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Time-Varying Effects of a Text-based Smoking Cessation Intervention for Urban Adolescents

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Abstract

Introduction—Craving to smoke is understood as an important mechanism for continued smoking behavior. Identifying how smoking interventions operate on craving with particular populations is critical for advancing intervention science. This study's objective was to investigate the time-varying effect of a text-delivered smoking cessation intervention.

Methods—Toward this end, we used ecological momentary assessment (EMA) data collected from a five-day, automated text-messaging smoking cessation randomized clinical trial with 200 urban adolescents. We employed a time-varying effect model (TVEM) to estimate the effects of stress (time-varying covariate) and baseline nicotine dependence level (time-invariant covariate) on craving over six months by treatment condition. The TVEM approach models behavioral

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Conflict of interest

All authors declare that they have no conflicts of interest.

Contributors

Michael Mason conceptualized the study and conducted the statistical analysis. Thomas Way developed the computer program to enable the texting program. Jeremy Mennis assisted in writing the methods. Stephanie Lanza and Michael Russell were the expert statisticians, with particular focus on the TVEM data analysis. Nikola Zaharakis assisted in writing the paper and providing references and APA style oversight.

change and associations of coefficients expressed dynamically and graphically represented as smooth functions of time.

Results—Controlling for gender, age, and current smoking, differences in trajectories of craving between intervention and control conditions were apparent over the course of the study. During months 2 to 3, the association between stress and craving was significantly stronger among the control group, suggesting treatment dampens this association during this time period. The intervention also reduced the salience of baseline dependence among treatment adolescents, with craving being reduced steadily over time, while the control group increased craving over time.

Conclusions—These results provide insight into the time-varying nature of treatment effects for adolescents receiving a text-based smoking cessation intervention. The ability to specify when in the course of an intervention the effect is strongest is important in developing targeted and adaptive interventions that can adjust strategically with time.

Keywords

text-based smoking intervention; time varying effect model; urban adolescents

1. INTRODUCTION

Understanding interventions focused on tobacco use prevention and cessation among adolescents offers the possibility of preventing adverse health outcomes in adulthood. The earlier a person starts smoking, the more likely he or she is to become an adult smoker (Yu et al., 2012; DHHS, 2012), with 90% of adult smokers reporting that they began smoking prior to age 18 (CDC, 2013). Among racial/ethnic groups, African Americans are at elevated risk for smoking related illness and deaths including cancer (CDC, 2014; National Cancer Institute, 2008). From 2012 to 2014, African American high school seniors' past 30 day cigarette use has increased from 8.6% to 9.6% while White and Hispanic seniors have reduced their use during the same time period (Johnston et al., 2015). 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 (CDC, 2013). Consequently, developing smoking cessation and reduction aids that are available to, and effective for, African American youth is crucial for improving public health and reducing health disparities.

Craving is understood as an important mechanism for continued smoking behavior, and thus needs to be more thoroughly examined (Wray et al., 2013). Identifying how particular smoking interventions operate on craving with particular populations is critical for advancing intervention science. Less is known about adolescent craving within the context of randomized clinical trials as compared with adults, with limited research supporting the linkage between craving scores and cigarettes smoked per day (Bagot et al., 2007). Variations in measurement may play a role in understanding craving and smoking behavior. In a recent review of craving, Wray and colleagues (2013) found support for the statistical use of continuous data in explicating the relationship between predictor variables such as craving and treatment outcomes. While adolescents also experience craving, which has been linked to negative cessation treatment outcomes (Upadhyaya et al., 2004), the connection between adolescent craving and smoking cessation has not been thoroughly researched.

Thus, the need exists to better understand the time-varying effects of treatment on craving and its correlates for adolescent smokers.

Closely related to craving is the perception of stress and how these are linked to smoking uptake. These constructs are closely interconnected, where increased levels of perceived stress have been found to activate craving, which then leads to increased smoking (Shiffman et al., 1997). Stress can serve as a trigger of smoking behavior in that smokers use tobacco to reduce tension associated with stress. For example, as many as 50% of smokers indicate that stress contributes to a smoking lapse (Kotlyar et al., 2011). In particular, higher levels of psychosocial stress have been linked with greater odds of continued smoking over the course of a decade in a national cohort of US adults (Slopen et al., 2013). Research has shown that craving is in part, a product of decreased self-efficacy related to the social skills necessary to cope with social stress (Niaura et al., 2002). For adolescents with decreased self-efficacy, interacting with peers may increase perceived stress due to social skills deficit (Myers and Macpherson, 2009). In contrast, social support can serve as a buffer to social stress and has been implicated in reducing relapse in smoking cessation trials (Creswell et al., 2015). Understanding the role of stress on craving within the context of a smoking cessation trial is important for the refinement of interventions. Identifying when stress plays the biggest role in activating craving could provide specific time-windows within an intervention that then could be leveraged for better outcomes.

The growth of mobile technology has begun to offer behavioral health researchers new tools with which to develop novel interventions. Mobile phone-based interventions that are evidence-based, are a recommended approach toward substance use prevention (Abrams et al., 2014; CDC, 2011a; Whittaker et al., 2012). Evidence-based, text-delivered interventions address critical gaps in human-delivered intervention approaches. Text-delivered interventions provide anonymity, in that these can be delivered directly to individuals thereby forgoing the need to come to a provider's office. Text interventions can be delivered any time, allowing for convenient and personalized intervention, and are delivered with 100% fidelity in that there is no drifting from the intervention protocol and no therapist effects to control for. The ubiquitous nature of texting across racial, socioeconomic, and demographic subgroups holds promise to reach underserved populations. Recent research reveals that African Americans utilize texting more than whites, and individuals with lower levels of education and income text more often compared to those with more education and income (Lenhart, 2012).

As evidence grows for the efficacy of text-based behavioral interventions (CDC, 2011b; Cunningham et al., 2011; Mason et al., 2015; Newman et al., 2011), there is a growing need to understand the dynamic mechanisms of change through new analytic approaches. For example, the utilization of mobile technology is capable of producing large, densely packed data sets within clinical trials. Mobile data assessment approaches have allowed researchers to capture these data in real-time such as what is derived from ecological momentary assessment (EMA) methods. EMA methods collect concurrent data within participants' natural settings, using repeated measurements of momentary states and behaviors which characterize participants' real-world experiences over a given period of time (Shiffman, 2007). Allowing research participants to answer questions about their smoking, craving,

stress, etc., with the clause "...right now" decreases recall bias (Shiffman, 2009a) as well as producing a more realistic picture of the individual's experience within the study, the ebbs and flows of moods, cravings, and behaviors.

An important issue to consider when employing EMA methods is that of reactivity, the possible influence that EMA may have on the particular behavior under study, thereby potentially biasing results. EMA methods would appear to be particularly vulnerable to reactivity as assessments are completed repeatedly, in close proximity to the behavior under study, increasing the chance to affect results (Shiffman, 2009b). However, there are studies that have examined EMA reactivity within smoking cessation trials and have found minimal to no behavioral changes due to EMA (Shiffman et al., 2002; Rowan et al., 2007). In a recent study designed to test EMA reactivity within a smoking cessation trial using randomly assigned EMA frequency conditions, researchers found that EMA frequency was unrelated to cessation or prolonged abstinence (McCarthy et al., 2015). Given these findings, it is reasonable to assume that EMA is an appropriate measurement method, particularly for smoking cessation clinical trials.

A new 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 (Lanza et al., 2014b). 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 (Lanza et al., 2014a). The recent developments of a SAS macro suite, %TVEM (Li, Tan et al., 2014) allows for fitting models with time-varying effects (see Shiyko et al., 2012 for details).

1.1 Randomized Controlled Trial Results of Original Study

The current study is a secondary analysis of data from our text-delivered randomized control trial of an adapted Motivational Interviewing-based peer network counseling substance use intervention (Mason et al., 2011). 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 the 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 (Prokhorov et al., 1996), 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 (non-smoking

related) health habits. The intervention lasted five days targeting urban adolescents. Our intervention followed the U.S. Department of Health and Human Services Clinical Practice Guidelines (Fiore et al., 2008), that recommend brief smoking cessation interventions, and specify adolescents and individuals with low-socioeconomic status as groups to be targeted for cessation interventions.

All adolescents were provided smartphones for the study and were assessed at baseline, and at one, three, and six 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 1-week intervention, was used to automatically populate tailored messages during each text-to-subject interaction. At six months the adolescents in the experimental condition decreased the number of cigarettes smoked per day ($p < 0.01$; $\eta^2 = 0.17$), increased intentions not to smoke in the future ($p < 0.05$; $\eta^2 = 0.14$), and increased peer social support ($p < 0.05$; $\eta^2 = 0.13$) (Mason et al., in press).

1.2 Current Study

Based on these positive outcomes we examined adolescent craving within the context of a text-messaging delivered tobacco cessation intervention. The purpose of the current study was to examine if and *when* craving was significantly reduced in adolescents in the treatment condition, and to understand the effects of stress and baseline nicotine dependence on craving over the course of the 6 month intervention. Specifically, we employed TVEM to estimate the time-varying effects of stress (a time-varying covariate) and baseline nicotine dependence level (time-invariant covariate) on craving over 6 months by treatment condition. Our first model tested the hypothesis that the time-varying effect of stress on craving will differ by experimental condition, such that in time the experimental treatment will weaken the association between stress and craving relative to the control condition. Our second model tested the hypothesis that the treatment would change the relationship between baseline dependence and craving over time, such that the effect of baseline dependence on craving would be reduced with time in the experimental group relative to control.

2. METHODS

2.1 Recruitment

We recruited and enrolled 200 adolescents between the ages of 14–18 in the greater Richmond, Virginia area from May, 2013 to August, 2014 into the 5-day automated text-messaging intervention program. Participants 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. Enrolled participants were given the opportunity of recruiting up to three peers and were compensated

for each successful enrollment (\$5 per enrollment). Over half (n=107, 53%) of the total sample was enrolled through direct referral from participating adolescents. Participants completed surveys at baseline, 1, 3, and 6 months post-intervention. Participants also completed EMA surveys monthly (see EMA procedures section 2.4 for details). Finally, participants were recruited from a convenience sampling framework and then randomized into experimental conditions.

2.2 Procedures

Inclusion criteria were being between the ages of 14 and 18 and scoring above a cut-point on the Modified Version of the Fagerström Tolerance Questionnaire (Prokhorov et al., 1996). 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. Following screening and informed consent, teens 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. All study procedures were approved by the first author's Institutional Review Board office.

2.3 Smartphones and Application of Automated Program

All participants were given a smartphone for the duration of the study with unlimited texting, internet, 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; Harris et al., 2009).

2.4 EMA Procedures

Every month for six 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 (preprogrammed 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 eight minute time window in which to complete each survey, with an additional one minute grace period, before a survey was marked as "missed." At the seven 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.

2.5 Measures

2.5.1 Nicotine Dependency—was measured with the Modified Version of the Fagerström Tolerance Questionnaire (FTQ; Fagerström, 1978) to screen adolescents on tobacco use and potential dependence. A total score was obtained from summing raw scores from 7 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.

2.5.2 Stress—was measured using the EMA item, "How STRESSED are you now?" encoded as 1= not stressed, 2 = mildly stressed, 3 = average stress, 4 = fairly stressed, 5= very stressed.

2.5.3 Craving—was measured using the EMA item, "How is your craving for cigarettes, cigars, cigarillos, little cigars, or black & milds right now?" encoded as 1= no cravings, 2 = mild cravings, 3 = medium cravings, 4 = pretty strong cravings, 5 = intense cravings.

2.5.4 Current 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.

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

2.6 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. Gender, age, and current smoking were included as covariates, stress and baseline nicotine dependence were the predictor variables, and craving 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 was based on 200 participants who completed the intervention and the follow-up assessments over 6 months. This resulted in a total of 11,996 assessments. For both treatment conditions, the following model was specified for predicting craving from the time-varying covariate stress (St) and baseline dependence (Bd), controlling for current smoking (S), age, (A), and gender (G) during the 6-month study period:

$$\text{Craving}_{ij} = \beta_0(t) + \beta_1(t) St_{ij} + \beta_2(t) Bd_i + \beta_3 S_{ij} + \beta_4 A_i + \beta_5 G_i + \varepsilon_{ij}$$

where Craving_{ij} , St_{ij} and S_{ij} are intensively measured longitudinal variables for individual i from assessment j measured at time t_{ij} and Bd_i represents baseline nicotine dependence for individual i . In this model, $\beta_0(t)$ represents mean craving over time for individuals with values of zero on all other predictors. Similarly, $\beta_1(t)$ is a nonparametric coefficient function describing the time-varying association between stress and craving, and $\beta_2(t)$ is a nonparametric coefficient function describing the time-varying association between baseline dependence and craving. Effects of momentary smoking, age, and gender 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 (i.e. t_{ij}), coded 1 to 72, with times 1 – 12 falling within month 1, 13 – 24 falling within month 2, and so on. The X axis on our graphs display 12 EMA surveys per month for six months, totaling 72 EMA surveys or discrete time points. Stress, baseline dependence, and craving 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. The SAS software 9.4 and the SAS macro %TVEM_normal was used to estimate the model. The macro as well as detailed technical information is available free for download at methodology.psu.edu.

3. RESULTS

Table 1 presents descriptive statistics for all variables in the study, divided by treatment 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. The sample was mildly stressed, and reported mild level of craving in response to the EMA surveys after the intervention. Between 12% to 14% of the sample reported momentary smoking when queried using EMA after the intervention.

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 mean level of craving across the 6 months of the study. If a confidence interval does not include 0, there is a nonzero mean level of craving, that is, there is a significant urge to smoke. Given that all confidence intervals do not include 0, there is significant urge to smoke among nonsmoking adolescents with average stress and baseline dependence for both treatment and control groups throughout the study period. Additionally, if at any point in time the confidence intervals do not overlap, craving is significantly different between the treatment and control groups at that specific point in time. Figure 1 shows a fairly even craving across the study with a slight separation occurring (non-overlapping lines) at month 4, indicating a significant difference between group craving levels.

Figure 2 shows the time-varying association between stress and craving 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 craving (Lanza et al., 2014b). At all time points in the study, stress was significantly associated with craving for both groups. Figure 2 shows that immediately following the 1-week texting intervention the curves for the treatment and control groups begin to diverge. Beginning at month 2 post-intervention through month 3, the association between stress and craving was significantly stronger among individuals in the control group, suggesting that the experimental intervention had a positive impact on reducing craving for about two months. Beginning at month 4, the effect of stress on craving for the treatment group returns to the level of the control condition and continues similarly for the remainder of the study.

Figure 3 illustrates the time-varying association between baseline dependence and craving, showing that these variables were significantly correlated at all points during the study for both groups. The time-varying association is positive and significant for both conditions at all times during the six month period, with higher baseline dependence associated with higher craving. The two curves do not separate enough to achieve significance. However, at six months post-intervention, group differences approach significance (i.e. non-overlapping confidence intervals), suggesting a possible delayed effect of the text-based intervention operating by reducing the link between baseline dependence and craving.

4. DISCUSSION

The significant finding of the time-varying effect of stress on craving by treatment condition provides insight into the mechanisms of the text-delivered intervention. Understanding the stepwise processes of how the intervention appears to reduce smoking allows for further testing of stress and craving relative to specific parts of the intervention. For example, the intervention is based upon Motivational Interviewing (MI) that focuses on peer smoking behaviors. It is reasonable to interpret that one of the intervention's active ingredients is addressing the social context of the adolescents' smoking behavior in a non-judgmental MI style. Adolescents engage in reviewing their own smoking, their peer's smoking, and where and when these behaviors typically occur. Participants reflect on their peer networks and consider modifying their behavior in relation to peer smoking, e.g. spending slightly less time with smoking peers, in known smoking settings. For those adolescents who were actively trying not to smoke, the unique social stress associated with spending time with peers who smoke may lead to relapse (O'Loughlin et al., 2014). Our intervention actively supports making small modifications within the adolescents' peer network, an identified active ingredient in smoking cessation (Cengelli et al., 2012; Mason et al., in press). Decreasing time spent with smoking peers may reduce interpersonal stress (conflicted feelings associated with friends' smoking), which in turn reduces craving (activated by stress and social context), which ultimately reduces smoking.

The effect of stress on craving appears immediately after receiving the intervention and becomes significant between months 2 to 4. Consequently, leveraging the early portions of the intervention with peer network focused conversation to encourage pro-social activities that increase social support, may elongate the treatment effect. Similarly, targeting late portions of the intervention with peer focused content may also improve outcomes. More process data is needed to further explain the pathways of smoking reduction among these urban adolescents.

The attenuation of the effect of baseline nicotine dependence on craving six months post-intervention among adolescents in the treatment condition, while not statistically significant, still offers support that the treatment's effectiveness as shown in initial trial (see Mason et al., 2014; Mason et al., in press) may be due, in part, to the tamping down of dependence effects over time. Relative to the treatment group, the control group's baseline dependence effect increases over months two to six of the study, while the treatment group's effect diminishes. The craving level difference between groups becomes most pronounced at month 5 and appears to be on a trajectory of significant group differences, if the measurement continued

past 6 months. This finding supports theories that suggest dependence level influences craving and ultimately treatment outcomes (Baker et al., 2012).

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 (Brener et al., 2002). 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. While it is reasonable that EMA methodology is suitable for collecting meaningful data within a smoking cessation RCT, it is not without potential biases. Repeatedly administering even very brief surveys, may influence responses and cravings, due to the intensive nature of data collection. Results should be interpreted in light of these potential biases. Adding a control condition not getting the repeated surveys would be a good design feature for future studies. 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. Future research would benefit from designs that capture intervention effects on craving more continuously.

Utilizing new statistical approaches such as TVEM allows researchers to leverage the dense and often big data arising from EMA data collection methods, particularly with the increased use of smartphones. To be able to visualize and test the dynamics of behavioral change within the context of a randomized control trial provides insights into the gradations of time-varying treatment effects. Treatment works differently, at different times, on different groups. Statistical models can be specified to test such questions explicitly, and in turn provide information to help design adaptive and personalized treatment interventions.

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Highlights

- We estimated time-varying treatment effects for text-based smoking intervention.
- Treatment reduced association between stress and craving during months 2 and 3.
- Treatment reduced salience of baseline dependence steadily over time.
- Illustrates the time-varying nature of treatment effects of a text-based intervention

Figure 1.

Intercept function showing mean craving during 6 month study by treatment condition.

Figure 2.
Time-varying effect of stress on craving by treatment condition.

Figure 3.
Time-varying effect of baseline nicotine dependence on craving by treatment condition.

Table 1

Descriptive Statistics of Study Variables

	Treatment %, Mean (SD)	Control %, Mean (SD)
Gender (female) %	54.3	55.2
Race/Ethnicity %		
African American	91.1	91.4
White	8.1	4.1
Other	.8	4.5
Age	16.3 (1.4)	16.2 (1.3)
Baseline Nicotine Dependence	4.5 (2.3)	4.3 (2.2)
Stress	1.8 (1.2)	1.8 (1.2)
Craving	2.3 (1.3)	2.3 (1.3)
Smoking, (yes) %	12	14