

## Cross-sectional and Longitudinal Associations of Neighborhood Social Environment and Smoking Behavior: the Multi-Ethnic Study of Atherosclerosis

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### **Abstract:**

**Background:** Social features of neighbourhood environments may influence smoking by creating a stressful environment or by buffering stress through social cohesion. However, the association of the overall neighbourhood social environment (NSE) with smoking, and the association of specific neighbourhood social factors with change in smoking behaviour over time, has rarely been examined. **Methods:** This study included 5856 adults aged 45–84 years from the Multi-Ethnic Study of Atherosclerosis (2000–2012, average follow-up: 7.8 years). Outcomes included current smoking status and smoking intensity (average number of cigarettes smoked per day among baseline smokers). NSE was assessed as a composite score composed of aesthetic quality, safety and social cohesion scales (derived from neighbourhood surveys). Generalised linear mixed models evaluated the association of baseline NSE (composite score and individual scales) with current smoking (modified Poisson models) and smoking intensity (negative binomial models) cross-sectionally and longitudinally. **Results:** Each SD increase in baseline NSE composite score was associated with 13% lower prevalence of smoking at baseline (adjusted prevalence ratio (aPR) 0.87 (95% CI 0.78 to 0.98). Neighbourhood safety and aesthetic quality were similarly associated with lower smoking prevalence (aPR 0.87 (0.78 to 0.97) and aPR 0.87 (0.77 to 0.99), respectively) but the association with social cohesion was weaker or null. No significant associations were observed for smoking intensity among baseline smokers. Baseline NSE was not associated with changes in smoking risk or intensity over time. **Conclusions:** Results suggest that neighbourhood social context influences whether older adults smoke, but does not promote smoking cessation or reduction over time.

**Keywords:** Neighborhood/place | social capital | smoking | psychological factors

## Article:

### Introduction

Despite declines in smoking prevalence over the past few decades,<sup>1,2</sup> smoking remains a major cause of preventable death worldwide. In recent years, researchers have increasingly focused on the impact of the neighbourhoods in which people live on health behaviours.<sup>3</sup> For example, low neighbourhood socioeconomic level has been found to be associated with higher smoking prevalence and decreased likelihood of smoking cessation.<sup>4-8</sup> Additionally, neighbourhood social factors including safety and social cohesion have gained increasing attention as potential contextual risk factors for smoking behaviour.

Specific aspects of the neighbourhood social environment theorised to be relevant to smoking behaviours include psychological stressors such as noise level or poor aesthetic quality,<sup>9,10</sup> perceptions of safety and crime in the neighbourhood,<sup>11-13</sup> and perceptions of social cohesion.<sup>11,14-16</sup> Prior studies have found that individuals living in neighbourhoods with higher levels of self-reported neighbourhood problems were more likely to smoke,<sup>9,10,15</sup> though not all studies found an association.<sup>17</sup> Similarly, studies have shown that people living in high crime areas had higher smoking prevalence<sup>12</sup> and were less likely to quit smoking,<sup>8,12</sup> likely a result of increased stress due to violence or disorder.<sup>11</sup> Fewer studies have evaluated the effect of neighbourhood problems and crime on smoking intensity, defined as the number of cigarettes smoked per day by current smokers. Prior work found no association with neighbourhood problems;<sup>9,17</sup> however, neighbourhood violence/crime was associated with higher smoking intensity.<sup>12,18</sup>

In addition to directly affecting smoking, neighbourhood social features may also buffer stress. Neighbourhood social cohesion, or how connected people feel with their neighbours,<sup>19</sup> is thought to influence health by promoting supportive neighbourhoods that buffer stress and connect residents to shared resources and services; this may in turn lead to adoption of healthy behaviours.<sup>20</sup> Prior research suggests that social cohesion may have a protective effect on smoking prevalence<sup>14,16,21</sup> although results for smoking intensity have been mixed.<sup>14,18</sup>

Although a number of studies have examined how neighbourhood social factors influence smoking behaviour, most prior research has been cross-sectional,<sup>9-12,14-17</sup> limiting causal inference. The association of neighbourhood social environment with smoking over time has been examined in only a few studies.<sup>18,22,23</sup> In addition, individual domains of the neighbourhood social environment such as social cohesion<sup>14-16</sup> and safety<sup>12</sup> have been examined separately, but studies have not integrated these distinct measures into one composite score to reflect the overall neighbourhood social context. In light of these knowledge gaps, this study aims to describe cross-sectional and longitudinal associations of the neighbourhood social environment (overall, and for the individual domains of aesthetic quality, safety and social cohesiveness) with smoking risk and intensity. We hypothesised that a better neighbourhood social environment would be associated with lower smoking prevalence and intensity at baseline. Furthermore, a better baseline neighbourhood social environment would be associated with greater reductions over time in smoking risk and intensity.

### Methods

## Study population

This study used data from the Multi-Ethnic Study of Atherosclerosis (MESA), a longitudinal cohort study of 6814 adults aged 44-84 and free of cardiovascular disease at baseline.<sup>24</sup> MESA participants were sampled from six US sites (Los Angeles, California; Manhattan and Bronx, New York; St. Paul, Minnesota; Chicago, Illinois; Baltimore, Maryland and Forsyth County, North Carolina). The baseline examination was conducted in 2000-2002, and four follow-up examinations were conducted between 2002 and 2012, with retention rates of 92.4% at year 2, 89.2% at year 3, 86.8% at year 5 and 75.7% at year 10. The Institutional Review Boards (IRB) at each MESA data collection site approved the study, and all participants provided informed consent. Drexel University IRB approved secondary analyses of these data under expedited category 7.

MESA participants (N=6191, 90.9% of the baseline sample) who participated in the MESA Neighborhood Study, an ancillary study to MESA which assessed neighbourhood environments and geocoded all residential addresses, were included. In the current study, we excluded those with missing outcome (N=53), exposure (N=108) or covariate data (N=33) and for whom the accuracy of geocoding was low (not at street level or zip+4 centroid level, N=23). In order to examine longitudinal associations of neighbourhood social environment on smoking, we included only participants who had outcome and exposure data from at least two examinations (N=5856, 95% of those in the neighbourhood study). Included and excluded participants were similar on most sociodemographic characteristics (see online supplemental table S1 ).

## Smoking outcomes

The primary outcomes included smoking status and smoking intensity. Both outcomes were assessed at each examination by self-report. Ever smoking was assessed by: 'Have you smoked at least 100 cigarettes in your lifetime?' and if the participant answered yes, current smoking status by: 'Have you smoked cigarettes in the past 30 days?'. In analyses, smoking status was dichotomised as current smoker versus former smoker/never-smoker. Smoking intensity was assessed among current and former smokers as follows: 'On average, how many cigarettes a day do/did you smoke?'. To reflect current habits, the number of cigarettes was recoded to 0 for baseline smokers who quit during follow-up at examinations subsequent to quitting.

## Neighbourhood social environment

The neighbourhood social environment was characterised using a composite score from subscales reflecting three domains: aesthetic quality, safety and social cohesion (box 1). Respondents were asked to rate an area within 1 mile of their residence. Questions were asked of MESA Neighborhood Study participants as well as an independent sample of community raters who were recruited from the same census tracts as MESA participants using random digit dialling or list-based sampling (the MESA Community Surveys).<sup>25</sup> MESA participants responded to each scale twice (social cohesion in 2000–2002, safety and aesthetic quality in 2003–2005, and all three scales in 2010–2012). We calculated baseline neighbourhood social environment scores for each participant as continuous variables based on the average score

reported at first measurement by all respondents (from the Neighborhood Study and Community Surveys) living within 1 mile of their residence, excluding the participant's own responses (range 1–738 respondents, mean 155, SD 168). This approach avoids the issue of same-source bias, in which individuals self-report both exposure and health outcomes and their health status affects how they report the exposure or vice versa.<sup>26</sup> The scales have good internal consistency (Cronbach's  $\alpha$  0.74–0.77), and test–retest reliability (0.65–0.88).<sup>25</sup> A 1-mile radius (Euclidian distance) was used instead of census tract because the survey defined neighbourhood as 'the area within about a 20 min walk (or about a mile) from your home'. In addition, census tracts vary in size across regions, are prone to the modifiable areal unit problem<sup>27 28</sup> and may be problematic for assigning neighbourhood characteristics to individuals living on the margins of the tract.<sup>29</sup>

**Box 1.** Neighborhood Social Environment Survey questions,\* the Multi-Ethnic Study of Atherosclerosis (MESA)

Domains and items:

*Aesthetic quality scale items*

- There is a lot of trash and litter on the street in my neighbourhood.
- There is a lot of noise in my neighbourhood.
- My neighbourhood is attractive.

*Safety scale items*

- I feel safe walking in my neighbourhood, day or night.
- Violence is not a problem in my neighbourhood.

*Social cohesion scale items*

- People around here are willing to help their neighbours.
- People in my neighbourhood generally get along with each other.
- People in my neighbourhood can be trusted.
- People in my neighbourhood share the same values.

\*Social environment questions were from MESA participants as well as community raters from the same census tracts. MESA participants completed each scale twice (social cohesion in 2000-2002, safety and aesthetic quality in 2003-2005, all three scales in 2010-2011). Community raters completed the scales in 2004 (5988 participants from the Maryland, New York and North Carolina study sites) and 2011-2012 (4212 participants from a subsample of census tracts in all six MESA sites). Response options were on a five-point Likert scale from 1 (strongly agree) to 5 (strongly disagree). Questions were rescaled as needed so a higher score reflected a more favourable neighbourhood environment.

Standardised z-scores were constructed for each participant for each subscale by centring at the mean and dividing by the SD across all time points. In this study, we assessed the effect of both the composite baseline neighbourhood social environment score and each of the separate subscales. The composite measure was constructed by summing the three standardised subscales, and then restandardising. All regression models report the effect of an SD increase in the neighbourhood domain of interest. For descriptive purposes, we calculated tertiles of neighbourhood social environment scores at baseline. We focused on baseline neighbourhood social environment because there was little change in neighbourhood social environment scores over the course of follow-up on average (intra-class correlation coefficients 0.94-0.97).

Covariates

Time-invariant individual-level covariates assessed at the baseline examination included baseline age (in years), gender, race (white, African-American, Hispanic, Asian), education (categorised as high school or less, some college/technical school/Associate's degree, Bachelor's degree or higher) and study site. Time-varying covariates included marital status (married/living with partner vs not), employment status (employed vs unemployed/retired), alcohol use (current use vs no current use), time since baseline (years) and income. Household income was assessed using a 13-category item with income categories ranging from <\$5000 to >\$100 000. A continuous income was constructed by assigning the midpoint of each category to participants who selected that category. This value was divided by the number of people in the household and adjusted for inflation to reflect the inflation-adjusted per capita household income. Sensitivity to alternative income definitions (categorical income or household, rather than per capita, income) was assessed, and results were found to be similar.

Neighbourhood-level socioeconomic status was evaluated using a composite measure that included the following census variables: log median housing value, per cent with a high school education, per cent with a Bachelor's degree, per cent in a managerial occupation, log median household income and per cent with interest/dividend income. Data from the 2000 US Census and the 2005-2009 and 2007-2011 American Community Surveys were used. Z-scores for each variable were summed to create the composite measure, with a higher score indicating higher census tract-level socioeconomic status.<sup>30</sup>

## Statistical analysis

Characteristics of the study population were described at each examination. We compared the distribution of sociodemographic characteristics between smokers and non-smokers, and by tertiles of baseline neighbourhood social environment scores.

We estimated cross-sectional and longitudinal associations of the baseline neighbourhood social environment scales with smoking outcomes using generalised linear mixed models (PROC GLIMMIX, SAS V.9.3, SAS Institute, Cary, North Carolina, USA). All models included repeated outcome measurements within participants over time (baseline and at least one additional measurement between examinations 2 and 5). We included a random intercept for each participant. The neighbourhood social environment domains were highly correlated ( $r=0.6-0.9$ ,  $p<0.0001$ ), thus, when using the disaggregated domains, each domain was modelled separately.

Smoking status was modelled using relative risk regression (via modified Poisson regression models with robust variance estimates).<sup>31 32</sup> Smoking intensity was modelled using negative binomial models to evaluate the effect of baseline neighbourhood social environment on the number of cigarettes smoked per day. Smoking intensity models included only the subset of the cohort who reported smoking at baseline ( $N=741$ ). We chose negative binomial models over Poisson as the distribution of the smoking intensity variable suggested overdispersion (mean across examinations 10.0, variance 162.9) and a likelihood ratio test indicated the negative binomial model was a better fit ( $p<0.0001$ ). In each model, we included the baseline neighbourhood social environment score, time since baseline (modelled continuously with

coefficients expressed in 5-year intervals for interpretability), and an interaction between the baseline score and time. The exponentiated coefficient of the neighbourhood environment main effect estimated the prevalence ratio (PR) of smoking *at baseline* associated with a 1 SD higher baseline score. The exponentiated coefficient of the interaction term estimated the ratio of the *change* in risk over a 5-year period associated with a 1 SD higher baseline score. Models were progressively adjusted as follows: model 1: baseline age (centred at the mean), sex, interaction between baseline age and time since baseline; model 2: further adjusted for race/ethnicity, education, baseline study site and the following time-varying characteristics: marital status, income, employment status and current alcohol use; model 3: further adjusted for neighbourhood socioeconomic status. We tested interactions between time-invariant covariates (sex, race, education) and time as prior research suggests trajectories of smoking behaviour change may differ in subgroups of the population.<sup>33</sup> We found that smoking intensity trajectories differed significantly by sex, race and education; these three interaction terms were retained in smoking intensity models. In preliminary cross-sectional analyses, we included a random intercept for census tract to account for neighbourhood clustering. As results were unchanged, and models including random intercepts for participants and census tracts did not converge, we did not include census tract random intercepts in final models.

### Sensitivity analyses

In a sensitivity analysis, we repeated analyses after excluding participants who did not live within a 1-mile radius of at least five other participants in either the main study or the community survey (N=298, for a total of 5558 participants). These exclusions were made to test the sensitivity of results to neighbourhoods with few participants rating neighbourhood social environment.

## Results

Among 5856 participants, 12.7% were current smokers at baseline. Current smokers smoked an average of 13.5 cigarettes per day at baseline. Table 1 presents demographic, behavioural and neighbourhood characteristics at each examination over the follow-up period.

Participants had an average of 7.8 years of follow-up. Current smoking prevalence declined over follow-up to 7.3%, and the mean number of cigarettes smoked per day among baseline smokers declined to 7.0. At baseline, overall neighbourhood social environment scores ranged from -11.1 to 7.3 (median -0.1). Prior to standardisation, the means and SDs of the neighbourhood subscales were: aesthetic quality: 3.7 (0.4), safety: 3.7 (0.4), social cohesion: 3.5 (0.3) on a scale from 1 to 5. Slightly more men, black or Hispanic participants, and participants with a high school degree or less were lost to follow-up compared with women, white or Asian participants, and participants with higher educational attainment. The proportion of participants who were married or currently working decreased as participants aged. Alcohol use declined over time while average neighbourhood socioeconomic status increased.

**Table 1.** Demographic, behavioural and neighbourhood characteristics of the study sample, by examination year

Sample characteristics*	Year 0, examination 1	Year 2, examination 2	Year 3, examination 3	Year 5, examination 4	Year 10, examination 5
N	5856	5641	5342	5092	4032
Demographic characteristics					
Mean age (SD) <sup>†</sup>	61.9 (10.1)	63.6 (10.1)	65.9 (10.0)	66.5 (9.9)	69.9 (9.4)
Gender (%)					
Male	2753 (47.0)	2648 (46.9)	2496 (46.7)	2372 (46.6)	1848 (45.8)
Female	3103 (53.0)	2993 (53.1)	2846 (53.3)	2720 (53.4)	2184 (54.2)
Race (%)					
White	2291 (39.1)	2213 (39.2)	2121 (39.7)	2049 (40.2)	1633 (40.5)
Black/African-American	1610 (27.5)	1553 (27.5)	1475 (27.6)	1385 (27.2)	1084 (26.9)
Hispanic	1261 (21.5)	1213 (21.5)	1121 (21.0)	1066 (20.9)	843 (20.9)
Chinese	694 (11.9)	662 (11.7)	625 (11.7)	592 (11.6)	472 (11.7)
Education (%)					
High school graduate or less	2051 (35.0)	1964 (34.8)	1842 (34.5)	1740 (34.2)	1290 (32.0)
Some college	1660 (28.4)	1600 (28.4)	1520 (28.4)	1438 (28.2)	1156 (28.7)
Bachelor's or graduate degree	2145 (36.6)	2077 (36.8)	1980 (27.1)	1914 (37.6)	1586 (39.3)
Currently employed (%) <sup>†</sup>	3190 (54.5)	2938 (52.1)	2722 (50.9)	2468 (48.5)	1764 (43.7)
Mean per capita annual household income adjusted for inflation, in increments of 10 000 (SD) <sup>†</sup>	2.6 (2.0)	2.6 (2.1)	2.5 (2.0)	2.4 (1.9)	2.5 (1.8)
Currently married (%) <sup>‡</sup>	3610 (61.6)	3459 (61.3)	3290 (61.6)	3175 (62.3)	2391 (59.3)
Health behaviours					
Current alcohol use (%) <sup>†</sup>	3287 (56.1)	2867 (50.8)	2628 (49.2)	2279 (44.8)	1724 (42.8)
Smoking status (%) <sup>†</sup>					
Never-smoker	2957 (50.5)	2624 (46.5)	2435 (45.6)	2285 (44.9)	1839 (45.6)
Former smoker	2158 (36.8)	2391 (42.4)	2347 (43.9)	2319 (45.5)	1897 (47.1)
Current smoker	741 (12.7)	626 (11.1)	560 (10.5)	488 (9.6)	296 (7.3)
Mean number of cigarettes smoked per day among baseline smokers (SD) <sup>†</sup>	13.5 (17.7)	10.1 (9.5)	9.7 (9.6)	8.4 (9.2)	7.0 (14.3)
Neighbourhood characteristics§					
Neighbourhood socioeconomic score, mean (SD) (range) <sup>†</sup>	0.0 (6.3) (-19.4-14.7)	0.0 (6.3) (-19.4-14.7)	0.6 (5.9) (-18.2-14.7)	1.8 (5.0) (-8.7-14.8)	1.0 (4.6) (-9.7-14.4)
Neighbourhood social environment score, mean (SD) (range) <sup>†</sup>	-0.1 (2.5) (-11.1-7.3)	-0.1 (2.5) (-11.1-7.3)	-0.1 (2.5) (-11.1-10.8)	0.1 (2.9) (-12.8-10.8)	0.3 (3.0) (-9.0-10.8)
Neighbourhood aesthetic quality score, mean (SD) (range) <sup>†</sup>	3.7 (0.4) (2.0-5.0)	3.7 (0.4) (2.0-5.0)	3.7 (0.4) (2.0-5.0)	3.7 (0.5) (2.0-5.0)	3.7 (0.5) (2.0-5.0)
Neighbourhood safety score, mean (SD) (range)	3.7 (0.4) (2.0-5.0)	3.7 (0.4) (2.0-5.0)	3.7 (0.4) (2.0-5.0)	3.6 (0.5) (1.5-5.0)	3.7 (0.5) (1.9-5.0)
Neighbourhood social cohesion score, mean (SD) (range) <sup>†</sup>	3.5 (0.3) (2.4-5.0)	3.5 (0.3) (2.4-5.0)	3.5 (0.3) (2.4-5.0)	3.6 (0.3) (2.0-5.0)	3.6 (0.3) (2.0-5.0)

\*Sex, race and education were only measured at baseline. Other variables were time-varying.

§Neighbourhood socioeconomic status score was calculated by summing z-scores for the following census variables: log median housing value, per cent with a high school education, per cent with a Bachelor's degree, per cent in a managerial occupation, log median household income and per cent with interest/dividend income. Neighbourhood social environment score was calculated by summing z-scores of the aesthetic quality, safety and social cohesion scores. Unstandardised scores for aesthetic quality, safety and social cohesion are shown in this table and were calculated by taking the average item score for each scale. For each scale, a higher score indicates a better neighbourhood environment.

The Multi-Ethnic Study of Atherosclerosis (2000-2012).

‡Indicates significant at the p<0.05 level based on [chi]<sup>2</sup> tests and analysis of variance.

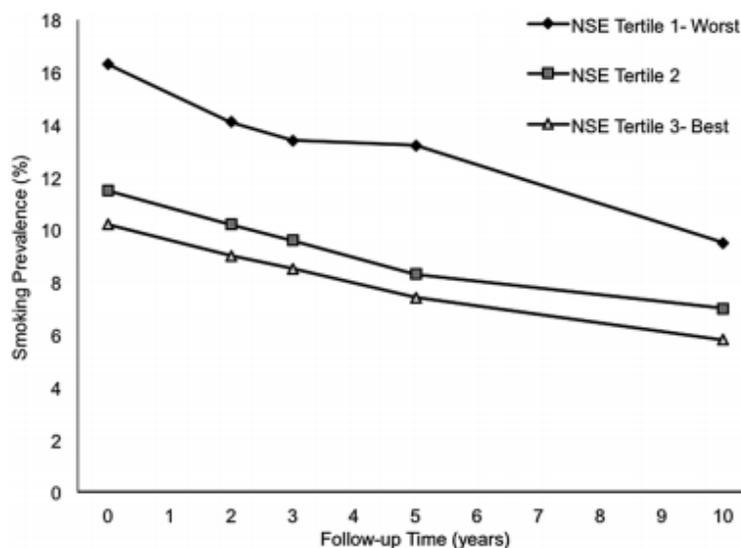
†Indicates significant at the p<0.001 level based on [chi]<sup>2</sup> tests and analysis of variance.

Bivariate analyses found that at higher tertiles of each neighbourhood environment domain (reflecting better neighbourhood environment), baseline smoking prevalence was lower (p for trends <0.01, table 2 ). However, among baseline current smokers, the crude mean number of cigarettes smoked per day was higher in neighbourhoods with better social environment scores (p for trends <0.01). Smoking prevalence declined over time across tertiles of baseline neighbourhood social environment and the slope of the decline was similar across tertiles (figure 1).

**Table 2.** Bivariate associations of baseline neighbourhood social environment with baseline smoking status and intensity, the Multi-Ethnic Study of Atherosclerosis examination 1 (2000–2002)

Baseline neighbourhood scale	N (entire cohort– N=5856)	N (%) Current smokers	p Value*	Mean (SD) number of cigarettes smoked per day– current smokers N=741	p Value*
Neighbourhood social environment	-	-	<0.0001	-	<0.0001
Tertile 1-worst	1932	315 (16.3)	-	11.6 (9.7)	-
Tertile 2	1991	228 (11.5)	-	13.4 (10.2)	-
Tertile 3-best	1933	198 (10.2)	-	16.6 (29.9)	-
Aesthetic quality	-	-	<0.0001	-	<0.0001
Tertile 1-worst	1932	292 (15.1)	-	11.6 (9.5)	-
Tertile 2	1993	252 (12.6)	-	13.6 (12.0)	-
Tertile 3-best	1931	197 (10.2)	-	16.3 (29.2)	-
Safety	-	-	<0.0001	-	<0.0001
Tertile 1-worst	1932	317 (16.4)	-	11.5 (9.5)	-
Tertile 2	1990	245 (12.3)	-	14.1 (10.2)	-
Tertile 3-best	1934	179 (9.3)	-	16.4 (31.4)	-
Social cohesion	-	-	0.003	-	0.002
Tertile 1-worst	1929	279 (14.5)	-	11.3 (9.0)	-
Tertile 2	1994	245 (12.3)	-	14.6 (12.7)	-
Tertile 3-best	1933	217 (11.2)	-	15.1 (27.9)	-

\*p Value from test for trend (based on Wald statistic in logistic (current smoking) and negative binomial (smoking intensity) models including an ordinal term for baseline neighbourhood social environment tertiles).



**Figure 1.** Unadjusted prevalence of smoking over follow-up, by tertile of baseline NSE, the Multi-Ethnic Study of Atherosclerosis (2000-2012). NSE, neighbourhood social environment.

**Table 3.** Cross-sectional and longitudinal associations of a 1 SD higher baseline neighbourhood social environment score with risk of current smoking, The Multi-Ethnic Study of Atherosclerosis (2000–2012)\*, † N=5856

	Relative risk (95% CI) for current smoking								
	Model 1			Model 2			Model 3		
	Baseline score	Time trend (5-year interval)	Baseline score × time (5-year interval)	Baseline score	Time trend (5-year interval)	Baseline score × time (5-year interval)	Baseline score	Time trend (5-year interval)	Baseline score × time (5-year interval)
Neighbourhood social environment	0.81 (0.75 to 0.87)	0.72 (0.69 to 0.76)	1.00 (0.96 to 1.05)	0.84 (0.75 to 0.93)	0.74 (0.70 to 0.78)	1.00 (0.95 to 1.04)	0.87 (0.78 to 0.98)	0.74 (0.70 to 0.78)	0.98 (0.94 to 1.03)
Aesthetic quality	0.83 (0.78 to 0.90)	0.72 (0.69 to 0.76)	1.01 (0.97 to 1.05)	0.84 (0.75 to 0.93)	0.74 (0.70 to 0.78)	1.00 (0.96 to 1.05)	0.87 (0.77 to 0.99)	0.74 (0.70 to 0.78)	0.99 (0.93 to 1.03)
Safety	0.76 (0.70 to 0.82)	0.72 (0.69 to 0.76)	1.01 (0.96 to 1.05)	0.84 (0.76 to 0.93)	0.74 (0.70 to 0.78)	1.00 (0.96 to 1.05)	0.87 (0.78 to 0.97)	0.74 (0.70 to 0.78)	0.99 (0.95 to 1.04)
Social cohesion	0.88 (0.82 to 0.96)	0.72 (0.69 to 0.76)	0.99 (0.94 to 1.03)	0.89 (0.80 to 0.99)	0.73 (0.70 to 0.77)	0.99 (0.94 to 1.03)	0.94 (0.84 to 1.05)	0.74 (0.70 to 0.78)	0.97 (0.92 to 1.02)

\*Relative risks and CIs are from generalised linear mixed Poisson models with robust variance estimates. All models include the baseline neighbourhood environment score, time in years since baseline and an interaction between baseline neighbourhood score and time since baseline to test whether neighbourhood social environment modifies the change in smoking status over time. All models included repeated measures and a random intercept for each participant.

†Model 1 adjusted for baseline age (centred at the mean), sex and baseline agex-time interaction. Model 2 further adjusted for race, education, baseline study site and the following time-varying covariates: marital status, income, employment, alcohol use. Model 3 further adjusted for neighbourhood socioeconomic status (time-varying).

**Table 4.** Cross-sectional and longitudinal associations of a 1 SD higher baseline neighbourhood social environment score with the average number of cigarettes smoked per day, the Multi-Ethnic Study of Atherosclerosis (2000–2012) \* † N=741 (restricted to participants who smoked at baseline)

	Rate ratio (95% CI) for average number of cigarettes smoked per day								
	Model 1			Model 2			Model 3		
	Baseline score	Time trend (5-year interval)	Baseline score × time (5-year interval)	Baseline score	Time trend (5-year interval)	Baseline score × time (5-year interval)	Baseline score	Time trend (5-year interval)	Baseline score × time (5-year interval)
Neighbourhood social environment	1.14 (1.04 to 1.24)	0.51 (0.47 to 0.55)	0.97 (0.92 to 1.02)	1.03 (0.92 to 1.15)	0.43 (0.38 to 0.49)	0.98 (0.93 to 1.04)	1.01 (0.89 to 1.14)	0.43 (0.38 to 0.49)	0.99 (0.93 to 1.04)
Aesthetic quality	1.13 (1.03 to 1.23)	0.51 (0.47 to 0.55)	0.99 (0.94 to 1.04)	1.02 (0.90 to 1.15)	0.43 (0.38 to 0.49)	0.99 (0.94 to 1.05)	0.99 (0.87 to 1.13)	0.43 (0.38 to 0.49)	1.00 (0.94 to 1.06)
Safety	1.11 (1.01 to 1.22)	0.51 (0.47 to 0.55)	0.97 (0.92 to 1.03)	1.03 (0.92 to 1.14)	0.43 (0.38 to 0.49)	0.99 (0.93 to 1.05)	1.01 (0.90 to 1.13)	0.43 (0.38 to 0.49)	0.99 (0.93 to 1.05)
Social cohesion	1.14 (1.03 to 1.25)	0.51 (0.47 to 0.55)	0.96 (0.91 to 1.02)	1.03 (0.92 to 1.16)	0.44 (0.39 to 0.50)	0.97 (0.92 to 1.03)	1.02 (0.90 to 1.15)	0.44 (0.38 to 0.50)	0.97 (0.92 to 1.03)

\*Results are from generalised linear mixed negative binomial models. All models include the baseline neighbourhood environment score, time in years since baseline, and an interaction between baseline neighbourhood score and time since baseline to test whether neighbourhood social environment modifies the change in smoking intensity over time. All models included repeated measures and a random intercept for each participant.

†Model 1 adjusted for baseline age (centered at the mean), sex, baseline agex-time interaction, and sexx-time interaction. Model 2 further adjusted for race, education, baseline study site and the following time-varying covariates: marital status, income, employment, alcohol use, and sexx-time, educationx-time and racex-time interactions. Model 3 further adjusted for neighbourhood socioeconomic status (time-varying).

Among current smokers, baseline neighbourhood social environment was initially positively associated with baseline smoking intensity; however, adjustment for additional sociodemographic characteristics attenuated this association and all CIs widened to include the null ( table 4 ). Baseline neighbourhood social environment did not modify the rate of change over time in the number of cigarettes consumed per day over time. Results were similar in sensitivity analyses that excluded participants who did not have at least five neighbours within a 1-mile radius of their residence (see online supplementary table S2 ).

In generalised linear mixed models, a 1 SD higher baseline neighbourhood social environment score was associated with a 16% lower probability of being a current smoker at baseline (PR 0.84 (95% CI 0.75 to 0.93), table 3) after adjusting for sociodemographic characteristics. Results were attenuated but still statistically significant after adjustment for neighbourhood socioeconomic status (0.87 (0.78 to 0.98)). For aesthetic quality and safety environment domains, the association was similar to the composite score (0.87 (0.77 to 0.99); 0.87 (0.78 to 0.97)) but for social cohesion there was a non-significant negative association. A higher baseline neighbourhood social environment score did not modify changes in smoking risk over time for either the composite score or individual domains, as risk ratios ranged from 0.97 to 1.00 across models for the interaction term between baseline social environment and follow-up time.

## Discussion

In this large longitudinal cohort of middle-aged and older adults, we found that baseline smoking prevalence was lower among participants living in neighbourhoods with better neighbourhood social environment compared with those in worse neighbourhoods. Adjustment for neighbourhood socioeconomic status slightly attenuated associations, but the composite score remained statistically significant. However, we found no evidence that neighbourhood social environment was associated with a change in smoking risk over time. Finally, we found no association between neighbourhood social environment and smoking intensity.

The association of neighbourhood social environment with baseline smoking in our study aligns with prior cross-sectional work<sup>8-10 12 13 15 34</sup> and may reflect an influence of neighbourhood context on earlier life smoking patterns. The finding of higher smoking prevalence among participants living in neighbourhoods with worse social environment scores, and lack of association with changes over time, suggests that neighbourhood social factors may be more relevant for smoking initiation than cessation/reduction. To date, few studies have examined the association of neighbourhood context with smoking initiation, and those that have primarily concentrated on neighbourhood socioeconomic status<sup>35-37</sup> and racial composition.<sup>37</sup> More research is needed in this area, particularly longitudinal studies examining the impact of social aspects of neighbourhood environments on smoking initiation.

Our cross-sectional results indicate that smoking prevalence was negatively associated with domains representing neighbourhood stressors (aesthetic quality and safety) but associations were weaker or null for social cohesion. These findings may suggest that environmental stressors play a larger role than social cohesion in smoking behaviour among older adults. The former finding is consistent with past cross-sectional studies,<sup>8-10 12 13 15 34</sup> and the latter finding somewhat aligns with several prior studies that found positive associations between neighbourhood social

cohesion and smoking prevalence,<sup>14-16 21</sup> although our results were weaker than seen in previous studies. Our results suggest that neighbourhood safety and aesthetic quality may be more promising targets for neighbourhood-level interventions than social cohesion.

Our finding that neighbourhood social environment was not associated with changes in smoking status or intensity over time can be compared with only a few prior studies using longitudinal data to assess this association. Slopen *et al*<sup>23</sup> found no association between neighbourhood stress, a scale related to safety and trust in the neighbourhood, and smoking behaviour change among a cohort of middle-aged US adults. In contrast, Fleischer *et al*<sup>18</sup> analysed a cohort of Mexican smokers (mean age 40 years) and found positive associations between neighbourhood social cohesion and both quit attempts and successful quitting. However, the study by Fleischer *et al* included only 2 years of data and could not evaluate whether smoking behaviour changes were sustained over a longer time period.

The MESA population included middle-aged and older adults, and prior studies have found older adults to have lower rates of smoking behaviour changes (eg, cessation, relapse) compared with younger adults,<sup>38-40</sup> suggesting smoking behaviour is more stable in older populations. In addition, as our study population had a fairly low baseline smoking rate, and relatively few individuals quit over follow-up, results should be interpreted with caution. Further study is needed to examine whether neighbourhood social environment is associated with smoking cessation and reduction in younger populations, where smoking behaviour patterns may be less solidly established.

This study had several limitations. Smoking outcomes were based on self-report, which might have led to under-reporting due to recall and social desirability biases. However, prior validation work in MESA has indicated that self-reported smoking is a reliable measure consistent with serum and urinary cotinine concentrations.<sup>41</sup> Although we adjusted for a large number of potential confounders, including neighbourhood socioeconomic status, it is possible that residual confounding was present from factors such as community/social network smoking norms or individual-level motivation to quit smoking. In addition, we used a 1-mile buffer to calculate neighbourhood social environment scores because that was how neighbourhoods were defined to participants in the survey. However, it is possible that this scale may be larger than what participants perceived as their actual neighbourhood, particularly in more deprived areas.<sup>42</sup> Finally, there was not enough variability in the exposure and outcome to evaluate associations of change in neighbourhood social environment with changes in smoking over time.

Strengths of this study include the large, multiethnic sample and inclusion of up to 12 years of follow-up. Our measures of neighbourhood social environment were based on perceptions of the social environment (derived from neighbourhood surveys) and results may be different if objective measures were used instead (such as crime reports or direct observations of aesthetic quality). However, perceptions of the social environment may be the more salient measure as has been found in some work.<sup>8 11</sup> In addition, the use of multiple neighbourhood informants to measure neighbourhood social environment is a more valid measurement of neighbourhood characteristics than individual self-report.<sup>43</sup>

## **Conclusion**

In summary, a better neighbourhood social environment was associated with lower smoking prevalence, particularly for the domains of safety and aesthetic quality. Neighbourhood social environment was not associated with changes in smoking behaviour over time. Further study is needed to determine whether neighbourhood social environment is associated with changes to smoking behaviour in younger populations.

**What is already known on this subject**

Social aspects of neighbourhood environments such as safety/crime and social cohesion have been cross-sectionally associated with smoking. However, the association of neighbourhood social environment with changes in smoking behaviour over time, and of the overall neighbourhood social context, have rarely been studied.

**What this study adds**

Neighbourhood social environment was associated with smoking at baseline, but not with changes over time. Results suggest that neighbourhood social context influences whether older adults smoke, but not whether they quit smoking or reduce the number of cigarettes smoked per day.

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**Contributors:** SLM designed the study, analysed the data, interpreted results and drafted the article. KAM assisted with analysing data. AVDR acquired the data. All authors provided guidance on study design and interpretation of results, critically revised drafts of the manuscript and approved the final version for publication.

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**Data sharing statement:** The Multi-Ethnic Study of Atherosclerosis (MESA) has hundreds of investigators, many active scientific working groups (on renal disease, eye disease and other topics) and dozens of ongoing analytic projects. The authors are always looking for outside investigators interested in using the data to answer their research questions. To help interested parties navigate the data and topics and find fruitful collaborations, they encourage you to contact the Coordinating Center or a MESA investigator. Here is a link to the website for more details: <http://www.mesa-nhlbi.org/> .

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