	23.0	8.2	33.1
2 days ago	28	34.1	4.7	62.9
3 days ago	9	3.7	2.1	5.7
4 days ago	6	14.5	0.0	29.1
5 days ago	3	0.0	0.0	0.0
6 days ago	3	6.5	3.1	7.3
7–30 days ago	64	3.7	0.0	7.1
>30 days ago	478	5.1	0.0	19.7
Never	306	7.2	0.0	70.1
All	1,024	12.6	0.0	53.1

Appendix

Frequency and means of covariates by cross-tabulation of self-reported smoking in last 3 days and cotinine value (cutpoint ≥ 11.4 ng/ml; wave 1/wave 2, $n=1,024$).

Covariate	No smoking, low cotinine	No smoking, high cotinine	Smoked, low cotinine	Smoked, high cotinine	Total
Gender, percent male	43.9	48.6	44.6	59.3	45.7
Age in years, mean (<i>SD</i>)	13.8 (1.3)	13.9 (1.6)	14.2 (1.4)	14.8 (1.1)	13.9 (1.4)
Race/ethnicity, percent					
White	25.1	26.3	29.1	28.8	25.8
African American	31.8	42.4	15.3	50.9	33.3
Hispanic	43.1	31.3	55.6	20.3	40.9
Parent in household smoked (self-report), percent					
Never	25.5	15.0	27.1	13.1	23.6
Smoked, not last year	33.4	18.1	27.4	18.7	30.4
Smoked last year	41.1	67.0	45.5	68.1	46.0
How many friends smoke currently, percent					
None	36.3	32.0	3.1	6.0	31.1
One	25.0	29.5	8.8	11.9	23.2
Some	30.9	28.6	72.6	41.6	34.3
Most/all	7.8	10.0	15.6	40.5	11.4
Number people in household smoked last 12 months, mean (<i>SD</i>)	0.8 (0.9)	1.4 (0.9)	1.0 (1.0)	1.4 (1.0)	0.9 (1.0)
Number days with smoker in room/car last 3 days, mean (<i>SD</i>)	1.2 (1.3)	2.2 (1.3)	1.8 (1.1)	2.6 (0.8)	1.5 (1.3)
Recency of smoking, percent					
Last smoked today	—	—	29.9	58.8	46.6
Last smoked yesterday	—	—	41.3	29.0	34.2
Last smoked 2 days ago	—	—	28.8	12.2	19.2
Number cigarettes smoked last 3 days, mean (<i>SD</i>)	—	—	2.2 (2.2)	7.1 (6.4)	5.0 (5.7)
How deeply inhales, mean (<i>SD</i>)	—	—	2.4 (1.0)	2.9 (1.0)	2.7 (1.0)
Usual cigarettes mentholated, percent	—	—	38.2	47.5	43.6
Used other tobacco products last 3 days, percent	—	—	5.5	6.6	6.2
Body mass index, mean (<i>SD</i>)	22.8 (4.8)	22.1 (5.0)	22.2 (3.9)	23.6 (5.0)	22.8 (4.7)
Lifetime delinquency, mean (<i>SD</i>)	2.7 (2.6)	2.8 (2.9)	4.0 (3.6)	4.4 (3.1)	2.9 (2.8)
Depressive symptoms, mean (<i>SD</i>)	0.7 (0.5)	0.7 (0.5)	0.9 (0.6)	0.7 (0.5)	0.7 (0.5)
Interview setting, percent					
No parent interview (wave 2)	2.4	33.2	56.8	49.8	12.7
Same day, same interviewer	30.3	30.0	13.3	15.5	27.9
Same, different interviewer	51.6	29.7	15.1	28.7	45.4
Different days	15.7	7.1	14.8	6.0	14.0
Sample size $\geq$	740	79	59	88	966
Last 3 day smokers $\geq$	—	—	54	91	145

Table 2**Table 2a. Consistency and inconsistency between salivary cotinine concentration and self-reported smoking in last 3 days.^a**

Reported smoking in last 3 days	Salivary cotinine concentration			
	≥ 11.40 ng/ml ^b		<11.40 ng/ml ^c	
	Sample size	Percent (95% confidence interval)	Sample size	Percent (95% confidence interval)
Smoker	94	50.9% (43.1–58.7)	61	7.7% (5.7–9.7)
Nonsmoker	82	49.1% (42.3–56.9)	787	92.3% (90.3–94.3)
Total	176	100.0%	848	100.0%

Table 2b. Consistency and inconsistency between self-reported smoking in last 3 days and salivary cotinine concentration.^a

Salivary cotinine concentration	Reported smoking in last 3 days			
	Smoker ^b		Nonsmoker ^c	
	Sample size	Percent (95% confidence interval)	Sample size	Percent (95% confidence interval)
≥ 11.40 ng/ml	94	58.0% (50.2–65.8)	82	10.0% (8.0–12.0)
<11.40 ng/ml	61	42.0% (34.2–49.8)	787	90.0% (88.0–92.0)
Total	155	100.0%	869	100.0%

^aNote. Unweighted Ns, weighted proportions.

^bSensitivity=94/176=50.9%; false negative=82/176=49.1%.

^cSpecificity=787/848=92.3%; false positive=61/848=7.7%.

^aNote. Unweighted N's, weighted proportions.

^bSensitivity=94/155=58.0%; false negative=61/155=42.0%.

^cSpecificity=787/869=90.0%; false positive=82/869=10.0%.

Range of cotinine values for the joint distribution of self-reported smoking in the last 3 days and salivary cotinine (11.4 ng/ml cutpoint; $n=1,024$).

Joint distribution	Cotinine value					Sample size
	Mean (ng/ml)	SD	Median (ng/ml)	Min (ng/ml)	Max (ng/ml)	
Cotinine above cutpoint, self-reported smoker (≥ 11.4 ng/ml)	86.22	83.75	70.7	11.4	622.3	(94)
Cotinine above cutpoint, self-reported nonsmoker (≥ 11.4 ng/ml)	49.51	136.22	20.9	11.5	1,217.1	(82)
Cotinine below cutpoint, self-reported smoker (<11.4 ng/ml)	2.27	2.99	0.0	0.0	9.1	(61)
Cotinine below cutpoint, self-reported nonsmoker (<11.4 ng/ml)	.89	2.09	0.0	0.0	11.4	(787)

Table 4

Logistic regression predicting Pattern 1 inconsistency: Not reporting smoking in the last 3 days among youths with positive cotinine above cutpoint (≥ 11.4 ng/ml; wave 1/wave 2, $n=176$).

Covariate	Univariate		Multivariate	
	Odds ratio	95% Confidence interval	Adjusted odds ratio	95% Confidence interval
Male (vs. female)	0.6	0.4–1.2	0.6	0.3–1.3
Age (years)	0.6***	0.5–0.8	0.7*	0.5–1.0
Race/ethnicity (vs. White)				
African American	0.9	0.4–1.8	0.5	0.2–1.4
Hispanic	1.7	0.7–3.8	1.3	0.5–4.0
Parent in household smoked (self-report; vs. did not smoke last 12 months)				
Smoked last 12 months	0.9	0.5–1.8	0.9	0.4–2.4
How many friends currently smoke (vs. none/one)				
Some	0.2***	0.1–0.4	0.2***	0.1–0.6
Most/all	0.1***	0.0–0.2	0.1***	0.0–0.3
Number people in household smoked last 12 months	1.0	0.8–1.4	1.1	0.7–1.7
Number days with smoker in room/car last 3 days	0.7**	0.5–0.9	0.7*	0.5–1.0
Lifetime delinquency	0.8***	0.8–0.9	0.9	0.8–1.1
Depressive symptoms	0.9	0.5–1.6	1.0	0.4–2.2
Interview setting (vs. wave 2 interview—no parent interview)				
Same day at wave 1, same interviewer for parent/child	2.9**	1.3–6.6	3.1*	1.1–8.4
Same day at wave 1, different interviewer for parent/child	1.6	0.8–3.2	1.9	0.7–4.6
Different days for parent and child at wave 1	1.8	0.5–6.1	1.5	0.3–7.5

Note. $-2 \log L=179.9$ ($df=14$).

* $p<.05$;

** $p<.01$;

*** $p<.001$.

Table 5

Logistic regression predicting Pattern 2 inconsistency: Cotinine below cutpoint (<11.4 ng/ml) among youths who reported smoking in the last 3 days (wave 1/wave 2, $n=155$).

Covariate	Univariate		Multivariate	
	Odds ratio	95% Confidence interval	Adjusted odds ratio	95% Confidence interval
Male (vs. female)	0.6 ⁺	0.3–1.1	0.8	0.2–3.0
Age (years)	0.7 ^{**}	0.5–0.9	0.6 [*]	0.3–1.0
Race/ethnicity (vs. White)				
African American	0.3 ^{**}	0.1–0.7	0.1 ^{**}	0.0–0.4
Hispanic	2.7 [*]	1.2–6.1	2.0	0.4–9.7
Parent in household smoked (self-report; vs. did not smoke last 12 months)				
Smoked last 12 months	0.4 ^{**}	0.2–0.8	0.4	0.1–1.4
How many friends currently smoke (vs. none/one)				
Some	2.6 [*]	1.0–6.7	1.9	0.4–9.3
Most/all	0.6	0.2–1.8	0.3	0.0–1.8
Number people in household smoked last 12 months	0.7 [*]	0.5–0.9	0.7	0.4–1.4
Number days with smoker in room/car last 3 days	0.5 ^{***}	0.3–0.7	0.5 [*]	0.3–1.0
Recency of smoking (vs. today)				
Last smoked yesterday	2.7 ^{**}	1.3–5.9	2.5	0.7–9.4
Last smoked 2 days ago	4.7 ^{***}	1.9–11.5	5.6 [*]	1.0–31.6
Number cigarettes smoked last 3 days	0.7 ^{***}	0.6–0.8	0.8 [*]	0.7–1.0
How deeply inhales	0.6 ^{**}	0.4–0.9	0.4 [*]	0.2–0.9
Usual cigarettes are mentholated	0.7	0.4–1.6	1.6	0.3–8.5
Used other tobacco products last 3 days	0.8	0.2–3.2	0.3	0.0–5.4
Body mass index	0.9 ⁺	0.9–1.0	1.0	0.9–1.1
Lifetime delinquency	1.0	0.9–1.1	1.1	0.7–1.4
Depressive symptoms	2.5 ^{**}	1.3–4.8	6.4 ^{**}	1.7–23.3

Note. $-2 \log L=94.9$ ($df=19$). ⁺ $p<.10$;

*
 $p<.05$;

**
 $p<.01$;

 $p<.001$.

Table 6

Logistic regression predicting Pattern 3 inconsistency: Positive cotinine above cutpoint (≥ 11.4 ng/ml) among youths who reported not smoking in the last 3 days (wave 1/wave 2, $n=869$).

Covariate	Univariate		Multivariate	
	Odds ratio	95% Confidence interval	Adjusted odds ratio	95% Confidence interval
Male (vs. female)	1.2	0.8–1.9	1.2	0.7–1.9
Age (years)	1.1	0.9–1.2	1.1	0.9–1.3
Race/ethnicity (vs. White)				
African American	1.3	0.7–2.2	1.5	0.8–2.6
Hispanic	0.7	0.4–1.2	1.0	0.6–1.9
Parent in household smoked (self-report; vs. did not smoke last 12 months)				
Smoked last 12 months	2.9***	1.8–4.6	1.4	0.7–2.5
How many friends currently smoke (vs. none/one)				
Some	0.9	0.6–1.5	0.9	0.5–1.6
Most/all	1.3	0.6–2.8	1.1	0.5–2.5
Number of people in household smoked last 12 months	1.8***	1.5–2.3	1.4*	1.0–1.9
Number days with smoker in room/car last 3 days	1.8***	1.5–2.1	1.6***	1.3–2.0
Body mass index	1.0	0.9–1.0	1.0	0.9–1.0
Lifetime delinquency	1.0	0.9–1.1	1.0	0.9–1.1
Depressive symptoms	0.8	0.5–1.3	0.7	0.4–1.1

Note. $-2 \log L=505.2$ ($df=13$).

*
 $p<.05$;

**
 $p<.01$;

 $p<.001$.