ORIGINAL INVESTIGATION

Smoking Antecedents: Separating Between- and Within-Person Effects of Tobacco Dependence in a Multiwave Ecological Momentary Assessment Investigation of Adolescent Smoking

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ABSTRACT

Introduction: Ecological momentary assessment (EMA) investigations have shown that the antecedents of smoking vary with individual differences in tobacco dependence. This has been interpreted as indicating that the transition to dependence is characterized by an erosion of external stimulus control over smoking. Rigorously testing this requires collecting multiple waves of EMA data, which permits separation of the influence of between- and within-person tobacco dependence variation in multilevel models.

Methods: Adolescents ($n = 313$, 9th or 10th grade at baseline) participated in up to 4 waves of week-long EMA assessment over the course of 2 years as part of a larger longitudinal, observational study. At each wave, participants recorded contextual features and subjective states in response to prompted diary assessments and when smoking. They completed a youth-specific form of the Nicotine Dependence Syndrome Scale at each wave.

Results: In cross-sectional multilevel analyses, smoking was less contingent on alcohol/drug use and was more common at home and in the morning for adolescents with higher levels of dependence. Multiwave analyses demonstrated that these effects were largely attributable to between-person variation in dependence, although parameter estimates for intraindividual dependence $\times$ antecedent effects tended to be in the predicted direction.

Discussion: Findings provided partial support for the contention that the antecedents of smoking shift as an individual progresses to higher levels of dependence. Distinctive choices concerning smoking settings also appear to reflect between-person differences in propensity to dependence. More generally, the findings illustrate the value of using multilevel modeling and repeated EMA assessments to investigate the correlates of tobacco dependence at different levels of analysis.

Attempts to characterize the momentary antecedents of smoking are among the earliest and most prominent uses of ecological momentary assessment (EMA) methodology in tobacco research. In this work, the frequencies of various contextual attributes recorded in user-logged smoking events are contrasted with the base rates at which each is observed during time-sampled diary entries (Paty, Kassel, & Shiffman, 1992). Features that are found more commonly during smoking than background states may represent triggers for cigarette use.

Theoretically, the salient triggers for smoking might change across the early smoking career as tobacco dependence progresses. The nature of such changes might help to refine our theoretical understanding of tobacco dependence and inform tobacco prevention and intervention efforts. Investigators have attempted to investigate this issue by collecting EMA data from

samples representing a range of tobacco involvement, then testing whether dependence level or daily smoking moderates associations between measured antecedent conditions and smoking events (e.g., Cronk & Piasecki, 2010; Krukowski, Solomon, & Naud, 2005; Otsuki, 2009; Otsuki, Tinsley, Chao, & Unger, 2008; Shiffman & Paty, 2006; Shiffman & Rathbun, 2011). Findings from these studies vary, but they frequently indicate that cigarette use among smokers higher in dependence is more weakly related to specific contextual setting events. Conversely, smoking among less dependent individuals occurs under more circumscribed conditions, especially “indulgent” conditions such as relaxing, socializing, eating, or drinking alcohol (Shiffman & Paty, 2006). Such results have been interpreted as suggesting that the progression of tobacco dependence is accompanied by an erosion of stimulus control

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over smoking (Piasecki, Richardson, & Smith, 2007; Shiffman & Paty, 2006). With increasing smoking exposure, cigarette use is thought to be increasingly driven by habit and withdrawal avoidance.

Although the existing EMA findings provide valuable clues about the trajectory of smoking patterns, they rely on comparing data from individuals who differ in dependence level at a single point in time. Thus, these designs cannot rigorously resolve the developmental question of whether the triggers for smoking evolve as a given individual's dependence grows. An alternate explanation might be that individuals who eventually develop dependence have always used cigarettes in distinctive conditions compared to persons destined to be long-term chipers, intermittent smokers, or those who "mature out" of smoking experimentation (Shiffman & Paty, 2006; Shiffman et al., 2012).

Longitudinal studies incorporating multiple waves of EMA data collection are needed to more directly address this developmental question. In this article, we investigate this question using data from a study of adolescents recruited in 9th and 10th grade and followed for 2 years. During this span, participants completed up to four 1-week bouts of EMA recording using electronic diaries, answering randomly timed prompts, and logging smoking events. At each wave, participants also completed a youth-specific version of the Nicotine Dependence Syndrome Scale (NDSS; Sterling et al., 2009). This design permits a separation of the NDSS data variation within a multilevel model into between-person and intraindividual components, allowing direct tests of whether each aspect moderates associations between contextual antecedents and smoking behavior.

METHODS

Participants

The sample was a subset of the Social and Emotional Contexts of Adolescent Smoking Patterns Study. All 9th and 10th graders at 16 Chicago-area high schools completed a brief screener survey ($N = 12,970$). Students were eligible to participate in the longitudinal study if they fell into one of four levels of smoking experience: (a) never-smokers; (b) former experimenters (smoked in the last 12 months, but not in the last 90 days, and smoked fewer than 100 cigarettes in their lifetime); (c) current experimenters (smoked in the past 90 days but smoked fewer than 100 lifetime cigarettes); and (d) regular smokers (smoked in the past 30 days and have smoked more than 100 cigarettes in their lifetime). Invitation/recruitment packets were mailed to eligible students and their parents, including a random sample of the never-smokers and former experimenters, and all current and regular smokers ($N = 3,654$). Youth were enrolled after written parental consent and student assent was obtained. Of those invited, 1,344 agreed to participate (36.8%), and 1,263 (94.0%) completed the baseline measurement wave. Agreement to participate did not vary by smoking history, race/ethnicity, or parental smoking, but girls were slightly more likely to agree to participate than boys.

The sample for this study included a subset of the 1,263 students from the overall longitudinal study who participated in the EMA portion of the study. Students were eligible for participation in the EMA substudy if they were former experimenters

($N = 112$), current experimenters ($N = 249$), or regular smokers ($N = 100$). These participants were subsequently invited to complete three additional 1-week bouts of EMA monitoring occurring 6, 15, and 24 months after the baseline recording period. This report includes data from the subset of participants who recorded at least one smoking event via EMA ($N = 313$). The participants included in these analyses were approximately evenly split between the sexes ($N = 176$, 56.2% female) and grade in school at baseline ($N = 150$, 47.9% ninth grade). The sample was predominantly White ($N = 240$, 76.7%), with smaller groups of African Americans ($N = 64$, 20.4%), Native Americans ($N = 14$, 4.5%), Asians ($N = 9$, 2.9%), and Pacific Islanders ($N = 8$, 2.6%). Overall, 63 participants (20.1%) reported Hispanic heritage. The top portion of Table 1 summarizes sample characteristics at each study wave for the full analyzed sample.

Measures

Ecological Momentary Assessment

During each 1-week wave of EMA assessment, participants recorded daily experiences and any smoking behaviors using a handheld palmtop computer programmed to serve as an electronic diary. The diary audibly prompted participants approximately five times per day (random prompts). In addition, participants were instructed to initiate recording whenever they (a) had smoked a cigarette, even a single puff (smoking records), (b) wanted to smoke but were not able to do so, or (c) had the opportunity to smoke but elected to resist cigarette use. The analyses were limited to data from random prompts ($n = 32,414$) and smoking records ($n = 4,081$). The top portion of Table 1 reports the number of smoking records and random prompts and the prevalence of smoking at each wave of EMA recording in the full analyzed sample. The average length of diary entry was <90 s across all types of EMA interviews. Mean compliance with the prompts averaged between 68% complete at baseline to better than 85% at subsequent waves.

Mood States. In each EMA diary assessment, participants were asked to rate 19 mood states using a 1–10 Likert scale. The item stem in random prompts instructed participants to "Think about how you felt just before the signal ... Before signal: I felt [mood state]." Each item was rated twice in smoking records. One set of ratings tapped current mood using the item stem, "Think about how you feel right now...". The second set of ratings instructed participants to "Think about the time just before you smoked: I felt [mood state]." Because we sought to understand the antecedents of smoking in this project, we analyzed the smoking record ratings made with reference to the pre-smoking period.

On the basis of preliminary factor analysis using Wave 1 random prompts and replicated in other record types, these mood items were reduced to five composite scores, with each composite computed as the average of a subset of items: positive affect (happy, relaxed, cheerful, confident, and accepted by others), negative affect (frustrated, angry, stressed, irritable, and sad), social isolation (lonely, left out, and ignored), tired/bored (tired, bored, and trouble concentrating), and nervous/embarrassed (nervous and embarrassed). Reliability of all mood scales was consistently good. Coefficient alphas for scales across waves were as follows: positive affect ($\alpha = .86-.87$); negative affect ($\alpha = .94-.95$); tired and bored ($\alpha = .80-.82$); social isolation ($\alpha = .94-.95$); and nervous/embarrassed ($\alpha = .74-.76$).

Table 1. Sample Characteristics and Key Ecological Momentary Assessment (EMA) Records at Each Study Wave

Measure	Assessment wave			
	Baseline	6 months	15 months	24 months
Single-wave analyses				
<i>N</i> contributing EMA data	313	272	241	259
Age, <i>M</i> (<i>SD</i>)	15.68 (0.60)	16.18 (0.60)	16.91 (0.58)	17.63 (0.58)
Male, <i>N</i> (%)	137 (43.8)	119 (43.8)	96 (39.8)	106 (40.9)
White, <i>N</i> (%)	240 (76.7)	205 (75.4)	181 (75.1)	200 (77.2)
Completed smoking records	1,140	811	981	1,149
Completed random prompts	9,427	7,997	7,010	7,980
Any EMA smoking record, <i>N</i> (%)	234 (74.8)	168 (61.8)	137 (56.9)	151 (58.3)
Smoking records/person, <i>M</i> (<i>SD</i>)	3.64 (5.54)	2.98 (5.37)	4.07 (7.83)	4.44 (8.24)
NDSS raw score, <i>M</i> (<i>SD</i>)	1.56 (0.79)	1.58 (0.82)	1.66 (0.90)	1.73 (0.89)
Multiwave analyses				
<i>N</i> contributing EMA data	196	181	162	173
Age, <i>M</i> (<i>SD</i>)	15.73 (0.57)	16.26 (0.59)	16.98 (0.57)	17.70 (0.57)
Male, <i>N</i> (%)	91 (46.4)	85 (47.0)	73 (45.1)	77 (44.5)
White, <i>N</i> (%)	152 (77.6)	138 (76.2)	121 (74.7)	134 (77.5)
Completed smoking records	943	779	961	1,071
Completed random prompts	5,906	5,199	4,590	5,178
Any EMA smoking record, <i>N</i> (%)	167 (85.2)	149 (82.3)	126 (77.8)	131 (75.7)
Smoking records/person, <i>M</i> (<i>SD</i>)	4.81 (6.42)	4.30 (6.13)	5.93 (8.96)	6.19 (9.27)
NDSS between, <i>M</i> (<i>SD</i>)	1.88 (0.77)	1.85 (0.76)	1.88 (0.76)	1.87 (0.77)
NDSS within, <i>M</i> (<i>SD</i>)	−0.13 (0.43)	−0.04 (0.43)	0.06 (0.42)	0.14 (0.46)

Note. NDSS = Nicotine Dependence Syndrome Scale.

Current Activities. In all diary assessments, participants reported any activities at the time of the report using a checklist. For analysis, we recoded checklist responses into a set of dichotomous variables indicating endorsement (scored 1) or nonendorsement (scored 0) of each activity. To identify important targets for analysis, we screened the diary data to identify activities that were reported in 5% or more in the combined set of random prompts and smoking records, pooled across waves. Activities meeting this criterion were as follows: hanging out, watching television, a movie, or listening to music, playing a computer or video game, being in transit, doing schoolwork, eating or drinking, resting or sleeping, and nothing. Although it was only present in only 3.6% of the diary reports, we elected to retain endorsement of “alcohol or other drug use” for analysis on the basis of prior EMA evidence indicating that alcohol use is more strongly associated with smoking at the momentary level among light or nondependent smokers (Krukowski et al., 2005; Shiffman & Paty, 2006).

Current Location. In each diary assessment, participants used a checklist to report their location immediately before the signal (for random prompts) or while smoking (for smoking records). As for activities, the location checklist was recoded into a set of dichotomous variables, and we retained for analysis those items present in at least 5% of the diary records: home, school, a friend’s house, and in a car. Although it was endorsed in only 3.2% of diary records, we retained “outside or public property” for analysis because it was expected to be associated with smoking behavior as a consequence of indoor smoking restrictions.

Social Context. The diary assessments asked participants to report who they were with immediately before the signal (random prompts) or while smoking (smoking records). For the

current analyses, these responses were recoded into a dichotomous variable indicating whether the participant was alone (1) or reported being with others (0, a combination of reporting being with others or “alone, others nearby”).

Time and Date Measures. Two additional measures were constructed using time/date stamps automatically recorded by the device at each assessment. Morning smoking is considered an important indicator of tobacco dependence (e.g., Baker et al., 2007). Therefore, we created a dichotomous variable indexing whether or not a record was made in the morning (i.e., after 4 a.m. but before 9 a.m.). Records were categorized as having been made on the weekend they occurred after 3 p.m. Friday but before 3 p.m. Sunday.

Questionnaire Measures

Participants completed questionnaire measures at baseline, and at 6-, 15-, and 24-months postbaseline. At each measurement wave, participants received the “paper and pencil” non-EMA questionnaires approximately 1 week prior to their first day of carrying the EMA device and handed in the questionnaire at the point of their first day of EMA training for each wave. Participants were paid \$20 for completion of each questionnaire at the baseline, 6-, and 15-month waves, and \$40 at the 24-month wave. Participants received project mailings such as birthday cards, holiday cards, and small gift incentives (e.g., water bottles, bags) in between measurement waves to help increase retention.

Age. At each wave of assessment, each participant’s current age was determined by computing the difference between the date the survey was completed and his/her date of birth.

Tobacco Dependence. At each assessment, participants completed the NDSS (Shiffman, Waters, & Hickcox, 2004)

modified for use in adolescent populations (Sterling et al., 2009). This modified NDSS utilized 10 items primarily representing the Drive and Tolerance subscales from the full NDSS. Items were presented as a four-point Likert scale (1 = *not at all true* to 4 = *very true*), with the total score representing the average of the 10 items. The youth-specific NDSS showed good internal consistency at each wave ($\alpha = .93-.95$) in the analyzed sample. The observed NDSS scores were right skewed at each wave (skewness = 0.64–1.06).

Data Analysis

The data were analyzed using multilevel modeling, with variations in model structure appropriate to each focal question. We first estimated a series of wave-specific, cross-sectional analyses testing moderation of antecedent-smoking associations by NDSS score. This strategy reflects the analytic approach typically employed when only one bout of EMA monitoring is available. At each wave, a series of two-level generalized linear mixed models (PROC GLIMMIX, SAS v. 9.3) were estimated. In each model, the dependent measure was a dichotomous indicator of whether a diary record was a smoking record (scored 1) or a random prompt (scored 0). The models used a logit link function and included a random intercept. In each model, smoking was predicted from the participant's age at that wave of assessment, the NDSS score at that wave, an antecedent variable, and an NDSS $\times$ antecedent interaction term. Given the number of statistical tests, we only selected antecedents showing consistent evidence for moderation by tobacco dependence in these cross-sectional models for more detailed scrutiny in analyses including data from all four assessment waves.

Multiwave analyses were limited to 196 participants who recorded at least one smoking event at two or more waves of EMA assessment. The bottom portion of Table 1 provides descriptive information concerning demographic characteristic, smoking, and tobacco dependence in this longitudinal cohort. We first conducted two preliminary two-level linear mixed models (a null model and a growth model; PROC MIXED, SAS v. 9.3) with NDSS scores as the dependent measure to (a) characterize sources of variation in tobacco dependence scores and (b) evaluate whether tobacco dependence levels changed over the course of the study period.

Multiwave analyses predicting smoking events used three-level generalized linear mixed models with a logit link function. We first fit a null model to evaluate whether a three-level model structure with random intercepts for participants and wave of measurement was appropriate. Next, as in the cross-sectional models, smoking was predicted from participant's age, NDSS score, the selected antecedents, and interactions involving the NDSS and the antecedents. The key difference was that the NDSS score was now represented using two variables, one indexing between-person variation (the NDSS person-mean) and one indexing intraindividual change (deviations of the NDSS score at each wave from the individual's person-mean). The odds ratio (OR) associated with the person-mean represents the cross-sectional impact of a one-point between-person difference in tobacco dependence on the odds of smoking. The OR for the within-person effect indexes the impact of a one-point change in an individual's dependence score on the odds of smoking. Detailed considerations of this parameterization and alternative approaches for separating between- and

within-cluster effects are provided by Begg and Parides (2003) and Curran and Bauer (2011).

RESULTS

Cross-Sectional Analyses

At each wave, we first fit a basic generalized linear mixed model that included the wave-specific NDSS score and age as predictors. Higher NDSS scores were associated with increased odds of smoking in all models (ORs = 2.57–3.88, $ps < .001$). Older age predicted smoking at the 6- and 15-month waves (ORs = 1.41–1.44, $ps < .05$).

Next, we fit a series of models at each wave in which this base model was expanded to include a particular antecedent condition and an antecedent $\times$ NDSS interaction. ORs and confidence intervals (CIs) associated with the interaction terms are presented in Table 2. Full results from these models are provided in Supplementary Table 1. Dependence level consistently moderated the effects of two antecedents: alcohol/drug use and the home location. At each wave, alcohol/drug use was more weakly related to smoking among individuals higher in tobacco dependence relative to those who scored lower (NDSS $\times$ alcohol/drug ORs = 0.36–0.62, $ps < .001$). Being at home was a stronger predictor of smoking behavior at higher levels of tobacco dependence (NDSS $\times$ home ORs = 1.26–1.61, $ps < .05$). These two diary measures were selected for further scrutiny in multiwave models. The odds of smoking in the morning were elevated among adolescents with higher levels of dependence at the baseline and 6-month waves (NDSS $\times$ morning ORs = 1.45 and 1.62, respectively, $ps < .05$) and marginally significant at the 24-month wave (OR = 1.42, $p = .074$). In multivariate models evaluating all antecedents and interactions simultaneously (Supplementary Table 2), results were very similar for alcohol/drug and home, but interactions involving the morning indicator were eclipsed. Although the total evidence for morning smoking was mixed, we elected to examine the morning variable in the multiwave model given the theoretical importance of morning smoking in tobacco dependence.

Multiwave Analyses

In a preliminary null two-level, random intercept multilevel regression analysis with NDSS score as the dependent measure, the intraclass correlation coefficient was .65. This indicates that 65% of the variation in tobacco dependence scores was attributable to between-person differences and 35% of the variation occurred at the within-person level. Next, a two-level growth model was estimated by including a centered time variable indexing follow-up months. In this model, the intercept was 1.89 ($t = 34.35$, $p < .001$), and the fixed effect for time was significant ($\hat{b} = 0.011$, $t = 4.33$, $p < .001$). This indicates a sample-wide trend toward growth in the NDSS, such that the mean NDSS score increased by 0.011 points per month, on average. Random effects variances were significant for both the intercept ($z = 8.86$, $p < .001$) and the slope of the wave–NDSS relation ($z = 4.50$, $p < .001$) indicating that the participants differed significantly from one another with respect to their mean levels and rates of change in tobacco dependence over the study period.

Table 2. Dependence × Antecedent Interaction Terms From Cross-Sectional Two-Level Generalized Linear Mixed Models Predicting Smoking (vs. Random Prompts) at Each Wave

Antecedent × NDSS	Assessment wave											
	Baseline			6 months			15 months			24 months		
	OR	95% CI	p value	OR	95% CI	p value	OR	95% CI	p value	OR	95% CI	p value
Alone	1.00	0.85, 1.19	.979	1.03	0.84, 1.27	.761	1.42	1.13, 1.77	.002	1.07	0.89, 1.29	.457
Weekend	0.96	0.80, 1.15	.631	0.96	0.77, 1.19	.717	0.85	0.67, 1.08	.176	0.87	0.71, 1.06	.172
Morning	1.45	1.09, 1.91	.010	1.62	1.06, 2.48	.026	1.43	0.76, 2.70	.264	1.42	0.97, 2.10	.074
Activities												
Hanging out	0.98	0.83, 1.16	.820	0.85	0.70, 1.03	.106	0.68	0.55, 0.84	<.001	0.85	0.70, 1.03	.100
TV/music	1.12	0.88, 1.42	.349	0.92	0.71, 1.18	.490	1.43	1.09, 1.89	.010	1.37	1.05, 1.79	.022
Game	1.43	0.93, 2.20	.106	0.76	0.49, 1.17	.208	0.94	0.61, 1.45	.772	0.83	0.50, 1.37	.465
In transit	1.16	0.84, 1.59	.371	1.18	0.83, 1.69	.358	1.04	0.76, 1.41	.818	0.87	0.68, 1.12	.286
School	0.81	0.60, 1.12	.210	0.57	0.39, 0.84	.004	0.99	0.56, 1.74	.960	0.71	0.49, 1.04	.079
Eat/drink	1.05	0.75, 1.47	.767	0.93	0.64, 1.34	.688	1.26	0.81, 1.95	.306	0.85	0.60, 1.18	.328
Rest/sleep	1.29	0.86, 1.93	.221	0.53	0.32, 0.88	.014	0.87	0.50, 1.53	.629	1.12	0.66, 1.90	.673
Alcohol/drug	0.47	0.36, 0.62	<.001	0.62	0.45, 0.86	.004	0.50	0.35, 0.72	<.001	0.36	0.26, 0.50	<.001
Nothing	1.03	0.79, 1.35	.831	1.10	0.79, 1.53	.571	1.22	0.81, 1.82	.342	0.98	0.73, 1.32	.881
Locations												
Home	1.40	1.18, 1.66	<.001	1.27	1.04, 1.55	.021	1.61	1.28, 2.02	<.001	1.46	1.20, 1.77	<.001
School	0.95	0.73, 1.24	.702	0.85	0.59, 1.22	.388	0.94	0.56, 1.56	.796	1.13	0.78, 1.64	.528
Friend's house	0.79	0.63, 1.00	.053	0.88	0.69, 1.13	.327	0.51	0.38, 0.68	<.001	0.85	0.63, 1.14	.276
Car	1.09	0.84, 1.41	.509	0.84	0.63, 1.12	.239	0.92	0.71, 1.20	.542	0.79	0.63, 0.98	.036
Outside public	0.79	0.60, 1.04	.097	1.34	0.92, 1.97	.127	1.18	0.77, 1.80	.446	0.40	0.27, 0.60	<.001
Affects												
Positive affect	1.01	0.97, 1.06	.579	0.99	0.94, 1.04	.758	0.97	0.91, 1.03	.301	0.98	0.93, 1.03	.394
Negative affect	0.95	0.92, 0.99	.011	1.03	0.98, 1.07	.248	1.01	0.96, 1.06	.767	1.01	0.96, 1.06	.788
Social isolation	0.94	0.90, 0.98	.002	0.97	0.93, 1.02	.279	1.02	0.96, 1.09	.440	1.00	0.95, 1.06	.947
Tired/bored	1.01	0.98, 1.05	.460	1.01	0.97, 1.06	.562	1.05	0.99, 1.10	.086	1.05	1.00, 1.10	.074
Nervous/embarrassed	0.94	0.90, 0.99	.008	1.00	0.95, 1.05	.843	1.03	0.97, 1.10	.313	1.00	0.95, 1.05	.945

Note. OR = odds ratio; CI = confidence interval; NDSS = Nicotine Dependence Syndrome Scale. Tabled effects are for the antecedent × NDSS interaction term. In each model, smoking records (vs. random prompts, the reference category) were predicted from age, the antecedent, NDSS score, and an antecedent × NDSS interaction. Significant effects are shown in boldface.

Table 3. Results From Three-Level Generalized Linear Mixed Model Predicting Smoking (vs. Random Prompts) Using All Waves of Ecological Momentary Assessment Data and Disaggregating Dependence Effects for Morning, Alcohol/Drug, and Home Antecedents

Predictor	<i>OR</i>	95% CI	<i>p</i> value
Age	1.06	0.98, 1.15	.175
NDSS, between	2.35	2.02, 2.72	<.001
NDSS, within	1.78	1.50, 2.12	<.001
Morning	0.66	0.38, 1.16	.147
Alcohol/drug	11.05	6.94, 17.61	<.001
Home	0.20	0.15, 0.27	<.001
Morning × NDSS between	1.50	1.20, 1.88	<.001
Alcohol/drug × NDSS between	0.53	0.44, 0.64	<.001
Home × NDSS between	1.44	1.28, 1.62	<.001
Morning × NDSS within	1.32	0.91, 1.91	.147
Alcohol/drug × NDSS within	0.85	0.57, 1.26	.412
Home × NDSS within	1.19	0.97, 1.45	.097

Note. *OR* = odds ratio; CI = confidence interval; NDSS = Nicotine Dependence Syndrome Scale.

In the null three-level, generalized linear mixed model with smoking (vs. random prompts) as the dependent measure, significant random effect variances were observed at the level of the wave ($z = 8.90$, $p < .001$) and the individual ($z = 7.61$, $p < .001$). This indicates that a three-level model structure is appropriate for predicting smoking events in the multiwave data.

Table 3 presents results from a three-level, multiwave generalized linear mixed model elaborated to include selected antecedents, NDSS score components, and interaction terms simultaneously. Higher NDSS scores at both the between- and within-person levels were associated with increased odds of smoking. Between-person variation in NDSS scores significantly moderated the effects of each of the selected antecedents on smoking. Interactions between antecedents and intraindividual variation in NDSS scores were each in the expected direction, but none was statistically significant.

DISCUSSION

A typical EMA study involves a single diary monitoring period lasting days or weeks. This design is powerful for examining the contextual correlates of smoking behavior. However, if we are interested in making inferences about how contextual determinants of smoking evolve with transitions in tobacco dependence, the conventional EMA design is limited. When only one bout of EMA assessments is available, it is not possible to determine the extent to which antecedent × dependence interactions reflect between-person effects (i.e., the kind of person who becomes dependent smokes in different contexts than the kind of person who merely experiments with cigarettes) or within-person effects (i.e., the contexts of smoking events change as tobacco dependence progresses). Disentangling these two interpretations requires longitudinal designs featuring multiple waves of EMA data collection and repeated assessments of tobacco dependence. This data structure permits the application of multilevel models evaluating how associations between momentary contexts and smoking are uniquely moderated by between- and within-person variation in tobacco dependence.

In single-wave analyses that conformed to the typical EMA design, we found consistent evidence for the moderation of two

smoking antecedents by tobacco dependence. Adolescents' smoking was strongly associated with alcohol/drug use overall. However, this association was less robust at higher levels of tobacco dependence. Being at home had a strong inhibitory effect on adolescents' smoking, possibly reflecting parental disapproval, home smoking prohibitions, or the absence of peer influences. At higher levels of dependence, however, the inhibitory effect of being at home was weaker. Less consistently, adolescents higher in dependence were found to have higher odds of smoking during the morning hours.

When we examined these effects simultaneously in a three-level model involving data from all four waves of assessment, we found limited support for the developmental inference that the stimulus conditions of smoking behavior change as tobacco dependence grows. Specifically, we observed a statistically marginal home × within-person NDSS effect. It is notable, however, that the *ORs* for the antecedent × within-person dependence interactions were all in the hypothesized direction.

More clear and consistent evidence emerged that the antecedents of smoking were moderated by between-person differences in tobacco dependence. This could hint that individuals who are prone to dependence start out their smoking careers with distinctive smoking patterns. These individuals may simply smoke more freely and regularly to being with. They may not require an initial "indulgent" smoking phase or have strong smoking prohibitions in the home. Another possibility is that more dependence-prone smokers progress through the early, "indulgent" pattern rapidly enough that it is not easily captured by EMA assessments that are not deliberately trained on the first lifetime smoking events. Other individuals, perhaps destined to be long-term intermittent smokers, might remain "fossilized" in this more stimulus-bound, instrumental smoking pattern (e.g., Shiffman & Paty, 2006). Longitudinal studies with repeated measures of tobacco dependence offer the opportunity to isolate between-person differences in tobacco dependence and study their early correlates more systematically. Both theory and intervention efforts might benefit from obtaining a better understanding of how between-person differences in youthful tobacco dependence are related to factors such as parental smoking, cigarette availability, home smoking restrictions, and smoking-related attitudes and motives.

To evaluate whether the effects seen here were attributable to some idiosyncrasy in the youth-specific NDSS, we conducted supplemental analyses using a seven-item modified Fagerström Tolerance Questionnaire (mFTQ; Prokhorov, Pallonen, Fava, Ding, & Niaura, 1996) that was administered along with the NDSS. This scale had reasonable internal consistency ($\alpha = .56-.69$) and correlated significantly with the NDSS ($r_s = .71-.78$, $p_s < .001$) at each wave in the analyzed sample. A multiwave three-level model parallel to the one conducted for the NDSS revealed significant interactions between all three antecedents and between-person variation in mFTQ scores (Supplementary Table 3). A significant alcohol/drug $\times$ within-person mFTQ interaction was also observed ($OR = 0.78$, 95% CI = 0.65–0.93, $p = .007$).

Although not the main focus of the analyses, the three-level models revealed that both between- and within-person variation in tobacco dependence, measured by either the NDSS or mFTQ, were significantly associated with smoking during arbitrary 1-week EMA monitoring periods (Table 3; Supplementary Table 3). The between-person effects replicate other EMA work (e.g., Beckham et al., 2008; Otsuki et al., 2008; Piasecki et al., 2011; Scharf, Dunbar, & Shiffman, 2008; Taylor & Cooper, 2010). The within-person findings demonstrate that, as an individual grows with respect to the underlying constructs tapped by tobacco dependence instruments, s/he is more likely to emit smoking behavior. This provides a novel and important form of validity data for the dependence scales used in this research.

Several limitations of this work should be considered. In this sample, young smokers were followed for 2 years. We found the majority of the variance in NDSS scores (65%) was attributable to between-person differences. Different findings might have emerged if participants had been followed longer and more within-person variation in dependence had been captured. It is possible that the temporal resolution of the EMA assessments was insufficient to sensitively detect within-person transitions in the setting events of smoking as dependence progresses. In very young light smokers, longer bouts of EMA assessment would be expected to capture more smoking events, perhaps allowing more reliable indices of smoking-antecedent associations at each wave. If some transitions happen very early in the smoking career, EMA assessments may need to be timed to capture the first series of lifetime cigarettes to capture the phenomenon. We used results from single-wave analyses to select antecedents for testing in multiwave models. It is possible that this strategy caused us to overlook antecedents that might have proved to interact with disaggregated components of dependence if they had been tested in multiwave analyses. The risk of this kind of oversight would be of particular concern if effects operated in countervailing fashion at different levels of analysis, thus potentially obscuring one another in single-wave analyses. This pattern seems unlikely in the case of tobacco dependence. Both the NDSS and mFTQ contain items related to morning smoking, complicating interpretation of findings from models involving the morning antecedent. We used a generalized linear mixed modeling framework that estimated individual-specific ORs. Results could differ using a population-averaged modeling approach, which tend to produce ORs that are smaller in magnitude (Neuhaus, Kalbfleisch, & Hauck, 1991). The models assume linear effects of predictors on log odds of smoking. In exploratory analyses, we found inconsistent evidence for curvilinear associations between particular mood states and smoking behavior. Adding these effects to the final

three-level model did not change any substantive conclusions. Nonetheless, undetected violations of the linearity assumption could remain. Some theoretically important antecedents, such as craving, were not assessed in these early waves, but are included in subsequent EMA waves beyond 2 years and will be examined in future work. Finally, idiographic analyses assessing the accuracy with which an individual's smoking can be predicted from the all measured antecedents in a multivariate model could yield complementary insights. Such a multivariate approach integrates over idiosyncrasies in smoking triggers to yield a comprehensive estimate of the degree to which smoking is stimulus-driven for each individual (Shiffman & Paty, 2006).

The high school years are a dynamic developmental phase, with social, emotional, and cognitive changes occurring among adolescents. Changes in smoking behavior occur within the context of multiple contextual and developmental changes for these youth, and no one contextual domain can completely explain these shifts in behavior. This study provides one of the few reports that examine the immediate proximal context of an adolescent's smoking and how these immediate situational antecedents are associated with changes in smoking and dependence. Some of these contexts are specific to the developmental high school period and reflect constraints and opportunities during adolescence, and as such may not generalize to other age groups. However, they provide a valuable window into characterizing changes in smoking and related contexts during the key period of adolescence when most smokers first experiment with cigarettes.

An important goal for tobacco research is to better understand how aspects of smoking behavior change across the transition to tobacco dependence. EMA represents a powerful tool for such research, but the strongest inferences will be obtained from studies featuring multiple waves of EMA assessment and spanning sufficient time for meaningful growth and change in tobacco dependence. Using this approach, this study found limited support for the speculation that the antecedents of smoking shift as dependence progresses. The findings also highlight the importance of between-person variation in dependence as a moderator of smoking pattern. Young people who are liable to tobacco dependence might choose to smoke under distinctive conditions from very early in their smoking careers.

SUPPLEMENTARY MATERIAL

Supplementary Tables 1–3 can be found online at <http://www.ntr.oxfordjournals.org>.

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DECLARATION OF INTERESTS

None declared.

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