ORIGINAL INVESTIGATION

Advancing Cessation Research by Integrating EMA and Geospatial Methodologies: Associations Between Tobacco Retail Outlets and Real-time Smoking Urges During a Quit Attempt

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Received January 10, 2013; accepted July 26, 2013

ABSTRACT

Introduction: Residential tobacco retail outlet (TRO) density and proximity have been associated with smoking behaviors. More research is needed to understand the mechanisms underlying these relations and their potential relevance outside of the residential setting. This study integrates ecological momentary assessment (EMA) and geo-location tracking to explore real-time associations between exposure to TROs and smoking urges among 47 economically disadvantaged smokers in a cessation trial (59.6% female; 36.2% White).

Methods: EMA data were collected for 1 week postquit via smartphone, which recorded smoking urge strength ≤ 4 random times daily along with real-time participant location data. For each assessment, the participants' proximity to the closest TRO and the density of TROs surrounding the participant were calculated. Linear mixed model regressions examined associations between TRO variables and smoking urges and whether relations varied based on participants' distance from their home. Covariates included sociodemographics, prequit tobacco dependence, treatment group, and daily smoking status.

Results: Main effects were nonsignificant; however, the interaction between TRO proximity and distance from home was considered significant ($p = .056$). Specifically, closer proximity to TROs was associated with stronger smoking urges ≤ 1 mile of home ($p = .001$) but not >1 mile from home ($p = .307$). Significant associations were attributable to assessments completed at participants' home addresses. All density analyses were nonsignificant.

Conclusions: Technological challenges encountered in this study resulted in a significant amount of missing data, highlighting the preliminary nature of these findings and limiting the inferences that can be drawn. However, results suggest that closer residential proximity to tobacco outlets may trigger stronger urges to smoke among economically disadvantaged smokers trying to quit, perhaps due to enhanced cigarette availability and accessibility. Therefore, limiting tobacco sales in close proximity to residential areas may complement existing tobacco control efforts and facilitate cessation.

INTRODUCTION

Ecological momentary assessment (EMA), an innovative methodology developed for real-time data collection, has dramatically improved the field's understanding of smokers' cognitions, emotions, and behaviors at the time of their occurrence in the natural environment (Shiffman, Stone, & Hufford, 2008). In particular, EMA adeptly captures the

dynamic mechanisms that drive smoking relapse, such as cue-induced craving. Cue-induced craving is a transient, context-specific construct that changes in response to environmental, social, and physiological cues (Ferguson & Shiffman, 2009). Over the last two decades, EMA-based research has delineated the difference between cue-induced craving and steady background craving, and it has highlighted the role of the former in smoking lapses and relapse in real-time and

doi:10.1093/ntr/ntt135

Advance Access publication September 21, 2013

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real-world settings (Shiffman et al., 1997, 2013; Shiffman, Paty, Gnys, Kassel, & Hickcox, 1996).

Concurrent with advances in the assessment of momentary changes in the individual-level mechanisms underlying smoking cessation, there has been a growing interest in the more macrolevel environmental influences on smoking behavior, particularly the role of tobacco retail outlets (TROs). Research indicates that a greater density of TROs in the residential neighborhood is associated with higher smoking rates among adults (Chuang, Cubbin, Ahn, & Winkleby, 2005). In addition, closer proximity of a TRO to the home has been linked to higher odds of smoking relapse in the context of a smoking quit attempt (Reitzel et al., 2011). However, the mechanism underlying the associations between TROs and smoking behaviors is unknown. It is possible that greater TRO density and/or closer TRO proximity affect smoking behaviors via the greater availability of tobacco products, easier access to tobacco products, or perhaps more frequent exposure to tobacco industry marketing efforts (e.g., cigarette advertisements). Availability and access may provoke higher levels of craving among smokers because of a greater perceived opportunity to smoke, which might be particularly salient among those who are attempting to quit (cf. Droungas, Ehrman, Childress, & O'Brien, 1995; Sayette, Martin, Hull, Wertz, & Perrott, 2003; Wertz & Sayette, 2001). Conversely, TROs might function as an environmental cue to smoke that induces craving upon exposure due to visual cues such as tobacco advertising and prominent product placement (Siahpush, Jones, Singh, Timsina, & Martin, 2010). A recent population-based study, for example, found that smokers who saw cigarettes for sale were more likely to smoke, and smoked more, within a 4-hr period than those without such exposure (Burton, Clark, & Jackson, 2012). More research is needed to better understand the circumstances in which TROs might induce cravings to smoke. Understanding these associations in the real-world setting and during the context of a specific quit attempt is particularly important as it might help explain the potential link between residential proximity to TROs and smoking relapse (Reitzel et al., 2011). Moreover, research that can capture exposures to TROs in the context of the smoker's dynamic environment is needed to better understand this relationship.

Integrating EMA and geospatial methodologies may allow researchers to better understand the real-time, real-world associations between TROs and smoking urges during a quit attempt. EMA provides information on the momentary experiences of smokers (e.g., cravings) and geo-location data provide information on participants' location during those experiences, which can be linked to information about the surrounding contextual environment (e.g., the surrounding density of TROs, proximity to the closest TRO). Therefore, the integration of EMA and geospatial methodologies provides a way for researchers to explore the potential influence of macrolevel environmental characteristics on momentary individual-level variables and enhance our understanding of the determinants of smoking behaviors at multiple levels.

The purpose of the current study was to combine EMA and geo-location tracking to analyze real-time associations between exposure to TROs and smoking urges among economically disadvantaged smokers who were enrolled in a cessation trial and undergoing a specific quit attempt. Since the majority of previous TRO research has focused on the smokers' residential environment, and because neighborhood TROs might

be particularly salient cues for smoking due to enhanced product availability at a time when smoking is possible (e.g., when the participant is at home) or greater personal relevance due to previous cigarette purchases at those locations (cf. Conklin, Perkins, Robin, McClernon, & Salkeld, 2010; Conklin, Robin, Perkins, Salkeld, & McClernon, 2008), the current study also sought to determine how associations between TRO exposures and smoking urges might differ based on smoker's proximity to their home.

METHODS

The Institutional Review Boards at the University of Texas Southwestern Medical Center, the University of Texas Health Science Center at Houston, and the University of Texas MD Anderson Cancer Center approved this study. Written informed consent for all study procedures was obtained before data collection.

Study Setting and Recruitment

Data were collected as part of an ongoing longitudinal study designed to evaluate the efficacy of an adjunctive contingency-management intervention for socioeconomically disadvantaged smokers. All participants were enrolled in a smoking cessation program at a safety net clinic in Dallas, TX. Participants were recruited during an initial orientation visit to the smoking clinic and were eligible to participate if they were ≥ 18 years of age, were English speaking and literate at a 7th grade level, were willing to quit smoking a week following their initial visit, had an expired carbon monoxide level of ≥ 8 ppm (suggestive of current smoking), self-reported current smoking of ≥ 5 cigarettes per day, and were willing to attend the required in-person study visits (1 week prequit, quit day, and 1, 2, 3, and 4 weeks postquit). Although there were no income requirements for inclusion, patients receiving treatment at this safety net clinic are generally of low income.

The current study could potentially include the 102 participants who enrolled in the parent study between August 30, 2011 and October 8, 2012; however, a complete lack of geo-location data for 55 participants limited the analyzable sample to 47. All participants received smoking cessation treatment consistent with clinical practice guidelines (Fiore et al., 2009), which was provided before or after each of the parent study's six in-person study visits. Treatment included weekly counseling sessions of approximately 45-min duration. In addition, all participants were offered pharmacological interventions (e.g., nicotine patch, varenicline) for smoking cessation. Approximately half of the participants were randomly assigned to the adjunctive contingency-management intervention, which allowed these individuals the opportunity to earn monetary compensation (gift cards) for self-reported and biochemically verified abstinence at each postquit study visit. Treatment group assignment was included as a covariate in all analyses.

Data Collection Procedures

EMA data of relevance to the current study were collected on a LG Optimus Android smartphone (model LG-P509) from the quit day through 1 week postquit. Participants were individually trained by research staff (~5–10 min) to use the touch screen

smartphone and practiced completing mock EMA assessments as part of the parent protocol. Participants were also provided with written instructions to take home with them. They were asked to keep the phone turned on, to carry it with them at all times, and to charge the phone each night. Participants had free calling time and could use the smartphone to contact study personnel if they encountered difficulty completing the EMA protocol.

The EMA protocol included four random assessments and one diary assessment each day. The random assessments were “pushed” to participants at random times during the day during self-reported waking hours. Participants were notified of random assessments with 30 s of audible and visual cues, which would be repeated up to three times before the assessment was counted as missed. The daily diary was pushed each morning 30 min after each participant’s self-reported waking time, with all items referring to the previous day. EMA compliance was incentivized with gift cards based on the proportion of assessments completed.

Variables of Interest

Sociodemographics

Sociodemographics were collected 1 week prequit and included age, gender, race, partner status, educational level, and employment status. The sample comprised 17 White smokers, 27 Black smokers, 1 American Indian/Alaskan Native smoker, and 2 participants endorsing “more than 1 race” as a response option. Because small group sizes were not ideal for analyses, the latter three participants were included in the Black category (forming a Black/other race designation).

Tobacco Dependence

Prequit tobacco dependence was assessed 1 week prequit using the Heaviness of Smoking Index (HSI), which was calculated from the number of cigarettes smoked per day and the time to the first cigarette of the day (Borland, Yong, O’Connor, Hyland, & Thompson, 2010; Heatherton, Kozlowski, Frecker, Rickert, & Robinson, 1989). Scores on the HSI could range from 0 to 6, and it was treated as continuous variable in analyses (see Fagerstrom, Russ, Yu, Yunis, & Foulds, 2012 for precedent).

Real-time Smoking Urge

Smoking urge was recorded at each random assessment during the first week postquit. The item read “I have an urge to smoke.” Participants were directed to “Mark the response that most applies to you RIGHT NOW,” and response options were (1) strongly disagree, (2) disagree, (3) neutral, (4) agree, and (5) strongly agree.

Participant Geo-location

The smartphone was programmed to collect latitude and longitude data via an internal Global Positioning System (GPS) chip at the time the random assessment was prompted (i.e., the “beep” to alert the participant) until the participant began to answer EMA items. The acquisition of this geo-location data at each EMA was dependent upon whether the geo-location capture period was sufficient to acquire positional information via satellites. The integrated GPS chip used in this study (Qualcomm chipset with GPS model # MAM7227) was capable of assisted GPS to improve signal accuracy in areas without

direct line of sight to the sky via the integration of GPS fixes, cell phone triangulation, and orbital data to map satellite locations. Nevertheless, terrestrial interference and other geo-location errors (e.g., inability to capture a fix within certain buildings) may have contributed to missing geo-location data for some assessments, as likely did the EMA programming rule to only acquire positional information until the participant began answering the EMA items.

TRO Locations

TRO addresses from August 2012 were obtained from the Texas Comptroller of Public Accounts, which keeps a record of all the facilities licensed to sell tobacco in Dallas and surrounding areas. TRO locations were geocoded using a composite address locator based on both local and national data and were used to calculate the proximity and density predictor variables.

TRO Proximity

The proximity of each participant to the closest TRO at the time of each completed assessment was measured using the closest facility tool in ArcGIS Network Analyst version 10 (ESRI). ArcGIS is a platform for geographic/spatial data processing, management, and analysis. Proximity was measured using distance along the street network, with higher values indicative of greater distance from the closest TRO.

TRO Density

The measurement of TRO density was completed in three steps. First, a 1 mile buffer was created along the road/street network around each participant’s geo-location at the time of the completed EMA using the service area tool in the ArcGIS Network Analyst. Second, the geocoded TROs were overlaid onto the road network buffer areas, and a count of TROs within each buffer was obtained using the Spatial Join tool within ArcGIS, which joins the polygons (buffers) to points (TROs). Finally, the count of TROs was divided by the actual geographic coverage area of each buffer area to obtain the TRO density variables. This procedure resulted in a value representing the density of TROs within 1 mile around each participant at each completed EMA.

Participants’ Distance from Home

Participants’ residential addresses were collected at the 1 week prequit visit and geocoded to calculate their Euclidean distance (as the crow flies) from home at the time of each EMA. Distance from home was then dichotomized into ≤ 1 mile from home (meant to roughly represent the immediate neighborhood and location most familiar to the participant) versus > 1 mile from home.

Daily Smoking Status

Postquit daily smoking status was based on participants’ response to a daily diary EMA item reading: “How many cigarettes did you smoke yesterday?” Participants self-reporting any cigarettes smoked were classified as “smoking” for the previous day, whereas those self-reporting 0 cigarettes smoked were classified as “abstinent.” Missing daily diary data ($n = 1$) resulted in classification as “smoking” for the previous day. Because there was no daily diary assessment on the final day of EMA data collection, participants who were

biochemically verified abstinent at the 1 week postquit visit (self-reported 24-hr abstinence and expired carbon monoxide of <8 ppm) were considered “abstinent.” Conversely, those not meeting this standard or failing to attend this visit were considered “smoking.”

Data Analyses

All analyses were performed using Statistical Analysis Software version 9.2 (SAS Institute). Preliminary analyses explored differences between participants who had geo-location data versus those who did not with regard to sociodemographics, tobacco dependence, treatment group assignment, and smoking urge using chi-square tests and one-way analyses of variance (ANOVA). Differences in mean urge ratings among the assessments with and without geo-location data for the 47 included participants were also explored. Mean differences in TRO proximity and density variables based on distance from home were explored among this group using repeated-measure ANOVA.

Main analyses examined the associations of TRO proximity and TRO density, respectively, and real-time urges to smoke using linear mixed model regressions that were adjusted for age, gender, race, partner status, employment, education, treatment group, prequit tobacco dependence, daily postquit smoking status, and the participants’ distance from home. The linear mixed model regressions (PROC MIXED; Littell, Milliken, Stroup, Wolfinger, & Schabenberger, 2006) accounted for the structure of the data whereby assessments were nested within days nested within participants (Raudenbush & Bryk, 2002). Following the assessment of the main effects of TRO proximity and density on smoking urges, their respective interactions with participants’ distance from home was examined by including an interaction term in models adjusted for age, gender, race, partner status, employment, education, treatment group, prequit tobacco dependence, and daily postquit smoking status. Because the sample size limited the power to detect interaction effects, the significance level for the interaction terms was defined at $p \leq .10$ (Twisk, 2006; cf. Oman, Reed, & Ferrara, 1999; Peels et al., 2012). Significant interaction results were further examined in analyses stratified by distance from home.

RESULTS

EMA Compliance and Geo-location Availability

The 47 participants included in this study generated 1109 EMA urge ratings from random assessments. This represented an EMA compliance rate of 84.2% for this item (47×4 daily random assessments $\times$ 7 days of collection = 1,316, $1,109/1,316 = 84.2\%$). Of the 1,109 random urge ratings, 29.9% ($n = 332$) had valid geo-location data. The within-participant number of assessments with geo-location data ranged from 1 to 28 (mean = 7.1 ± 7.2). This was equivalent to a within-participant proportion of 3.7%–100% of completed assessments with geo-location data (mean = 30.4 ± 27.9).

Participant Characteristics

Participants ($N = 47$; 36.2% White and 63.8% Black/other race) were 52.3 years of age (± 7.4) on average. Participant characteristics are in Table 1. On average, participants were

Table 1. Participant Characteristics ($N = 47$)

Variable	<i>N (%)</i> / <i>M [SD]</i>
Age	52.29 [7.42]
Gender	
Male	19 (40.4)
Female	28 (59.6)
Race	
White	17 (36.2)
Black/other race	30 (63.8)
Partner status	
No current partner/spouse	23 (48.9)
Current partner/spouse	24 (51.1)
Education	
$\leq$ High school degree/GED	27 (57.4)
$>$ High school degree/GED	20 (42.6)
Employment status	
Employed	6 (12.8)
Unemployed	16 (34.0)
Unable to work/disabled	25 (53.2)
Treatment group	
Usual care	22 (46.8)
Contingency management	25 (53.2)
Tobacco dependence	2.91 [1.25]
Smoking urge	2.74 [0.99]

Note. GED = General Education Development Certificate; *M [SD]* = mean [and standard deviation]. Smoking urge represents the mean urge rating at the participant level over the week of data collection. Specifically, urge ratings were first averaged within participants and then between participants, resulting in the *M [SD]* presented above.

within 0.46 (± 0.33) miles of the closest TRO when completing random assessments (range = 0.007–2.64 miles). On average, participants were surrounded by 11.75 TROs within 1 mile of the place where they completed random assessments (range from 0 to 82). This was equivalent to an average density value of 8.27 (± 7.22) and a range of 0–41.89.

Preliminary Analyses

Results indicated no significant differences between included participants (i.e., those with geo-location data, $n = 47$) and excluded participants (i.e., those with no geo-location data, $n = 55$) on sociodemographics, treatment group assignment, or smoking urge. However, excluded participants were more dependent on tobacco than included participants ($F_{1,100} = 4.42$, $p = .03$; mean HSI = $3.40 [\pm 1.1]$ among excluded versus $2.91 [\pm 1.2]$ among included). There were no significant differences in mean urge ratings among the 47 included participants for assessments with ($n = 332$) and without ($n = 777$) geo-location data ($\beta = -.02$, $SE = .06$; $t = -.31$; $p = .73$; $n = 1,109$).

Unadjusted repeated-measures ANOVA indicated that TRO proximity values for assessments conducted within 1 mile of home ($n = 226$) versus >1 mile from home ($n = 106$) were significantly different ($F_{1,183} = 61.57$, $p < .0001$). On average, participants were 0.53 (± 0.04) miles from the closest TRO during random assessments completed within 1 mile of home, whereas they were 0.31 (± 0.05) miles from the closest TRO during random assessments completed >1 mile from home. In addition, unadjusted repeated-measures ANOVA indicated that TRO density values for assessments conducted within 1

mile of home versus >1 mile from home were significantly different ($F_{1,183} = 29.1, p < .0001$). Density values for random assessments completed within 1 mile of home averaged 6.96 ($\pm .87$), whereas density values for random assessments completed >1 mile from home averaged 10.57 ($\pm .96$).

Main Analyses

The main effects of TRO proximity on real-time smoking urges were nonsignificant ($\beta = -.31, SE = .22; t = -1.41; p = .16; n$ [hereafter, number of observations] = 332) in covariate-adjusted analyses. Likewise, the main effects of TRO density on real-time smoking urges were also nonsignificant ($\beta < .01, SE < 0.01; t = .66; p = .51; n = 332$) in adjusted analyses.

There was a significant interaction effect for TRO proximity and distance from home on real-time smoking urges ($p = .056$). Follow-up analyses indicated that closer proximity to TROs was associated with stronger urges to smoke within 1 mile of home, but not >1 mile from home. See Table 2. Further investigation of the 226 assessments completed within a mile of home suggested that 187 of them (82.7%) were completed within 50 feet of the participants' geocoded residential addresses, suggesting that the majority of the assessments driving the significant associations were completed when participants were at home. Analyses conducted among these 187 at-home assessments supported significant associations between TRO proximity and smoking urges ($\beta = -1.84, SE = .62; t = -2.99; p = .007$). We also reran the TRO proximity and distance from home interaction analyses excluding the 187 at-home assessments. The interaction term among these remaining assessments ($n = 145$) was nonsignificant ($p = .413$), suggesting that the slope relevant to the association between TRO proximity and urges among assessments completed within a mile of home but not at the home ($n = 39$) was not significantly different from the slope relevant to the assessments completed >1 mile from home ($n = 106$).

The second interaction analysis, examining whether relations between TRO density and real-time smoking urges were modified by participant's distance from home, was nonsignificant ($p = .99$).

DISCUSSION

The current study was the first to link real-time EMA assessments with real-time geo-location data to evaluate associations between TROs and smoking urges among a population of economically disadvantaged smokers enrolled in a cessation program. Although highly innovative from a methodological standpoint, there were significant technological challenges in the implementation of this study that contributed to a large amount of missing geo-location data, lending to the preliminary nature of the empirical results. These challenges should inform future research in this area. Specifically, 55 potential participants were excluded from analyses due to geo-location missingness. One likely source of this missingness was an EMA programming rule that restricted the search for geo-location data to only a limited timeframe during the beginning of the EMA assessment. Although this approach helped to conserve the smartphone battery charge (thereby potentially allowing a higher EMA compliance rate for the purposes of the parent study), it might have resulted in the systematic noncapture of geo-location data for participants who routinely

responded very quickly to the EMA prompts. Consequently, missing geo-location data may not be missing at random. In addition, this programming rule may also have influenced the unequal contribution of assessments with geo-location data among the included participants, based on their varying EMA response times. Therefore, collected geo-location data may not be fully representative of participants' daily exposures. Moreover, patterns in delay-based geo-location missingness might exist based on social or locational circumstances, or other factors that might affect craving, and the extent to which these issues are relevant to our data is unknown.

An additional source of geo-location missingness might have been the inability to acquire positional information as the result of terrestrial interference (e.g., the participant was in a large building and could not obtain a GPS fix). Such limitations are common to public health studies utilizing GPS technologies for geo-tracking, including cellular phone GPS chipsets as in this study. Future studies should collect more continuous geo-location data to provide a basis for the imputation of missingness in positional data. Emerging research supports the feasibility of continuous geo-tracking to better understand smokers' dynamic interactions with the tobacco retail environment over time (Kirchner et al., 2012). If continuous geo-tracking is not possible due to potential battery drain issues, geo-tracking at regular intervals supplemented by cellphone accelerometry data and external Wi-Fi triangulation may provide additional sources of position information (cf. Brown et al., 2012; Guha et al., 2010). Additional limitations of geo-location research include potential geo-location error (positional inaccuracy) attributable to satellite signal loss, atmospheric conditions, and interference from terrestrial objects (multipath error; Wing, Eklund, & Kellogg, 2005), which might have affected the accuracy of proximity data. However, our geo-location data were estimated at $\geq 90\%$ accurate to within 20 m based on testing on similar hardware using a known geodetic point.

Although the technological challenges encountered in this study highlight the preliminary nature of these findings and limit the inferences that can be drawn, results suggest that closer residential proximity to a TRO was associated with stronger real-time smoking urges. A prior study indicated that closer residential proximity to the closest TRO (within 500 m) was associated with a lower likelihood of maintaining abstinence during a specific quit attempt (Reitzel et al., 2011), and the current study suggests that the mechanism underlying this relation could be that proximal TROs engender stronger urges to smoke among those trying to quit. This may be because a close TRO represents enhanced cigarette availability at a time when smoking is possible (e.g., when the participant is at home) rather than at work or in other settings where smoking is disallowed. Previous research suggests that a greater perceived opportunity to smoke is associated with stronger urges (Wertz & Sayette, 2001), and the present study suggests that close residential TRO proximity may contribute to that perception. The definitive link between residential TRO proximity, smoking urges, and smoking relapse awaits future research, but the current results suggest that disallowing the sale of tobacco products at TROs in close proximity to residential areas might be helpful in facilitating smoking cessation by reducing their association with smoking urges during a quit attempt.

Contrary to the proximity analyses, results failed to support significant relations between the density of TROs and the

Table 2. Linear Mixed Model Results Highlighting Interaction Between TRO Proximity and Distance to Home on Smoking Urges

Variables	Model with interaction term		Stratified analyses pursuant to significant interaction			
	All assessments (N = 332)		Assessments ≤1 mile from home (N = 226)		Assessments >1 mile from home (N = 106)	
	Estimate (SE)	p value	Estimate (SE)	p value	Estimate (SE)	p value
TRO proximity	0.13 (0.32)	.685	-1.83 (0.54)	.001	0.41 (0.39)	.307
Distance from home (REF = >1 mile)	0.49 (0.23)	.033	—		—	
TRO proximity × distance to home	-0.85 (0.44)	.056	—		—	
Age	-0.01 (0.02)	.804	-0.02 (0.03)	.420	0.04 (0.03)	.173
Gender (REF = male)	0.26 (0.34)	0.445	0.24 (0.38)	.539	0.09 (0.44)	.833
Race (REF = Black/other race)	0.02 (0.33)	.953	0.14 (0.37)	.712	-0.38 (0.48)	.441
Partner status (REF = current partner/spouse)	-0.23 (0.35)	.516	-0.27 (0.38)	.493	-0.42 (0.48)	.392
Education (REF = >high school degree/GED)	0.10 (0.31)	.742	0.02 (0.37)	.959	0.04 (0.45)	.924
Employment status (REF = unable to work/disabled)						
Employed	0.65 (0.48)	.179	1.31 (0.63)	.045	0.51 (0.57)	.378
Unemployed	-0.44 (0.36)	.223	-0.59 (0.39)	.145	0.21 (0.57)	.710
Treatment group (REF = usual care)	-0.24 (0.32)	.446	-0.30 (0.39)	.448	0.20 (0.45)	.667
Smoking status (REF = relapsed)	-0.06 (0.14)	.640	-0.09 (0.17)	.611	0.04 (0.20)	.830
Tobacco dependence	0.11 (0.13)	.401	0.04 (0.16)	.829	0.24 (0.19)	.210

Note. GED = General Education Development Certificate; REF = reference group; TRO = tobacco retail outlet. Results were from adjusted linear mixed model regressions focused on the interaction of the participant's proximity to the closest tobacco retail outlet and the participant's distance from home at the time of the ecological momentary assessment on real-time smoking urges.

strength of smoking urges, regardless of participant's nearness to their home at the time of the random assessments. These results complement those of a previous study citing null relations between residential TRO density and smoking cessation during a quit attempt (Reitzel et al., 2011) and suggest that a single proximal TRO is a more salient to craving than the presence of multiple surrounding TROs. One possibility is that participants are aware of a nearby TRO, but they might be relatively unaware of the surrounding density of TROs, especially if they are not located within the line of sight. Moreover, even in a highly familiar area, such as the residential neighborhood, it is likely that most individuals have an established travel routine (cf. Kirchner et al., 2012) contributing to a constrained awareness of nonproximal TROs and/or the availability of tobacco products at nearby but nonfrequented (or not commonly frequented) locations. Moreover, if availability accounts for the link between a proximal TRO and greater smoking urges, the surrounding TRO density may be irrelevant because only one TRO is sufficient to purchase cigarettes.

Our original analyses did not account for potential interactions between the spatial variables examined; however, post-hoc analyses indicated a significant interaction between TRO proximity and TRO density ($p < .02$). Specifically, there were stronger relations between TRO proximity and smoking urges in high TRO density areas ($\beta = -3.65$, $SE = 1.23$, $p < .005$) than in low TRO density areas ($\beta = -1.93$, $SE = .71$, $p < .02$) among the assessments taken within 1 mile of home. These exploratory results suggest that TRO density warrants additional consideration in future research as a potential moderator of TRO proximity effects. This pattern of results might also suggest the influence of an unmeasured third factor (e.g., neighborhood socioeconomic conditions); however, the literature on associations between TRO density and neighborhood socioeconomic conditions has been largely mixed (see Mayers, Wiggins, Fulghum, & Peterson, 2012 for summary). Other variables, such as TRO density effects on local cigarette pricing and promotions, which might make the close availability of cigarettes particularly alluring for individuals of lower economic means, might be considered in future research.

The current study was innovative for its pairing of EMA and geo-location data to better understand how TROs affect smoking urges in real-time, real-world environments. However, results of the current study suggest that it is residential proximity to TROs that is associated with urge, rather than TRO proximity in the context of participants' travels outside of the home. This may be the case because randomly sampling TRO proximity in the context of daily life/travels outside of the home does not necessarily represent access or availability (participants could be in close proximity of a TRO but traveling on a bus at the time) or take into account whether smoking is disallowed (e.g., in public places). It is also possible that the current results are reflective of sample characteristics (e.g., more than 80% of the sample was unemployed, likely contributing to the greater proportion of at-home than not-at-home random assessments in the present study). Consequently, additional research using these methodologies among other samples is needed prior to drawing definitive conclusions. Future studies might benefit from a larger sample, the examination of participant-initiated urge assessments, the use of more time-sensitive smoking status data, and information about whether a proximal TRO is accessible and if smoking is allowable at the time of the assessments.

This study focused on a single residential buffer zone (1 mile) and a single TRO density buffer around EMA assessments (1 mile). It is possible that results would differ if other buffer zones were used. However, post-hoc analyses using two alternative residential buffer zones (1/2 mile and 2 miles) and an alternate TRO density buffer (1/2 mile) yielded results consistent with our reported findings. Likewise, further controlling for the within-person mean of TRO proximity in analyses using the original 1 mile buffer yielded similar results. Finally, additionally covarying for the assessment day (e.g., Day 1 postquit and Day 2 postquit) in order to parse the variance related to background craving and better isolate phasic craving responses also yielded consistent findings. Nonetheless, future research in this area should be designed to better delineate whether relations between residential TRO proximity and smoking urges are attributable to greater spikes in cue-induced craving or, perhaps more likely, a generally higher level of background craving.

Findings should be replicated among larger samples with greater power to detect interaction effects at $p \leq .05$ (vs. $p \leq .10$). Given the nature of the sample, results may not generalize to nontreatment-seeking smokers, smokers of greater economic means, or smokers from rural areas. In addition, included participants were less nicotine dependent (as measured by the HSI) than were excluded participants (i.e., those lacking geo-location data). Therefore, results may not be generalizable to heavier smokers. Although analyses adjusted for several potential confounders, the presence of unknown and unmeasured confounders might have influenced these results. Finally, relations between TRO locations and smoking urges beyond 1 week postquit are unknown and should be addressed in future studies.

In summary, the integration of EMA and geospatial methodologies provides researchers with the ability to make connections between the built environment and real-time cognitions, emotions, and behaviors that drive smoking relapse (e.g., cravings). Therefore, the combination of these methodologies has the potential to substantially advance the field's understanding of the multilevel determinants of smoking cessation. This preliminary study highlights both the potential strengths of this approach as well as the challenges in its implementation that can cloud inference. Results suggest that closer residential proximity to TROs was associated with stronger urges to smoke during the first week postquit in this sample of economically disadvantaged smokers. Future research will need to replicate these findings with other samples, but results suggest that zoning restrictions to limit tobacco sales in close proximity to residential areas may complement existing tobacco control efforts and potentially facilitate smoking cessation among the economically disadvantaged by reducing the availability of cigarettes and the smoking urges this may engender.

FUNDING

Funding for this research was provided by the University of Texas Health Science Center, School of Public Health (to MSB and DEK). Data analysis and manuscript preparation were additionally supported through grant MRS GT-10-104-01-CPPHS (to DEK) and MRS GT-12-114-01-CPPB (to MSB) awarded by the American Cancer Society. Further, this research was supported in part by a cancer prevention

fellowship supported by the National Cancer Institute Grant R25E CA56452 (to KLW), the National Institutes of Health through MD Anderson's Cancer Center Support Grant (CA016672), the e-Health Technology Program, a resource of the Duncan Family Institute for Cancer Prevention and Risk Assessment, and by start-up funds (to LRR) as provided by the University of Texas MD Anderson Cancer Center.

DECLARATION OF INTERESTS

None declared.

ACKNOWLEDGMENTS

The authors appreciate the contributions of all research and support staff at affiliated institutions. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the sponsoring organizations.

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