Youth daily exposure to tobacco outlets and cigarette smoking behaviors: does exposure within activity space matter?

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ABSTRACT

Aims To examine whether daily exposure to tobacco outlets within activity spaces is associated with cigarette smoking and with the number of cigarettes smoked by youth that day. **Design** The study used geographic ecological momentary assessment (GEMA) data that combined daily surveys with ecological momentary assessment of global positioning systems (GPS) using geographic information systems (GIS) to allow for real-time data collection of participants' environments and behaviors. **Setting** Eight mid-sized California (USA) city areas. **Participants** The analytical sample included 1065 days, which were clustered within 100 smoker and non-smoker participants (aged 16–20 years, 60% female). **Measurements** Any cigarette smoking and number of cigarettes smoked on a given day, the number of tobacco outlets within 100 m of activity space polylines each day, the number of minutes participants spent within 100 m of tobacco outlets each day and demographic characteristics (age, sex, race/ethnicity and perceived socio-economic status). **Findings** Controlling for demographic characteristics, the findings of multi-level mixed effects logistic models were inconclusive, whether or not the number of tobacco outlets within 100 m of youths' activity space polylines or the number of minutes spent within 100 m of tobacco outlets were associated with whether the participant smoked cigarettes on a given day [odds ratio (OR) = 1.05, $P = 0.24$; OR = 0.99, $P = 0.81$, respectively]. However, in multi-level zero-inflated negative binomial models, the risk of smoking an additional cigarette on a given day increased with each additional tobacco outlet [incidence rate ratio (IRR) = 1.04, $P < 0.05$] and each additional minute spent within 100 m of tobacco outlets (IRR = 1.01, $P < 0.001$) each day. **Conclusions** Among young people in urban California, differences in day-to-day exposure to tobacco outlets within activity spaces does not seem to be significantly associated with whether a person smokes a cigarette on a given day, but higher exposure to tobacco outlets appears to be positively associated with the number of cigarettes smoked on that day.

Keywords Activity space, cigarette smoking, GEMA, retail access, tobacco outlets, youth.

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Submitted 10 September 2019; initial review completed 9 December 2019; final version accepted 31 January 2020

INTRODUCTION

Tobacco use remains the leading cause of preventable death globally [1]. It has long been known that initiation of tobacco use during the adolescent and young adult years contributes to continued use in adulthood [2]. Understanding the factors that contribute to young people's risk for engagement with tobacco has both short- and long-term prevention and public health applications.

Ecological models of health behavior stipulate that the environments in which individuals spend their time impact their health risks and behaviors [3]. Tobacco outlet density is hypothesized to be one important environmental factor that may be associated with tobacco use through a variety of mechanisms including increased access which may be higher in socio-economically deprived areas, exposure to marketing, exposure to others who use this substance (i.e. role models) or through favorable tobacco use norms in the landscape of available goods in the

community [4–11]. Extant research has investigated the impact of tobacco outlet density around young peoples' homes and schools and their tobacco use [12–15], and a recent meta-analysis suggests that density around homes may be a particularly salient risk [16].

Although relying on indicators of tobacco outlet density around young people's homes and schools plays an important role in understanding how these environmental characteristics may negatively impact health, they may fail to capture potential exposure to tobacco outlets within activity spaces or the broader environments where youths spend their time. For example, exposure may occur in other settings such as traveling to and from locations, community centers, parks or malls. Indeed, a pilot study found that traditional measures of tobacco outlet density around homes and schools may misrepresent youths' environmental exposures [17]. A small body of work has examined the impact of tobacco outlet exposure within activity spaces on individuals' smoking behavior. A study of young adults found that the mean proximity of tobacco outlets within an individual's activity space was associated with smoking [18]. Among adolescents, a study showed that young people experience considerable exposure to tobacco outlets within their activity spaces and that frequency of exposure increases within income deprived areas [19]. Further, among 16–20-year-olds, greater numbers of tobacco outlets within activity spaces were associated with greater tobacco use on a given day through exposure to peer use [20]. Although this research area is growing, there is a paucity of studies exploring to what extent youths' exposure to tobacco outlets within their activity spaces is an important determinant of cigarette smoking behaviors. Such research may inform policy and prevention programs designed to limit exposure to tobacco outlets in young people's daily lives and would highlight the importance of considering areas that go beyond residential or school neighborhoods in research and practice.

Therefore, the current study extends past research on tobacco outlet density around youth specific locations to also include youths' activity spaces. Specifically, this study uses geographic ecological momentary assessment (GEMA) data combining daily surveys with ecological momentary assessment of global positioning systems (GPS) using geographic information systems (GIS) to allow for real-time data collection of participants' environments and behaviors. Specifically, the following research questions were examined.

1 Are daily number of tobacco outlets within 100 m of activity space's polylines or the number of minutes within 100 m of outlets associated with cigarette smoking by youth that day?
2 Are these exposure indicators associated with the number of cigarettes smoked that day?

METHODS

Study cities and participants

Study cities

We collected data from youth aged 16–20 years (n = 101 participants) in eight mid-sized California city areas. Cities were selected from an existing geographically diverse sample of 50 non-contiguous California cities (population range = 50 000–500 000) [13,21]. To select the eight cities, we considered cities within a 50-mile radius of Oakland, CA, where our research center was located at the time of the study. Of the 50 cities, 11 met this criterion. To maximize variation in youth exposure to tobacco outlets in their living environments, we first stratified these cities based on measures of socio-economic status (SES) (i.e. a measure derived from median household income, percentage of population with a college education and percentage of population unemployed) and tobacco outlet density (i.e. number of licensed tobacco outlets per 10 000 people) and then randomly selected eight cities representing low versus high SES and low versus high tobacco outlet density. We recruited participants who lived in these eight cities or in cities that were within a 10-mile buffer of the eight cities. On 9 June 2016, California had raised the minimum tobacco sales age to 21, which applied to all cities across the state. Data collection occurred after the law went into effect (February 2017–May 2018).

Participants

We recruited participants through internet and social media advertisements, such as Craigslist and Facebook. Also, participants were recruited through flyers distributed to youth-serving organizations in the study cities, by contacting participants from a previous study and by referral. Potential participants were screened for eligibility (i.e. age, city of residence and speak English). Also, to assure enough power to address the aims of the overall project, the sample was stratified by tobacco use status at screening (~50% any past-month tobacco users). Parental consent was obtained for those younger than 18 years. All participants provided signed consent or assent to participate in the research. The Pacific Institute for Research and Evaluation (PIRE) institutional review board (Federal-wide Assurance no. FWA00003078) approved the study prior to implementation.

Procedures

Initial survey

After recruitment, participants completed an initial online survey (30 minutes), which included questions about demographic characteristics and past-month tobacco use.

GEMA

Using GPS-enabled smartphones with a survey application, participants then responded to brief daily surveys and location coordinates (latitude and longitude) were obtained at 1-minute intervals for 14 days. The research team provided GPS-enabled telephones to participants and briefed them about study procedures. The phone survey application was programed to send reminders to complete the survey each evening at 8 p.m. Youth had a 3-hour window to respond to the survey each day. Each participant in the study provided, on average, 11.4 days of data (range = 4–14 days).

Incentives

As compensation for their time, participants could receive up to $150. They received $10 for completing the initial survey, $5 for each daily survey and a $20 bonus if they completed all surveys. Additionally, they received $40 for returning the phone at the end of the study and $10 for returning the charger. Participants could use the telephones with unlimited texting and calling during the study. Upon completion of the study, they received a resource card that included links to resources and referral information on how to quit tobacco.

Analytical sample

Data were obtained from participants for a total of 1483 days. From this total, we excluded data for days in which participants were tracked for less than 360 minutes (n = 123), and for some participants for days that exceeded the 14 study days (n = 73). Of the remaining 1287 days, 222 days were missing study variables used for the analyses. The final analytical sample therefore included 1065 days, which were clustered within 100 participants. Sample characteristics are in Table 1.

Measures

Cigarette smoking behaviors

Each day, participants were asked: 'Since this time yesterday, did you smoke at least one cigarette?'. Response options were 'yes' (coded as 1) or 'no' (coded as 0). Those who responded 'yes' were also asked: 'How many cigarettes did you smoke since this time yesterday?'. Participants indicated the number of cigarettes they smoked. Those who responded 'no' to the first question received a value of 0 to this question.

Exposure to tobacco outlets within activity space

Using the Dun & Bradstreet, Inc. (D&B) commercial list, the North American Industry Classification System (NAICS) codes were used to identify probable tobacco outlets in the eight cities and within a 10-mile buffer of city boundaries. Specifically, probable tobacco outlets were searched using the NAICS codes of the top 10 retail industries that sell tobacco products, including supermarkets and other grocery (except convenience) stores (445 110), convenience stores (445 120), tobacco stores (453 991), gasoline stations with convenience stores (447 110), warehouse clubs and supercenters (452 910), news dealers and news-stands (451 212), beer, wine and liquor stores (445 310), pharmacies and drug stores (446 110), discount department stores (452 112) and other gasoline stations (447 190). These codes are industries that represent approximately 98% of all tobacco sales and were used in a study that validated the use of commercial lists to identify tobacco outlets in states that do not have a comprehensive list of tobacco outlet addresses [22]. Chains

Table 1 Study variables and sample characteristics.

	Percentage (n)	*Mean (SD)*	*Range*
Daily exposures and behaviors (n = 1065 days)			
Number of outlets within 100 m of activity space polylines		4.27 (4.95)	0.00–27.07
Number of minutes within 100 m of outlets within activity space		17.09 (47.29)	0.00–573.00
Any cigarette use on a day	9.95 (106)		
Number of cigarettes per day, full sample		0.40 (1.53)	0.00–18.00
Number of cigarettes per day, cigarette smokers only		1.76 (2.81)	0.00–18.00
Tobacco use history and demographics (n = 100)			
Past month tobacco use	33.7 (34)		
Past month cigarette smoking	17.8 (18)		
Female	60.00 (60)		
Non-Hispanic white	37.00 (37)		
Age		18.16 (1.50)	16.00–20.00
Subjective SES[1]		3.80 (1.37)	1.00–7.00

[a]Seven-point scale from poor (1) to rich (7). SES = socio-economic status; SD = standard deviation.

with policies restricting the sale of tobacco (e.g. Target and CVS) were excluded from the list. To ensure that our study included places that sell alternative nicotine delivery systems (ANDS) but do not sell other tobacco products (e.g. hookah bars), we conducted an on-line search of places that sell hookahs and e-cigarettes in study areas. All identified tobacco outlets were contacted by telephone to verify business status, sale of tobacco products, address and hours of operation. Next, these outlets were visited by observers to record outlet GPS point locations and obtain data concerning tobacco products and marketing (not reported in the current study).

Tobacco outlet addresses and participants' GPS locations were geocoded, and activity spaces were constructed by joining sequential GPS points into a polyline, which was then buffered and overlaid with tobacco outlet locations. An example of a participant's activity space and our approach has been published previously [20]. Exposure measures included (a) the number of tobacco outlets within 100 m of activity space's polylines each day and (b) the number of minutes participants spent within 100 m of tobacco outlets. These measures were weighted by the time participants were within the study area each day.

Control variables

All control variables were obtained from the initial survey and included sex assigned at birth (male, female or intersex), race/ethnicity (non-Hispanic white), age and perceived SES. Perceived SES was a continuous variable that asked participants: 'Compared with other people in America, how rich or poor do you consider yourself?'. Respondents could answer on a seven-point scale ranging from rich to poor. We reverse coded these responses (1 = poor; 7 = rich) for the analyses. Previous research has found that perceived SES is associated with health behaviors [23–25].

Tobacco use history

In the initial survey, participants were asked about past-month tobacco use, including use cigarettes, cigars, cigarillos or little cigars, blunts, smokeless tobacco or e-cigarettes. These items were used to describe the tobacco use history of the sample.

Data analysis

We first examined means, standard deviations (SDs) or frequencies of study variables. Next, to assess the associations between any cigarette smoking on a given day (outcome) and exposure to tobacco outlets within activity spaces (exposure measures), we used multi-level mixed-effects logistic models to control for clustering of observations within participants over time. Finally, preliminary specification tests indicated that the number of cigarettes smoked outcome was negative binomial distributed with considerable zero inflation. Therefore, zero-inflated negative binomial models were used to assess the associations between the exposure measures and this outcome, with a sandwich variance estimator to correct for loss of unit independence related to nesting of assessments within participants. A logistic distribution was assumed to represent zero inflation and further specification tests were conducted to assess correlates of this component of each analysis model; each covariate was tested separately to be included in the inflation equations. As none of the covariates were significant, only the constant estimate was included in the zero-inflation component of the models. The intraclass coefficients (ICCs) for cigarette smoking and number of cigarettes smoked on a given day by city were 0.12 and 0.04, respectively, suggesting that participants' cities had small effects on daily cigarette smoking behaviors. Analyses were conducted with Stata version 15.0. We ran separate models for each of the exposure measures due to multicollinearity of these measures. For all analyses, we set critical $\alpha = 0.05$ and used two-tailed statistical tests. Sensitivity analyses were conducted restricting the sample to only participants who reported any cigarette smoking during the GEMA (GEMA cigarette smokers; 243 observations clustered within 23 participants). As the analysis was not pre-registered, the results should be considered exploratory.

RESULTS

Sample characteristics and descriptive statistics

Of the 100 participants, 60.0% ($n = 60$) were female and more than a third identified as non-Hispanic white (37.0%, $n = 37$). Participants' mean age was 18.16 (SD = 1.50). Subjective SES was approximately average on the seven-point scale (mean = 3.80, SD = 1.37). In the initial survey, 33.7% ($n = 34$) reported past-month use of any tobacco product and 17.8% ($n = 18$) reported smoking part or all of a cigarette during the past month. In the daily surveys, cigarette smoking was reported on 9.95% of the 1065 study days ($n = 106$ days), and on average participants reported smoking 0.40 (SD = 1.53) cigarettes each day (range = 0.00–18.00). Among those who reported cigarette smoking during the GEMA, the average number of cigarettes smoked was 1.76 (SD = 2.81; range = 0.00–18.00). In terms of exposure to tobacco outlets, participants were exposed to an average of 4.27 (SD = 4.95) tobacco outlets within 100 m of activity space polylines per day. On average, they were within 100 m of tobacco outlets for 17.09 minutes (SD = 47.29) per day. Study variables, sample characteristics and tobacco use history are in Table 1.

Cigarette smoking and exposure to tobacco outlets in activity spaces

Any cigarette smoking on a given day

Controlling for demographic characteristics (age, sex, race/ethnicity and perceived SES), the findings were inconclusive as to whether either the number of tobacco outlets within 100 m of youths' activity space polylines or the number of minutes spent within 100 m of tobacco outlets were associated with whether the participant smoked cigarettes on a given day (Table 2). Restricting the sample to GEMA cigarette smokers, findings were the same for the number of outlets within 100 m of activity spaces polylines [odds ratio (OR) = 1.07, confidence interval (CI) = 0.98, 1.16] and the number of minutes spent within 100 m of tobacco outlets (OR = 1.00, CI = 0.98, 1.02).

Number of cigarettes smoked on a given day

Controlling for demographic characteristics, exposure to each additional tobacco outlet within 100 m of activity space polylines on a given day increased the risk of smoking an additional cigarette that day by 4% [incidence rate ratio (IRR) = 1.04, $P < 0.05$]. Similarly, each additional minute spent within 100 m of tobacco outlets increased the risk of smoking an additional cigarette, controlling for demographic characteristics (IRR = 1.01, $P < 0.001$). Results are displayed in Table 3. Restricting the sample to GEMA cigarette smokers, results were the same for the number of tobacco outlets within 100 m of activity space's polylines (IRR = 1.04, CI = 1.01, 1.07; $P < 0.05$) and the number of minutes within 100 m of tobacco outlets (IRR = 1.01, CI = 1.00, 1.01; $P < 0.001$) exposures.

DISCUSSION

We investigated the associations of cigarette smoking behaviors with the number of tobacco outlets that 16–20-year-old youths were exposed to on the day and time that they spent within proximity of those outlets. By considering exposure to tobacco outlets in the broader environments where participants interact daily, this study addresses an important gap in extant research about environmental risks for cigarette smoking in the youth population [16]. We found that among young people, differences in day-to-day exposure to tobacco outlets within activity spaces was not uniquely associated with whether a participant smoked a cigarette on a given day, but was

Table 2 Results of multi-level mixed effects logistic regression model to assess associations between exposure to tobacco outlets within activity spaces and any cigarette smoking on a given day.

	Any cigarette smoking per day			
	OR (95% CI)	*P-value*	*OR (95% CI)*	*P-value*
Number of outlets within 100 m of activity space polylines	1.05 (0.96, 1.15)	0.242	–	–
Number of minutes within 100 m of outlets within activity space	–	–	0.99 (0.98, 1.01)	0.813
Age	1.62 (0.74, 3.55)	0.229	1.61 (0.75, 3.51)	0.224
Female	0. 82 (0.93, 7.31)	0.861	0.89 (0.10, 7.92)	0.916
Non-Hispanic white	0.74 (0.77, 7.11)	0.797	0.78 (0.10, 7.39)	0.830
Subjective SES	0.61 (0.26, 1.44)	0.262	0.62 (0.28, 1.36)	0.234

SES = socio-economic status; OR = odds ratio; CI = confidence interval.

Table 3 Results of zero-inflated negative binomial regression model to assess associations between daily exposure to tobacco outlets within activity spaces and number of cigarettes smoked per day.

	Number of cigarettes smoked per day			
	IRR (95% CI)	*P-value*	*IRR (95% CI)*	*P-value*
Number of outlets within 100 m of activity space polylines	1.04 (1.01, 1.06)[a]	0.004	–	–
Number of minutes within 100 m of outlets within activity space	–	–	1.01 (1.00, 1.01)[b]	0.000
Age	0.99 (0.68, 1.45)	0.964	0.94 (0.65, 1.37)	0.765
Female	1.24 (0.66, 2.33)	0.500	1.12 (0.65, 1.95)	0.676
Non-Hispanic white	1.18 (0.78, 1.81)	0.420	1.15 (0.78, 1.73)	0.474
Subjective SES	0.79 (0.69, 0.91)[b]	0.001	0.79 (0.69, 0.90)[b]	0.000

SES = socio-economic status; IRR = incidence rate ratio; CI = confidence interval. [a]$P \leq 0.05$; [b]$P \leq 0.001$.

positively associated with the number of cigarettes smoked on that day.

Past research by Shareck and colleagues has found that the number of tobacco outlets within 500 m of young adults' regular activity locations (i.e. studying, working, grocery shopping, physical activity, leisure activity and other activities) is associated with smoking status (i.e. being a current smoker) [18]. Although the current study found no association between exposures to tobacco outlets within youths' activity spaces on a given day and smoking any cigarettes on that day, exposure and time spent near outlets were both associated with the number of cigarettes youth smoked. These results complement and extend Shareck and colleague's findings by assessing earlier in the life-span (16–20 versus 18–25 years), a new location (California, USA versus Montreal, Canada), and a novel assessment of the outcomes (smoking on a given day versus cross-sectional assessment of smoking status). Further, whereas in the current study we used GPS tracking data to assess participants' environments and exposure to tobacco outlets in real time, the previous study used a retrospective activity space questionnaire to collect information on respondents' regular activity locations and assessed the number of tobacco outlets within 500 m of those locations. To the best of our knowledge, no other published study has considered the association between tobacco outlet activity space exposures and cigarette smoking behaviors among young people using real-time measures. Additional research is needed to accurately assess individual travel patterns and the retail environment to understand cigarette smoking and other tobacco use behaviors among this vulnerable population [19,26,27].

We found that the number of and time around tobacco outlets within activity spaces each day were associated with the number of cigarettes participants reported smoking on that day but not their cigarette smoking status on that day. It is possible that effects of exposure to tobacco outlets on young people's cigarette smoking status may be long term and may accumulate through perceived community norms and exposure to point-of-sale tobacco marketing. In other words, perhaps it is less of a momentary process, but rather the impact of consecutive exposures over time. Indeed, using traditional measures of youths' exposure to tobacco outlets around their homes, previous cross-sectional research has shown that living in neighborhoods with greater numbers of tobacco outlets was associated with life-time, past-month or past-year cigarette smoking among young people [12–15].

However, daily exposure to tobacco outlets within activ-ity spaces seems to matter for cigarette smoking quantity such that, on any given day, exposure to an additional to-bacco outlet increased the likelihood of youth smoking an additional cigarette by 4%. Although these small effect sizes are similar to those identified in a recent meta-analysis examining tobacco outlet density around residential areas and adolescents' past-month cigarette smoking status [16], the studies in the meta-analysis were based on much larger samples and varied greatly in how variables were defined across studies. Moreover, the outcomes are different (i.e. smoking quantity versus status), making it difficult to compare. Our current results suggest that, unlike the effects on cigarette smoking status or initiation on a given day, the effects of daily exposure to tobacco outlets on cigarette quantity may be momentary via creating more opportunities for youth to illegally buy cigarettes through tobacco outlets. A review paper that evaluated efforts to prevent the sale of tobacco to youth concluded that every intervention that has successfully disrupted the sale of tobacco to minors has been associated with an observed reduction in tobacco use among youth [28]. Also, similar to findings among adults, perhaps exposure to outlets reinforces this health risk habit as youth are cued through seeing tobacco marketing, others smoking or are simply reminded of cigarettes in these environments [26,27].

Results of the current study present several important prevention implications. First, they suggest the importance of policies to regulate young people's exposure to tobacco outlets beyond residential or school neighborhoods. The findings also provide support for regulating youth access and availability of cigarettes through retail outlets. Reducing availability of tobacco products may be important for the youth population in general, but in particular for youth in socially disadvantaged areas who encounter high levels of exposure to tobacco outlets in their daily routine activity spaces [19] or in communities with greater youth retail access to tobacco [29]. Finally, results of the current study emphasize the importance of considering individuals' travel patterns and activity spaces when assessing exposure to tobacco outlets and tobacco use behaviors.

A few study limitations should be noted. First, the data came from a convenience sample of youth in California and results may not generalize to other populations or locations. Secondly, we relied on self-reported measures of cigarette smoking behaviors. Assessment of smoking status through other mechanisms (e.g. salivary cotinine) in future research may enhance the validity of these reports. Thirdly, we did not control for or consider other potential factors that may have influenced youth cigarette smoking behaviors such as family or peer tobacco use, tobacco beliefs, or exposure to other environmental factors, such as neighborhood deprivation or local smoking norms within activity spaces. Future research should operationalize and examine effects of momentary changes in such environmental factors within individuals' activity spaces. Finally, due to the cross-sectional design of the study, we cannot definitively determine the direction of causality. For example, although in the current study we obtained novel fine-grained spatial and temporal information on

individuals' mobility patterns, environmental exposures and behaviors, our analyses do not allow for examination of the possibility that youth may select into certain environments (e.g. tobacco outlets) based on their tobacco use behaviors (i.e. selective daily mobility) [30,31]. Despite these possible shortcomings, by using a cutting-edge methodology to assess the effects of real-time exposure to tobacco outlets on youth cigarette smoking, this study highlights the importance of considering young people's exposure to tobacco outlets in the broader environment where they interact daily for future research, policy development and prevention interventions.

Declaration of interests

None.

Acknowledgements

This research and preparation of this manuscript were supported by grant 25IR-0029 from the California Tobacco-Related Disease Research Program (TRDRP) and grant P60-AA006282 from the National Institute on Alcohol Abuse and Alcoholism (NIAAA) of the National Institutes of Health (NIH). The content is solely the responsibility of the authors and does not necessarily represent the official views of the TRDRP, NIAAA or NIH.

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