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Geospatial Exposure to Point-of-Sale Tobacco:

Real-Time Craving and Smoking Cessation Outcomes

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Abstract

Background—Little is known about the factors that drive the association between point-of-sale marketing and behavior, because methods that directly link individual-level use outcomes to real-world point-of-sale exposure are only now beginning to be developed.

Purpose—Daily outcomes during smoking cessation were examined as a function of both real-time geospatial exposure to point-of-sale tobacco (POST) and subjective craving to smoke.

Methods—Continuous individual geospatial location data collected over the first month of a smoking cessation attempt (N=475) in 2010–2012 were overlaid on a POST outlet geodatabase (N=1060). Participants' mobility data were used to quantify the number of times they came into contact with a POST outlet. Participants recorded real-time craving levels and smoking status via ecologic momentary assessment (EMA) on cellular telephones.

Results—The final data set spanned a total of 12,871 days of EMA and geospatial tracking. Lapsing was significantly more likely on days with any POST contact (OR=1.19 [95% CI=1.18, 1.20]), and increasingly likely as the number of daily POST contacts increased (OR=1.07 [95% CI=1.06, 1.08]). Overall, daily POST exposure was significantly associated with lapsing when craving was low (OR=1.22 [95% CI=1.20, 1.23]); high levels of craving were more directly associated with lapse outcomes.

Conclusions—These data shed light on the way mobility patterns drive a dynamic interaction between individuals and the POST environment, demonstrating that quantification of individuals' exposure to POST marketing can be used to identify previously unrecognized patterns of association among individual mobility, the built environment, and behavioral outcomes.

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Background

There is a considerable body of empirical evidence suggesting that point-of-sale tobacco (POST) marketing influences tobacco users' product preferences as well as decisions to initiate or refrain from use.^{1–6} Yet little is known about the factors that drive the association between point-of-sale marketing and behavior, because methods that directly link individual use outcomes to real-world point-of-sale exposure are only now beginning to be developed. These methods embrace more fully the “ecologic” aspect of the ecologic momentary assessment (EMA) approach,⁷ enriching field-based EMA data with the expanding array of data available within GIS.^{8–10}

Early work linking continuous individual mobility patterns to health-related geospatial data occurred in the area of environmental epidemiology, primarily to understand individual exposure to air pollution.^{11–13} More recently, these methods have been applied to the study of physical activity, retail food environments, diet, and weight,^{14–17} although only two studies have linked individual geo-location to the density of food retailers in the surrounding area,^{14,15} and none has included retail outlet-level data on actual marketing practices or product availability, or quantified individuals' exposure to specific outlets over time.

One recent analysis used geospatial tracking to examine individual differences in POST over time, incorporating comprehensive data on marketing intensity and product-specific pricing at each retail outlet participants encountered.¹⁸ Results reveal a dynamic interaction between individuals and their point-of-sale environment, demonstrating the marked degree to which differences regarding when and where individuals encountered tobacco at the point of sale determined the product availability and pricing to which they were exposed.¹⁸ These findings support the idea that each individual experiences the POST environment differently, but leave open questions about the implications this might have for corresponding motivational and behavior change processes.

Empirical evidence and prominent models of addictive behavior indicate that each temptation to use a drug involves a complex interaction between intrinsic and extrinsic factors, including motivational drive states and environmental cues.^{19–22} Research that has sought to isolate these factors with controlled laboratory methods has produced conflicting accounts of the association between cue-exposure, craving and behavior.^{23–25} One reason for this is that dynamic exposure to complex real-world stimuli is difficult to approximate in the laboratory. The current study integrates field-based measures of drug-craving, continuous tracking of exposure to point-of-sale tobacco, and their joint association with daily smoking cessation outcomes. Analyses were designed to test the hypothesis that individuals who experienced increasing craving to smoke as their daily point-of-sale tobacco exposures increased would be especially likely to experience a lapse.

Methods

Participants

Participants were Washington DC (DC) resident smokers who contacted the DC Tobacco Quitline (DCQL), were aged >18 years, and subsequently quit smoking for at least 24 hours. The study was approved by Western IRB, and data collection took place between July 2010 and February 2012. Smoking and abstinence status were bio-verified via expired carbon monoxide and saliva-based nicotine testing. Participants were offered the option of tracking their location to learn more about the influence of environmental factors on their cessation experience. Of those offered the tracking option ($n=531$), consent was obtained from 486 (92%), and tracking was successfully conducted with 475 participants (89%) over their first month of cessation.

Demographic characteristics of this relatively homogenous sample were representative of DCQL callers between 2005 and 2010 (Table 1). The geographic distribution of the sample's home addresses corresponds closely to estimates of the geographic distribution of tobacco prevalence across the DC City Council Wards,²⁶ supporting the representativeness of the sample regarding overall patterns of association between sociodemographics and smoking prevalence in DC. Self-reported daily 30-minute physical activity status was assessed and controlled for in all analyses, along with nicotine dependence and the other smoking-related and sociodemographic variables (Table 1).

Geospatial Location Tracking

Individual mobility was measured via wireless cellular telephone geo-location tracking, recorded every 15 minutes over the 1st month of the cessation attempt. GPS coordinates were captured with the SiRFstar III chipset within Blackberry 9330 smartphones, distributed for use during the study. MAC-address (i.e., "wifi hot-spot") and cellular-tower triangulation provided location coordinates when GPS was unavailable. Geo-location data were securely uploaded to an ArcGIS Tracking Server located behind the Legacy IT firewall, processed and cleaned, including removal of coordinates with a margin of error ≥ 30 m. Average margin of error for the remaining 92% of the data was 6.08 m (SD=3.25 m).

Point-of-sale exposure—Annual tobacco retail licensure records (N=1060) were obtained from the DC Department of Consumer and Regulatory Affairs (DCRA) via a data-sharing agreement between the Schroeder Institute and the DC Department of Health. ArcGIS software (Version 10.1) was used to geo-code the location of each outlet referencing the DC Master Address Repository, and this geospatial data set was field-verified during data collection.²⁷ For the present analyses, the ArcGIS point proximity tool was used to surround each outlet by a circular "Euclidian buffer" extending 30 m from the centroid of the building, and daily variation in the frequency that each person's real-time location fell within the spatial boundary surrounding each outlet in DC was quantified. Additional detail about the POST landscape encountered by participants is presented elsewhere.^{18,27}

Craving—Participants used the mEX support system to create a real-time record of their cessation experience. An EMA protocol within the mEX system administered three daily random prompts to make an entry (plus a fourth if the user opted not to put the software to sleep overnight). Compliance relative to an EMA protocol of this sort was excellent, with responses to 79% of random prompts. EMA records were used to calculate the average daily craving level reported by each participant. Of note, momentary craving was not assessed when participants reported a smoking event, so daily craving levels do not include ratings from self-initiated entries that would have been immediately affected by smoking.

During nonsmoking, randomly prompted entries, severity of temptation to smoke (i.e., craving) was assessed with the item *Right now, how much do you want to smoke a cigarette, cigar, or pipe?* on a single 0–10 scale (0=Not at all, 10=Extremely). Use of a single-item craving assessment follows the recommendation of the Society for Research on Nicotine and Tobacco work group on the assessment of craving,²⁸ which concluded that single-item measures are preferable, allowing the measure to reflect craving at the particular moment of the report, minimizing the intrusiveness of the report itself, and decreasing the probability that completing the measure will affect the reported craving level.²⁹

Behavioral outcomes—Each day, participants' self-reported entries were used to classify their current smoking status as either actively quitting and abstinent, actively quitting with a recent "slip" or lapse, or no longer trying to refrain from use (i.e., relapsed). Days were excluded from the analysis if they occurred after the point that a participant reported having

given up and was no longer attempting to remain abstinent. During each random or self-initiated entry, active quitters reported whether they had smoked in the preceding 2 hours (i.e., whether they had “lapsed”). Participants could also report tobacco use during an end-of-day summary report. Self-reported use data were closely associated with 1-month abstinence testing, with 100% agreement among those admitting to recent lapses or relapse, and 94% confirmed abstinence status among those reporting either continuous abstinence or isolated lapses more than 1-week prior to the 1-month checkpoint.

Data Analysis

Given a recurrent binary outcome variable (daily abstinence status), along with a recurrent count-based covariate (daily retail exposure counts), log-linear modeling techniques, developed to analyze multidimensional contingency tables, were utilized. Log-linear models convert the multiplicative relationships among joint and marginal counts in a contingency table to additive, linear associations by transforming the counts to logarithms.³⁰ Model coefficients and inference are similar to standard Poisson regression for counts, and thus, observed (i.e., ORs) and model estimated probabilities (i.e., log-odds) are reported here. Mixed-effect models were used to account for many observations clustered within participants over time. Negative binomial rather than Poisson models were used to deal with slight overdispersion, which was also mitigated by the inclusion of random intercepts for each participant. To probe significant effects and clarify the results, model-based predicted values were calculated and then converted to represent the relative odds of a lapse associated with each additional POST outlet exposure.

Results

Participants' (N=475) smoking status and geographic location were tracked continuously over the first month of their cessation attempt (M=27.1 days, SD[within]=3.7), producing a data set spanning a total of 12,871 days. Lapses were recorded on 26.3% of all days (N=3381, M[within]=29%), with 86.7% (n=411) of participants lapsing on at least 1 day. Participants recorded a lapse on an average of 7.1 days (SD=8.6; median=4.0). Participants who relapsed by 1-month follow-up (biochemically verified; 25.5%; n=121) averaged 7.3 lapse days (SD=8.8; median=4.0) prior to relapse; those who did not relapse averaged 6.6 lapse days (SD=8.3; median=4.0).

Exposure

A majority of subjects' real-time locations fell within the DC municipal boundary (87%) and followed redundant daily patterns of movement, which is consistent with human mobility research.^{14,22} All participants came into contact with POST, averaging 2.7 contacts per day (SD=5.7, median=1.0; Figure 1, left axis), on 57.1% (n=7347) of all days, for an average total of 72.6 (SD=143.9) contacts. Variation in the average number of daily retail exposures was significant both between individuals and over days.

Figure 1 presents the within-subjects SD (circles, right axis), along with the range of SD among subjects (error bars, right axis) across average levels of daily exposure. It is apparent that greater average daily exposures are associated with greater variation in daily exposures, although the graphic also suggests that the range of SDs among participants with the same daily average was fairly stable, ranging between three and six daily exposures from the mean.

Exposure and Daily Outcome

Log-linear models of the link between POST exposure counts and daily outcomes revealed a significant pattern of association. Overall, lapsing was more likely on days with any POST

contact (OR=1.19 [95% CI=1.18, 1.20]), and increasingly likely as the number of daily POST contacts increased (OR=1.07 [95% CI=1.06, 1.08]). To illustrate and improve interpretation of this finding, the model was used to calculate the predicted relative odds of a daily lapse across all levels of POST contact (Figure 2, dummy ORs). These ORs reflect the odds of a daily lapse given each level of POST exposure versus no daily POST exposure at all. Upward from one-or-more (i.e., any) contacts, the incremental effect of each 1-unit increase in the number of daily POST contacts versus all previous levels of POST contact is also presented (Figure 2, step-wise ORs). This analysis revealed that the incremental effect of another POST contact was highly significant (mean OR=1.26) and reasonably stable (range: 1.11–1.38).

Exposure and Craving

Contrary to a priori expectation, results indicated that daily POST contacts were not associated with corresponding daily craving levels ($\beta=0.007$, $p=0.26$). In fact, a trend in the observed data suggests that the number of average daily POST contacts was greater ($M=2.7$, $SD=5.6$) when corresponding daily craving was zero, while daily POST contacts were lower when daily craving was elevated, both at the low ($M=2.5$, $SD=5.8$) and high ends of the continuum ($M=2.5$, $SD=5.75$).

Craving and Daily Outcome

Daily craving levels varied significantly across all days (i.e., within subjects), as well as among individuals. Craving was reported to be zero on about half of the study days (50.6%; $n=5569$); it was reported to be in the low range of the scale (≤ 5) on 33.4% ($n=3677$) of days and on the high end of the scale (>5) on the remaining 15.9% ($n=1751$) of days. Participant lapse days were characterized by elevated daily craving levels, such that relative to days with zero craving, the odds of a lapse day were more than twice as likely when craving levels were reported to be in the low range (OR=2.05 [95% CI=2.04, 2.06]), and more than three times as likely when craving levels were >5 on the scale (OR=3.23 [95% CI=3.21, 3.24]).

Exposure, Craving, and Daily Outcome

Contrary to expectation, the association between POST contacts and lapsing was especially strong in the absence of craving (OR=1.22 [95% CI=1.20, 1.23]), while it progressively decreased by 9% when it was associated with low craving levels (OR=1.13 [95% CI=1.12, 1.14]), and decreased by another 13% and to nonsignificance when associated with high daily craving (OR=1.0 [95% CI=0.99, 1.01]). Model-predicted odds of a lapse at different levels of POST contact and craving indicated that across all levels of POST contact, when daily craving was zero (50% of observed days), the significant association between POST exposure and lapsing emerged beginning at POST Contact 6 (OR=1.15 [95% CI=1.12, 1.18]), and beyond (ORs >1.35 ; Figure 3). A significant association between POST exposure and lapsing was also apparent when daily craving was elevated but low, beginning at POST Contact 8 (OR=1.07 [95% CI=1.01, 1.12]) and beyond (ORs >1.17 ; Figure 3).

Discussion

This paper describes the use of a methodologic approach that provides real-time data on the degree to which individuals are exposed to POST as they move through their daily activities, as well as the way accumulating POST exposure is associated with subjective drug-craving and individual-level use patterns. Results demonstrate that quantification of individuals' exposure to POST advertising can be used to identify previously unrecognized patterns of association among individual mobility, the built environment, and behavior.

Overall, daily POST exposure was significantly associated with lapsing when craving was low, whereas craving was observed to be associated with lapse outcomes more directly on days characterized by high craving levels. Nonetheless, even at relatively low levels of exposure, the association between increasing numbers of daily POST contacts and outcomes progressively overshadowed that of low to moderate levels of daily craving, occurring on a large majority of days (Figure 3). Put another way, it appears that exposure to POST mattered most when the temptation to smoke was otherwise low, perhaps because these were days on which participants were less likely to lapse if left unprovoked.

Findings contradict the authors' a priori expectations regarding the association among POST exposure, craving, and outcomes, but they reveal an interesting pattern of results that is consistent with what has been observed in both EMA studies of craving^{31,32} and laboratory-based cue-reactivity research.²⁵ As in the present study, the association between cue-induced craving and behavior has been found to weaken as background levels of craving become more intense, presumably due to a kind of "ceiling effect," beyond which there is insufficient variation in craving for cues to affect it. This possibility is consistent with data from the nicotine replacement therapy literature, which show that modalities that lower overall "background" craving do not protect against peaks in craving triggered by cues,^{33,34} and that combination tonic and phasic nicotine replacement therapy approaches (i.e., those that administer nicotine continuously [e.g., patch] versus all-at-once [e.g., gum], respectively) produce incremental, additive efficacy, while simply increasing nicotine dose does not.^{35–37} This pattern of results may also be relevant for understanding nondaily or otherwise light smoking patterns, as light smokers have been found to be more affected by shifts in craving^{25,38} and thus may be more sensitive to environmental cues than heavier smokers.

Strengths and Limitations

The comprehensive real-time observational design presented here has several strengths: (1) it enhances external validity by capturing both intended and unintended POST contacts. Although individuals sometimes self-select when and where they come into contact with POST, a majority of POST contacts are unintended, occurring as part of daily activities. These data suggest that such unintended POST contacts affect tobacco use behavior above and beyond that which would reasonably be expected in a self-selected purchase-only model; (2) this approach also provides valuable data on the large majority of geospatial locations that did not include POST, something that is critical in determining relative effects of exposure; and (3) this approach captures the dynamic interplay among POST factors, individuals' active engagement with their environment, and naturally occurring tobacco use behaviors.

A limitation of the design is its inability to allow for strong causal-inference statements. To make such direct inferences, researchers would need to experimentally randomize or otherwise manipulate individuals' exposure to a point-of-sale environment, a design that would be logistically unfeasible, as well as making it difficult to disentangle the complex and dynamic influence of real-world POST versus that being manipulated and delivered. As they stand, the observed data reveal a counterintuitive pattern that is informative despite the lack of an experimental design.

Other limitations include the time resolution of the geospatial location data, which at every 15 minutes were relatively frequent considering the 1-month length of the observation period, but certainly could have been more frequent and thus enabled greater coverage of contacts with POST, as well as estimation of contact duration and travel mode (based on distance traveled between points). Finally, the generalizability of the data are limited. They

are representative of a fairly homogeneous population navigating a dense urban landscape; extensions to other populations and to rural landscapes require additional research.

Conclusion

Interest in the link between the local built environment and health is growing rapidly.^{39,40} A common assumption is that health-related factors measured at the community level have a proportionate, stable association with individual community members' experience on a daily basis. Findings of the present study contradict this assumption, indicating that there are large individual differences in mobility patterns that drive a dynamic interaction of individuals with their surroundings over time. The current study adds to the emerging literature on methods that link people to the retail environment, revealing novel, bidirectional and cross-level influences on health outcomes.⁴¹

This methodology is not restricted to research on tobacco. There are more general implications for the study of individual behavior change dynamics as they relate to the real-time built environment, as well as regulatory policies that vary across neighborhoods. For example, results suggest that real-time quantification of exposure to products available at point-of-sale could provide valuable information about decision-making, and acquisition and consumption of alcohol and/or high-calorie food and beverages. Directly linking point-of-sale practices to health-related behavioral decision-making may provide much needed empirical support for "narrowly tailored" regulatory actions. Future work should incorporate POST alongside other policy-relevant community-level health factors such as those associated with food and alcohol products. Extensions should also incorporate the full spectrum of sociodemographic factors among youth and young adults, as well as additional information on product purchase and use trajectories, especially patterns of product experimentation, switching, and "dual" or concurrent product use.

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Figure 1.
Distribution of average daily retail exposures and SDs

Figure 2.
Relative probability of a lapse as a function of daily POST contacts
POST, point-of-sale tobacco

Figure 3.
Relative probability of a lapse as a function of daily POST contacts and daily craving level
POST, point-of-sale tobacco

Table 1Participant demographics ($n=475$)

Variable	M	SD	IQR
Age, years	44.71	11.05	38.0 : 53.0
Cigarettes per Day	12.1	9.29	6.0 : 15.0
Years Smoking	23.86	11.98	15.0 : 34.0
Number of Previous Quits	5.43	3.57	2.0 : 10.0
FTND (0–10)	4.76	2.02	3.0 : 6.0
	%	<i>n</i>	IQR
Gender: Male	0.66	312	0.0 : 1.0
Ethnicity: African-American	0.94	446	0.0 : 1.0
Education: high school graduate	0.76	363	0.0 : 1.0
Married: yes	0.17	83	0.0 : 1.0
Daily physical activity (30 minutes): yes	0.64	305	0.0 : 1.0
Menthol Preference: Yes	0.71	389	0.0 : 1.0

FTND, Fagerstrom Test of Nicotine Dependence (0–10); IQR, interquartile range;