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The Dynamic Role of Urban Neighborhood Effects in a Text-Messaging Adolescent Smoking Intervention

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Abstract

Introduction: Neighborhood features such as the density of tobacco outlets relative to one's home and evaluations of safety of one's activity space (routine locations), are known to influence health behaviors. Understanding the time-varying nature of these aspects of the urban ecology provides unique insights into the dynamic interactions of individuals and their environments.

Methods: The present study tested the time-varying effects of tobacco outlets and perceived safety within a randomized controlled trial of an adolescent text-messaging smoking intervention. We used ecological momentary assessment data (EMA) from an automated text-messaging smoking cessation randomized trial with 197 primarily African American urban adolescents. We employed a time-varying effect model to estimate the effects of density of tobacco outlets within one-half mile of participants' home locations (time-invariant covariate) and evaluations of safety of their activity space (time-varying covariate) on momentary smoking over 6 months by treatment condition. The time-varying effect model approach models behavioral change and associations of coefficients expressed dynamically and graphically represented as smooth functions of time.

Results: Differences in trajectories of smoking between treatment conditions were apparent over the course of the study. During months 2 and 6, the association between tobacco outlet density and smoking was significantly stronger in the control condition, suggesting treatment dampens this association during these time periods. The intervention also significantly reduced the association of perceived safety and smoking among the treatment condition during months 3 through 6.

Conclusions: Results support testing the time-varying effects of urban ecological features and perceptions of safety among adolescents in text-based smoking cessation interventions.

Implications: This study makes a unique contribution towards understanding the time-varying effects of urban neighborhoods on adolescent tobacco use within the context of a text-delivered intervention. Helping to adjust the long-held conceptualization of intervention effects as a static outcome, to that of a dynamic, time-varying process, is an important contribution of this study. The ability to specify when behavioral change occurs within the context of a randomized control trial provides understanding into the time-varying treatment effects of text-based smoking intervention. For example, researchers can modify the intervention to have strategically timed booster sessions that align with when the odds of smoking begin to increase in order to provide more precise treatment. The current study results show that increasing support to participants during months 2 and 4 may help suppress smoking over the course of a 6-month intervention.

Introduction

Cigarette smoking remains one of the foremost public health concerns in the United States and worldwide.[1] Tobacco use among adolescents is of particular concern, as age of initiation of smoking has been shown to be an important predictor of adult cigarette smoking,[2] with consequent negative health outcomes over the life course. Among racial/ethnic groups, African Americans are at elevated risk for smoking related illness and deaths including cancer.[3,4] Specific to youth, African American high school seniors' past 30-day cigarette use has increased recently from 8.6% to 9.6%.[5] Cigar smoking among African American teens is also on the rise with 16.7% of African American teens smoking cigars—more than twice the 2009 rate.[6] Many factors contribute to the uptake and continuation of tobacco use among urban youth. The present study examines two factors in longitudinal detail: (1) the density of tobacco outlets relative to an adolescent's home and (2) their perceptions of safety within their activity space (routine locations).

Tobacco Outlet Density

A recent review reveals that exposure to tobacco retail outlets is consistently correlated with cigarette use,[7] which may be seen to act not only through providing access to tobacco but also through advertising in the form of banners and posters, as well as promotions and other marketing materials.[8] Regular exposure to tobacco sales and advertising in stores that sell cigarettes, such as convenience stores, drug stores, and gas stations, nearby one's home can reduce the stigma of smoking by normalizing cigarette use and initiate smoking by glamorizing cigarettes.[9]

A number of studies have demonstrated an association between the density of tobacco retail outlets nearby both schools and residences and smoking among youth. In an analysis of middle and high school students in Illinois, Adams et al.[10] found that tobacco retail density around schools was associated with higher rates of smoking experimentation and initiation. Tobacco retail density nearby one's home was also found to be positively associated with smoking frequency in a study of youth residing in California,[11] while Novak et al.[12] found that youth living in Census tracts with a higher concentration of tobacco retailers had a higher likelihood of cigarette smoking.

Urban youth may be particularly vulnerable to exposure to tobacco outlets because of the concentration of commercial activity, including tobacco sales in close proximity to residential neighborhoods in urban areas, thus facilitating regular exposure to tobacco retailers among urban youth. Notably, African American youth are disproportionally concentrated in the inner city of many US metropolitan areas, and thus may be particularly prone to the negative influences of exposure to tobacco retail outlets.

Perceived Safety

Beyond the concentration of tobacco outlets that are prominent in many low-resource urban areas, is the constant demand for residents to be vigilant against community violence. Thus, perceptions of safety serve as an important touchstone toward understanding urban adolescents' experience of their unique social ecology. Community level research has documented the positive relationship between self-reported community violence exposure and substance use among adolescents (eg, Lee[13]; Winstanley et al.[14]; Zinzow et al.[15]). Limited research exists that examines perceptions of safety and the association with tobacco use. Perceptions of neighborhood safety have been shown to partially mediate the influence of neighborhood disorder on tobacco use among European adults.[16] Among African American adults, lower levels of safety and trust in the neighborhood have been related to increased odds of current smoking,[17] while higher levels of neighborhood vigilance, or perceptions of threat and unsafe conditions, were related to tobacco dependence.[18] Lambert and colleagues[19] found that neighborhood disorganization (violence/safety and drug activity) was related to tobacco use 2 years later. In the present study, we extend Winstanley and colleagues'[14] argument that capturing adolescents' subjective ratings of their environment is crucial to preventing adolescent substance use, and suggest that measuring safety in real-time using ecological momentary assessment (EMA) methods can better inform interventions aimed at tobacco use among teens. While interventions don't change the features of neighborhoods, a method that integrates place and thus safety, into an intervention's approach is likely to increase external validity of treatment effects, particularly for urban residents.

Time-Varying Effect Modeling

A statistical approach that allows for the testing of real-time data and the dynamic associations that unfold over time, is time-varying effect modeling (TVEM). TVEM models behavioral change as coefficients which are expressed dynamically and are graphically represented as smooth functions of time.[20] TVEM is exceptionally well suited for capturing complex change in momentary associations, such as those measured using EMA. This approach does not assume that levels or outcomes or effects of covariates change as a parametric function of time; rather, the direction and potency of coefficients can be estimated as a flexible function of time using EMA that varies across individuals in timing and spacing of observations.[21] The basic assumption of TVEM is that the time varying coefficient functions vary smoothly over time.[22] The recent developments of a SAS macro suite, %TVEM[23] allows for fitting models with time-varying effects (see Shiyko et al.[24] for details).

Randomized Controlled Trial Results of Original Study

The current study is a secondary analysis of data from our text-delivered randomized control trial of a Motivational Interviewing-based peer network counseling tobacco cessation intervention.[25] We summarize the trial findings to provide a context for interpreting the current study. We recruited 200 current smoking adolescents (90.5% African American) between the ages of 14–18 in Richmond, Virginia area from May 2013 to August 2014 from a community adolescent substance abuse facility (66%), public health clinics (21%), university medical center pediatric clinics (10%), and dorms and high schools (3%) using in-person recruitment and flyers. Adolescents were screened with the Modified Version of the Fagerström Tolerance Questionnaire,[26] a screening measure that assesses the level of nicotine dependence. Screening scores of 1 were used as a cutoff score to include adolescents with potential tobacco use problems, as well as those with moderate to severe dependence levels. Participants were randomized into an automated texting intervention where they received either the experimental intervention of 30 personalized motivational interviewing-based peer network counseling messages, or the attention control intervention, consisting of text messages covering general (nonsmoking related) health habits. The intervention lasted 5 days.

All adolescents were provided smart phones for the study and were assessed at baseline, and at 1, 3, and 6 months post intervention. Participants received a text message with an embedded URL (webpage link) where upon clicking, they were directed to the secure web-based survey. The pertinent baseline survey information (smoking behavior) was automatically abstracted from the study database and was included in the personalized text conversation for each subject. This personalized baseline information (including name of teen, smoking behavior and frequency, peer smoking behaviors, readiness to quit, and values and goals), along with text messaging responses from each subject throughout the duration of the 5-day intervention, was used to automatically populate tailored messages during each text-to-subject interaction. We obtained effect sizes using Partial η^2 statistic which are interpreted as 0.01 = small, 0.06 = medium, and 0.14 = large. At 6 months the adolescents in the experimental condition decreased the number of cigarettes smoked per day ($P < .01$; $\eta^2 = 0.17$), increased intentions not to smoke in the future ($P < .05$; $\eta^2 = 0.14$), and increased peer social support ($P < .05$; $\eta^2 = 0.13$).[25]

Current Study

Based on these positive outcomes we examined adolescent momentary smoking (as captured via EMA) within the context of a text-messaging delivered tobacco cessation intervention. The purpose of the current study was to examine if and when smoking was significantly reduced in adolescents in the treatment condition, and to understand the effects of safety and tobacco outlet density on smoking over the course of the 6-month intervention. Specifically, we employed TVEM to estimate the time-varying effects of safety (a time-varying covariate) and tobacco outlet density (time-invariant covariate) on craving over 6 months by treatment condition. Our first model tested the intercept function (ie, time-varying odds ratio of momentary smoking) by treatment group, with no covariates. Our second model tested the hypothesis that the treatment would change the relationship between tobacco outlet density and smoking over time, such that the effect of tobacco outlet density on smoking would be reduced with time in the experimental group relative to control. Our third model tested the hypothesis that the time-varying effect of safety on smoking will differ by experimental condition, such that in time the experimental treatment will weaken the association between safety and smoking relative to the control condition.

Methods

Procedures

Recruitment procedures were described in the Randomized Controlled Trial Results of Original Study section above and will not be repeated here. Inclusion criteria were being between the ages of 14 and 18 and scoring above a cut-point on the Modified Version of the Fagerstrom Tolerance Questionnaire.[26] For all participants younger than 18, consent was obtained from the parent or legal guardian, as well as assent from the teen; consent was obtained from all participants aged 18. Participants were recruited from a convenience sampling framework and then randomized into experimental conditions. Following screening and informed consent, adolescents were randomized into either the treatment or control group. Randomization was completed using a random number table and blocked randomization to create equal numbers allocated to treatment and control groups. Participants completed surveys at baseline, 1, 3, and 6 months post-intervention. Participants also completed EMA surveys monthly (see EMA procedures section below for details). All study procedures were approved by the first author's Institutional Review Board office.

Smart Phones and Application of Automated Program

All participants were given a smart phone for the duration of the study with unlimited texting, internet access, and limited voice minutes. Participants were trained during enrollment on responding to the text messages that would be delivered during the week-long intervention and answering web-based follow-up surveys on their phones. Parental monitor controls were made available for all families. These controls allowed parents to limit teens' internet access, but parents were not able to monitor or interrupt the content of teens' messages. Upon enrollment, subjects completed the baseline survey covering smoking and peer network characteristics through a secure, web-based data collection and database management application called Research Electronic Data Capture (REDCap[27]).

EMA Procedures

Every month for 6 months, participants received EMA surveys on their study phones beginning on Thursday through Sunday, with three EMAs per day for a total of 12 per month. Participants could complete up to 72 EMA surveys over 6 months. This time parameter allowed for the capturing of both weekday and weekend EMA surveys, thereby providing a more representative characterization of adolescents' lives. EMA surveys were sent in the late afternoon on weekdays so as to not conflict with school. Participants received an automated text message (preprogramed conditioned on their baseline enrollment date) with an embedded URL which, upon clicking, the web-based, brief EMA survey was launched. Twelve items covering participant activities, moods, friends' behaviors, cravings, and readiness to stop smoking were included. Each survey took less than 60 seconds to complete. Participants were given an 8-minute time window in which to complete each survey, with an additional 1-minute grace period, before a survey was marked as "missed." At the 7-minute mark, a reminder text message was sent to any participant who had not yet completed the current survey. The gathered data included the EMA survey responses along with timestamps noting when each survey was sent and finished. Survey data submitted beyond the designated time window was still gathered, with timestamps used to differentiate out-of-window data as needed. Please see the Supplementary Material for the actual EMA items used in this study.

Measures

"Nicotine Dependency" was measured with the Modified Version of the Fagerström Tolerance Questionnaire (FTQ[28]) to screen adolescents on tobacco use and potential dependence. A total score was obtained from summing raw scores from seven items producing a range of scores from 0 to 9. As noted above, cut-scores of 1 and above were used for inclusion into the study.

"Momentary Safety" was measured using the EMA item, "How SAFE are you now?" encoded as 1 = not safe, 2 = slightly safe, 3 = average safe, 4 = fairly safe, 5 = very safe.

"Tobacco Density" variable was created in two steps. First, all 200 subjects' home addresses were geocoded successfully; however, three subjects' homes were located outside the 17 counties and cities of the greater Richmond, Virginia region and were therefore removed from the analysis, leaving 197 subjects in the study. We used ArcGIS 10.1 and Business Analyst Geographic Information System (GIS) software (Environmental Systems Research Institute, Inc) for spatial data processing, including geocoding. Second, we followed the methods of Cantrell et al.[9] and other researchers, using the North American Industry Classification System codes to identify businesses most likely to sell tobacco within the study region. The US Office of Management and Budget created the North American Industry Classification System for the collection and dissemination of business data by federal agencies. We acquired geocoded business information for all grocery stores, convenience stores, gas stations, drug stores and pharmacies, and liquor stores using Dun and Bradstreet business listings as provided through Environmental Systems Research Institute, Inc, Business Analyst software. Duplicate business listings with identical addresses were removed, leaving 1251 tobacco retail outlets in the study region. Using the ArcGIS 10.1 and Network Analyst extension we calculated a half mile service area around each subject's home address, that is, an area extending a half mile along the street network outwards from each subject's home. Using a spatial join operation, we calculated the number of tobacco retail outlets within the half mile service area of each subject's home, encoded in the subject-level variable Tobacco Density.

"Momentary Smoking" was measured using the EMA item, "What are you doing right now?" encoded as 0 = not smoking cigarettes, cigars, cigarillos, little cigars, or black & milds, 1= smoking cigarettes, cigars, cigarillos, little cigars, or black & milds.

"Demographic data" were captured on participant age, gender, race and ethnicity.

Analytic Approach

TVEM models were estimated separately for treatment and control conditions to depict the effects of treatment condition on the dynamic processes across 6 months. Age, gender, and baseline nicotine dependence level were included as covariates, safety and tobacco density were the predictor variables, and smoking was the outcome variable. Race and ethnicity were not included in the models as the sample was 90.5% African American. For the current study, our analysis is based on 197 participants who completed the intervention and the follow-up assessments over 6 months. This resulted in a total of 11 996 assessments. This model was run in SAS using the %TVEM_logistic macro, version 2.1.1.[29] For both treatment conditions, the following equation was specified for predicting the odds of smoking from the time-varying covariate safety (S) and tobacco density (T), controlling for age, (A) gender, (G) and baseline nicotine dependence level (N), during the 6-month study period:

$$\ln\left(\frac{p_{ij}}{1-p_{ij}}\right) = \beta_0(t) + \beta_1(t)\ \mathrm{S}_{ij} + \beta_2(t)\ \mathrm{T}_i + \beta_3\mathrm{A}_i + \beta_4\mathrm{G}_i + \beta_5\mathrm{N}_i + \varepsilon_{ij}$$

In this model, β_0 (t) represents the odds of smoking over time when all other predictors are 0 (ie, female from control group with average scores on baseline dependence, safety, and tobacco outlet density). Similarly, β_1 (t) is a nonparametric coefficient function describing the time-varying association between safety and smoking, and β_2 (t) is a nonparametric coefficient function describing the time-varying association between tobacco density and smoking. Effects of age, gender, and baseline nicotine dependence level were specified as time-invariant.

The data were in long format, so that each record contained one EMA survey for one participant, and each participant had multiple rows of EMA surveys. A time variable was created, representing the time at which a given EMA occurred (ie, t_{ij}), coded 1 to 72, with times 1 to 12 falling within month 1, 13 to 24 falling within month 2, and so on. The x-axis on our graphs display 12 EMA surveys per month for 6 months, totaling 72 EMA surveys or discreet time points. Safety and tobacco density were mean centered to facilitate interpretation. In order to enable the statistical program to calculate the intercept function, we created a variable that was coded 1 for every record. Our assessment plan randomly selected times for each participant, creating a nearly continuous time scale, allowing our data structure to meet the assumption of smooth time variation.[22] The SAS software 9.4 and the SAS macro %TVEM_logistic was used to estimate the model. We utilized the P-spline basis function as recommended by Lanza and colleagues,[20,21] where the %TVEM macro automatically selects the number of knots in order to control for model complexity for coefficient functions by a maximum likelihood approach.[22] The macro as well as detailed technical information is available free for download at http://methodology.psu.edu.

Results

Table 1 presents descriptive statistics for all variables in the study, divided by experimental condition. The sample is primarily African American (91%), just over half female, and 16 years old on average. Baseline nicotine dependence mean scores for both conditions indicated that the sample was moderately dependent on nicotine. Both conditions reported feeling fairly safe and each condition had three tobacco outlets within one half mile of their homes. The sample reported momentary smoking 12% (treatment group) and 14% (control group) of the time when queried using EMA after the intervention.

Table 1. Descriptive Statistics of Study Variables n = 197

	Treatment	Control
	%, Mean (*SD*)	%, Mean (*SD*)
Gender (female) %	54.3	55.2
Race/ethnicity %		
African American	91.1	91.4
White	8.1	4.1
Other	0.8	4.5
Age	16.3 (1.4)	16.2 (1.3)
Tobacco outlet density[a]	3.1 (2.8)	3.5 (2.6)
Safety	4.3 (1.2)	4.1 (1.3)
Fagerström Dependence Score	4.5 (2.3)	4.3 (2.2)
Momentary smoking, (yes) %	12	14

[a]Density = number of tobacco outlets within 0.5 mile from participant's home.

Figure 1 presents the intercept functions separately, with no covariates, for the treatment group (black lines) and the control group (gray lines), along with corresponding 95% confidence intervals. The solid curves represent the odds ratios of momentary smoking across the 6 months of the study. If a confidence interval is above 1, the odds of smoking are increased. Similarly, a confidence interval below 1 is interpreted as decreased odds of smoking. Given that all confidence intervals are below 1, there are decreased odds of smoking among adolescents with average safety evaluations and tobacco density for both treatment and control groups throughout the study period. Additionally, if at any point in time the confidence intervals of each group do not overlap, smoking is significantly different between the treatment and control groups at that specific point in time. Overall, there is a large suppression of momentary smoking for individuals with average tobacco density and perceptions of safety (ie, for individuals with values of 0 on all covariates). Figure 1 shows a slight separation occurring (non-overlapping lines) at months 2 and 3, indicating a significant difference between group odds ratios of smoking for individuals with average tobacco density and perceptions of safety.

Figure 2 shows the time-varying association between tobacco outlet density and smoking by treatment condition. It is helpful to consider that any point in time, the level on the curves represent that time-specific association between the covariate and smoking.[20] At all time points in the study, the treatment group had reduced odds to smoke while the control group had increased odds to smoke during months 1 and 2, and during months 5 and 6. Figure 2 shows a slight separation between confidence intervals during month 2 and then again at month 6, indicating the association between tobacco density and smoking was significantly different between groups. This suggests that the treatment significantly suppressed the relationship between tobacco density and smoking during these two time points in the study. The trajectories for both groups at month 6 appear to be diverging, possibly indicating a delayed treatment effect. We conclude that the influence of high tobacco density on smoking is mitigated to some degree by the text-based intervention.

Figure 3 illustrates the time-varying association between perceptions of safety and smoking, showing distinct curves between groups, with the treatment group consistently decreasing the odds of smoking over the course of the study. At month 3 noticeable separation between the groups appears and continues until month 6, with the control condition increasing the risk of smoking while the treatment group smoking curve slopes downward, reducing the risk for smoking. We conclude that the text-based intervention reduced the association between perceived safety and smoking for about one half of the study period among the treatment condition relative to controls.

Discussion

This study makes a unique contribution towards understanding the time-varying effects of urban neighborhoods on adolescent tobacco use within the context of a text-delivered intervention. Helping to adjust the long-held conceptualization of intervention effects as a static outcome, to that of a dynamic, time-varying process, is an important contribution of this study.

Consistent with our first hypothesis, we found that the intervention weakened the association between tobacco density and smoking for the treatment condition relative to the controls. We attribute this finding to the intervention's focus on peers and place (see Mason et al.[25]) where adolescents in the treatment condition interacted within personalized text-conversations that provided feedback about their smoking, close peer smoking, and locations of these behaviors. Treatment participants were encouraged to consider with whom they were spending their time and where they frequented. Participants are supported to reflect on their peer networks and to consider modifying their behavior in relation to peers, for example, spending slightly less time in known smoking settings in order to reduce the likelihood of smoking. This interpretation is based upon findings from our text-based intervention which demonstrated a reduction of close peers' daily smoking.[24] Possible treatment mechanism interpretations could be: (1) treatment teens are spending more time in locations that restrict smoking, (2) treatment teens are altering their close peer network, that is, reducing the number of smoking peers, (3) their close peers have begun reducing their smoking, indicative of a positive peer contagion effect, or (4) some combination of these. Future research should collect detailed peer network data to address these complex questions involving neighborhoods, peers, and health behavior. This finding underscores the utility of

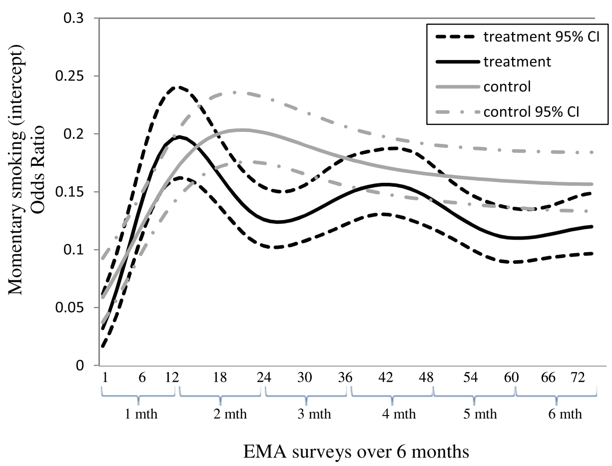

Figure 1. Intercept function showing odds ratios of momentary smoking during 6-month study by treatment condition.

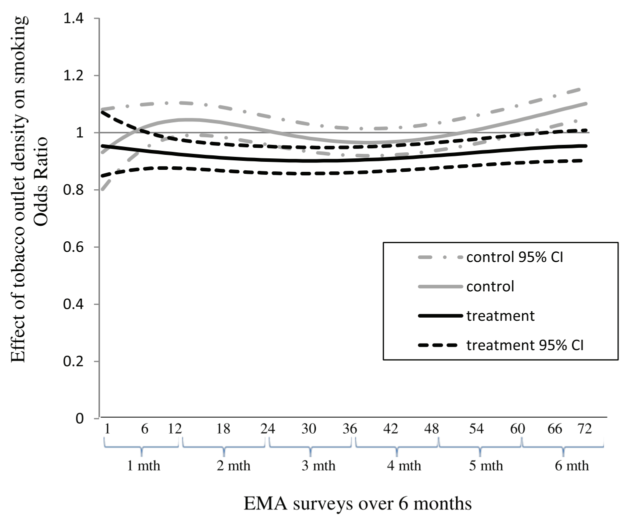

Figure 2. Time-varying effect of tobacco outlet density[a] on momentary smoking by treatment condition. [a]Density = tobacco outlets within 0.5 mile from participant's home.

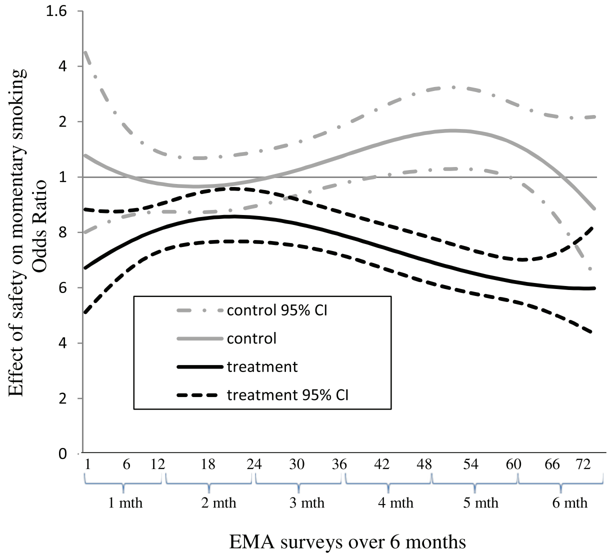

Figure 3. Time-varying effect of safety on momentary smoking by treatment condition.

incorporating a place-based peer network approach into interventions that target urban youth.

Our third model tested the hypothesis that the experimental treatment would weaken the association between safety and smoking relative to the control condition. A plausible interpretation is that adolescents in the treatment group may have become more aware of their risk-enhancing environmental surroundings, thereby reducing the likelihood of smoking. Treatment may have increased their awareness of the quality of safety within their activity space or routine locations. This interpretation is based on our earlier work where non-substance using adolescents were significantly more aware of their risky environments compared to their substance using counterparts. Non-substance users more accurately attributed locations as risky that were objectively measured (criminal activity) compared to substance users.[30,31]

Results from this study should be interpreted in light of the following study limitations. We used self-report measures for the entire assessment battery. Obtaining biological specimens may increase confidence in these results. However, the validity of self-reported tobacco use among adolescents is very high, and higher than other health-risk behaviors, thus providing reasonable confidence in our results.[32] Next, our sample was limited to urban, primarily African American adolescents, therefore the generalizability to other groups is limited. However, this is also a strength of this study, providing more randomized controlled trials to underserved populations, such as African American adolescents. In addition, we have not accounted for neighborhood effects in our models, which may emerge due to unaccounted for neighborhood-level mechanisms of smoking or through behavioral contagion among study participants. Common approaches for handling neighborhood effects include spatial fixed, random (ie, multi-level), or mixed effects models,[33] as well as spatial econometric models that incorporate spatial autocorrelation explicitly as an explanatory variable or into the error term,[34] though we are not aware of any studies integrating these approaches within the TVEM modeling framework. We note that due to the randomized allocation procedure whereby subjects are assigned to experimental and control groups we would not expect significant differences in neighborhood or spatial clustering characteristics between the two groups. Finally, because the current study contained gaps between each monthly EMA period, the time-varying coefficient functions presented here may smooth over differences between months. Because of these data gaps, interpretation of results need to be tempered. However, as the EMA surveys were distributed three times per day across both weekdays and weekends, we have guarded confidence in these data being representative. Future research would benefit from designs that capture intervention effects on craving more continuously.

In all, these results provide new insights into the time-varying nature of urban neighborhood effects such as tobacco density and safety. The ability to specify when behavioral change occurs within the context of a randomized control trial provides understanding into the time-varying treatment effects of text-based smoking intervention. The application of TVEM allows researchers to leverage the unique data arising from EMA methods, particularly with increased use of smart phones, and specify models to address questions regarding time variance. This study also made a contribution in providing a model for incorporating salient neighborhood effects into randomized controlled trials, thereby allowing researchers to include ecological features into state of the art analytic models. Understanding the unique differences of intervention effects with particular groups provides guidance toward developing and testing personalized and adaptive interventions.

Supplementary Material

Supplementary Material can be found online at http://www.ntr.oxfordjournals.org

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Declaration of Interests

The authors declare that they have no conflict of interest. The manuscript was not reviewed or edited by the sponsor. The manuscript is not under review by another publication.

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