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Neighborhood Food Environment, Dietary Fatty Acid Biomarkers, and Cardiac Arrest Risk

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Abstract

We explored links between food environments, dietary intake biomarkers, and sudden cardiac arrest in a population-based longitudinal study using cases and controls accruing between 1990 and 2010 in King County, WA. Surprisingly, presence of more unhealthy food sources near home was associated with a lower 18:1 *trans*-fatty acid concentration (−0.05 percent per standard deviation higher count of unhealthy food sources, 95% Confidence Interval [CI]: 0.01, 0.09). However, presence of more unhealthy food sources was associated with higher odds of cardiac arrest (Odds Ratio [OR]: 2.29, 95% CI: 1.19, 4.41 per standard deviation in unhealthy food outlets). While unhealthy food outlets were associated with higher cardiac arrest risk, circulating 18:1 *trans* fats did not explain the association.

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Conflicts of Interest statement

The authors declare that there are no conflicts of interest.

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Keywords

Food Supply; Out-of-Hospital Cardiac Arrest; Residence Characteristics; Sudden Cardiac Death; Trans Fatty Acids

Introduction

Sudden cardiac arrest causes between 180,000 and 450,000 adult deaths in the United States each year,(Deo and Albert, 2012; Kong et al., 2011; Zheng et al., 2001) but both incidence and fatality vary by geographic locale. In particular, cardiac arrest incidence rates are higher in neighborhoods in lowest income quartiles (Reinier et al., 2011) while survival following cardiac arrest appears higher for residents of higher income neighborhoods.(Sasson et al., 2011)

These disparities might result from disparities in neighborhood food environments. Several prior studies have shown density of unhealthy food outlets to be associated with incidence of harmful cardiovascular events such as stroke (Hamano et al., 2013) and cardiovascular mortality.(Alter and Eny, 2005; Daniel et al., 2010) Some studies have suggested that the food environment shapes diet, though the evidence for this relationship remains inconclusive.(Black et al., 2014; Caspi et al., 2012; Cummins et al., 2014; Mejia et al., 2015) Circulating *trans* fatty acids have been associated with higher risk of sudden cardiac death, (Lemaitre et al., 2006a; Lemaitre et al., 2006b; Lemaitre et al., 2002) potentially as a result of fatty acid release and eicosanoid formation or vascular inflammation.(Lemaitre et al., 2016; Siddiqui et al., 2009) Thus, improving the food environment (Dannefer et al., 2012; Leggat et al., 2012) may decrease *trans* fat consumption and thereby either lower the risk of cardiac arrest, or decrease the severity of incident arrests (e.g. if a healthier diet lessens vascular inflammation (Esposito et al. 2004)), leading to better survival after arrest.

However, neighborhood research can be methodologically challenging.(Oakes, 2004) Neighborhood characteristics such as food environments are frequently correlated with other characteristics that are often also health determinants. By using dietary biomarkers to explore the relationship between food environment and diet in both cardiac arrest cases and community controls, we can test whether the food environment specifically, as opposed to some other neighborhood mechanism, is likely responsible for observed associations.

We examined associations between residential neighborhood food environment and 1) dietary biomarkers of fatty acid intake, 2) risk of cardiac arrest, and 3) survival after out of hospital cardiac arrest attended by paramedics and due to ventricular fibrillation.

Methods

Setting

We used subject data from the Cardiac Arrest Blood Study – Repository (CABS-R). CABS-R, which has been described in more detail elsewhere,(Johnson et al., 2012; Siscovick et al., 1995; Sotoodehnia et al., 2006) is a population-based registry that includes blood samples and interview data for out-of-hospital cardiac arrest incidents attended by paramedics within

King County, Washington, as well as a smaller group of population-based controls. King County has about 2 million residents and is geographically large (approximately 6000 km²) and varied, including both the city of Seattle and the Cascade Mountains. Rates of survival after cardiac arrest in King County are among the highest in the world.(Lance and Becker, 2015)

The Human Subjects Review Committee at the University of Washington approved all data collection protocols, and the Human Subjects Review Committees at both the University of Washington and Columbia University Medical Center approved the geographic linkage and analyses for this study. The use of repository data from the CABS-R for the study analyses was authorized under a waiver of consent.

Subjects

Case ascertainment in CABS-R was based on paramedic reports, death certificates, medical examiner reports, and autopsy reports.(Siscovick et al., 1995) Cardiac arrest cases were defined as a sudden, pulseless condition that arose in an otherwise apparently stable individual in the absence of a non-cardiac cause of arrest, such as traumatic injury or drug overdose. CABS-R case identification began in 1988 and is ongoing; for this analysis, we used subjects whose cardiac arrest occurred between 1990 and 2010. CABS-R staff classified subjects as having had definite, probable, or possible cardiac arrest after reviewing records of initial rhythm (ventricular fibrillation, pulseless electrical activity, or asystole), circumstances (e.g. witnessed or unwitnessed), and possible contribution of comorbidities to the event. To avoid misclassification, we excluded CABS-R cases with only possible cardiac arrest.

Population-based controls available for this analysis were recruited by random-digit dialing within King County as part of the Diet and Primary Cardiac Arrest Study.(Siscovick et al., 1995) Controls were matched to a subset of CABS-R cases without diagnosed heart disease before their cardiac arrest, based on sex, age (+/- 7 years), and calendar year. Subjects were not matched on neighborhood geography or neighborhood features. The control response rate was 64%.

Paramedics collected blood samples from cases, usually within 45 minutes of cardiac arrest. CABS-R staff collected blood samples from controls during a home interview. Case and control samples were assessed using gas chromatography to measure red blood cell membrane fatty acids. We used two measures of *trans* fats, each compiled as a percentage of total circulating fatty acids. First, we summed concentrations of five *trans* isomers of oleic acid (12 *trans*-18:1, 11 *trans*-18:1, 10 *trans*-18:1, 9 *trans*-18:1, and mix of 6 to 8 *trans*-18:1). Oleic acids have previously been associated with the consumption of foods commonly sold by unhealthy food outlets, due to outlets' use of partially hydrogenated vegetable oil.(Micha et al., 2010; Tyburczy et al., 2012) We also used chromatography measures of linoleic acids (*trans*-18:2 fatty acids), which have previously been more strongly associated with sudden cardiac arrest (Lemaitre et al., 2006b; Lemaitre et al., 2002). Linoleic acids are present in small amounts in most cooking oils and are less likely to be affected by neighborhood food environments. Because uncertainty remains about each isomer's impact on cardiac arrest risk and association with food environment, we analyzed both. Lab procedures and

validation against a dietary intake questionnaire for these data have been described previously.(Lemaitre et al., 2002; Lemaitre et al., 2014) Biomarker data were available for 416 controls and 1570 cases.

Retail and Socio-economic Environment

We used the National Establishment Time-Series (NETS) database, which contains yearly registration data for businesses, including company name, street address, and Standard Industry Classification (SIC) code (Kaufman et al., 2015; Walls, 2009) to build a spatio-temporal food environment measure for each US Census tract (geographical units typically containing about 4,000 residents (Bureau, 2012)) in King County for each year from 1990 to 2010. NETS was developed from Dun & Bradstreet's business registry, which has previously been validated for neighborhood food environment research.(Liese et al., 2010)

After cleaning and processing the data as described elsewhere,(Kaufman et al., 2015) our procedure for estimating food outlet density within each tract for each year comprised: 1) geocoding each businesses' reported address, 2) using SIC codes and business names to classify each retail establishment into potentially health relevant categories informed by previous literature, of which healthy food sources (e.g. supermarkets, fish markets) and unhealthy food sources (e.g. fast food restaurants, bakeries) are of central interest for this analysis, 3) using ArcGIS to identify the year 2000 census tract in which each business was located, and 4) tabulating by census tract identifier to estimate the number of each type of business within each census tract. This food environment measure, though imperfect, is consistent with prior research.(McInerney et al., 2016; Mercille et al., 2016) Complete details on the classification of food outlets into healthy and unhealthy are given in the online appendix. Notably, we classified supermarkets as healthy, as is conventional when measuring food environment from administrative data,(Chaparro et al., 2017; Cobb et al., 2015; McInerney et al., 2016) despite many supermarkets selling unhealthy foods.

Next, we used ArcGIS to identify the year 2000 census tract for each subject's reported residential address. We considered the count of each type of food source present within the year 2000 tract's boundaries in the index year to represent the food environment context. Our analyses operationalized the food environment in three ways: 1) As a count of healthy food outlets in the tract, 2) as a count of unhealthy food outlets in the tract, and 3) as the proportion of total food outlets classified as healthy.

Primary Analyses

We theorized that a relationship between the food environment and cardiac arrest might be mediated by the previously established relationship between dietary and circulating fatty acids and cardiac outcomes.(Leaf et al., 2003; Lemaitre et al., 2006b; Lemaitre et al., 2002; Lemaitre et al., 2014; Siscovick et al., 1995) For analysis 1, we fit linear regression models predicting each participant's biomarker concentration from the food environment in the home census tract in the year of SCA event or control recruitment, adjusting for year, age and sex. We present this analysis stratified by case/control status because of the risk of "collider bias" in cases (Hernán et al., 2004). (The risk of bias is this: If higher levels of fatty acids result in cardiac arrest, and if neighborhood factors also associated with more food

outlets (e.g. air pollution) also cause cardiac arrest, then an analysis oversampling cases as compared to the general population will display an artificially inflated association between food outlets and fatty acids. This bias will not be present in the controls because their inclusion in the study was not conditional on a cardiac arrest incident.)

Analysis 2 focused on risk of cardiac arrest. From the registry, we identified population-based controls and the cases that matched the controls' selection criteria, which comprised being 79 or younger, lacking a history of diagnosed heart disease and having an index event prior to 2007. Because case ascertainment was less complete outside Seattle city limits during the early years of CABS-R, we further limited this analysis to the 475 cases and 215 controls who met the above criteria and also lived within Seattle city limits. Among the selected cases and controls, we fit logistic regression models predicting case status from healthy food outlets, and unhealthy food outlets in the home census tract during the index year (i.e. year of cardiac arrest incident for cases and year of recruitment for controls) after adjusting for matching criteria (age, sex, and index year). Though restricting to subjects living within Seattle city limits precluded a matched analysis, statistical adjustment for matching criteria minimizes selection bias induced by matching. (Pearce, 2016)

In analysis 3, we used logistic regression to model the probability of survival to hospital discharge conditional on residential food environment, among those whose home addresses were geocoded successfully, controlling for whether the arrest was witnessed and whether a bystander performed CPR before emergency medical services arrived. This analysis was limited to the 1,649 cases who presented with out of hospital ventricular fibrillation, because only 2.8% of cardiac arrest cases presenting with other heart rhythms survived.

Eligibility for all three main analyses and resulting sample sizes are detailed in Figure 1.

Sensitivity Analyses

We were concerned that shifting dietary norms and improved medical technologies might attenuate the relationship between food environment and survival after cardiac arrest. We visually explored time trends in circulating fatty acids among controls, stratified by socioeconomic quintile, and tested adding an interaction term for index year and food environment into the model.

Software

We performed all statistical analyses with R for Windows version 3.2.3 (Vienna, Austria). All regression analyses used cluster robust standard errors to account for subject clustering within census tracts.

Results

Table 1 summarizes the demographic characteristics of all definite or probable cases and all controls available in the CABS-R dataset, as well as the specific groups used in these analyses. Both the 416 controls for whom dietary biomarker data were available and the 215 controls who lived in Seattle were demographically comparable to the overall control sample. Cases matching the control selection criteria were slightly younger and more likely

to survive 30 days after arrest than the overall case sample. Cases who presented with ventricular fibrillation were also more likely to survive, as expected, somewhat less likely to be female, and more likely to have had their arrest witnessed.

Primary Analyses

Analysis 1 indicated that the food environment was not consistently associated with circulating fatty acid concentrations (Figure 2, Appendix Table 1). After controlling for age, index year, and gender, a one standard deviation higher count of unhealthy food outlets was associated with a 0.05 (95% CI = 0.01, 0.09) percentile lower proportion of total fatty acids that were 18:1 *trans* fats among controls. However, food outlets were not significantly associated with 18:1 *trans* fats among cases, nor were proportion of food outlets that were healthy associated with any *trans* fat measures.

In Analysis 2, cardiac arrest incidence was associated with exposure to unhealthy food outlets (Table 2). After controlling for age, index year, and race, each standard deviation higher unhealthy food outlets in the home census tract was associated with a 2.29 (95% CI: 1.19, 4.41) times higher odds of arrest incidence. However, prevalence of healthy and unhealthy food outlets were correlated (Spearman $r = 0.41$, Figure 3), and there was also a modest positive association between prevalence of *healthy* food outlets and cardiac arrest incidence (OR: 1.26, 95% CI: 1.04, 1.53).

Analysis 3 indicated that neither prevalence of healthy food outlets (OR for survival: 1.00, 95% CI: 0.92, 1.09) nor prevalence of unhealthy food outlets (OR: 1.03, 95% CI: 0.96, 1.12) was significantly associated with survival to hospital discharge among cases who presented with ventricular fibrillation (Table 3).

Sensitivity Analyses

The proportion of fatty acids that were *trans* fats decreased over the course of the study period. (Appendix Figure 1). However, there was no evidence of interaction between time and prevalence of unhealthy food outlets in models of survival after cardiac arrest (AIC for interaction model = 2002.0, for no interaction model = 2000.4, LRT test $p = 0.54$).

Discussion

In this analysis, we examined the food environment as a contributor to cardiac arrest mortality in King County, WA. We found that living in a neighborhood with more unhealthy food outlets such as fast food restaurants and convenience stores was associated with a higher risk of cardiac arrest. However, we also found that living in such neighborhoods had null or modestly *negative* associations with concentrations of 18:1 *trans* fats, the *trans* fats expected to be in more widespread use in unhealthy food outlets, and 18:2 *trans* fats, the *trans* fats previously linked to sudden cardiac arrest. We found no consistent association between neighborhood food environment and survival after ventricular fibrillation. Taken together, these findings suggest that if the food environment contributes to cardiac arrest risk, *trans* fat consumption does not mediate the relationship.

Our findings are consistent with previous literature linking unhealthy food outlets to negative cardiovascular outcomes.(Alter and Eny, 2005; Daniel et al., 2010; Hamano et al., 2013) However, our finding that prevalence of unhealthy food outlets was associated with lower *trans* fat concentrations among controls suggests the food environment – cardiac arrest association is unlikely to be because proximity to food outlets that use *trans* fats causes subjects to consume harmful *trans* fats and subsequently enter cardiac arrest.

We caution that the magnitude of the inverse association we observed has little clinical relevance. A previous study found that a difference of 0.13% in proportion of fatty acids that were 18:2 *trans* fats was associated with a 30% decrease in cardiac arrest risk.(Lemaitre et al., 2006b) If, as a thought experiment, we assumed this relationship held in our dataset, we would expect the decrease in arrest risk associated with one standard deviation more unhealthy food outlets to be less than 1%. We further caution that this inverse association was present only in controls; no association was observed among cases. The difference between associations in cases and controls was unlikely to be due to collider bias operating in the controls: if both denser environments and *trans* fats are causes of cardiac arrest, then collider bias would induce a more robustly negative association between environment and *trans* fat. Taken together, the small magnitude and inconsistency of association across all subjects suggest the inverse association among controls may have arisen due to chance.

However, our dietary biomarkers of *trans* fat intake, i.e. circulating *trans* fats as a proportion of total fatty acids, comes with three important caveats. First, the distinction between 18:1 and 18:2 *trans* fats is important. While 18:1 *trans* fats are present in partially hydrogenated vegetable oils and thus typically more prevalent in foods sold by unhealthy food outlets, several prior studies have failed to link 18:1 *trans* fats to cardiac outcomes.(Lemaitre et al., 2006b; Lemaitre et al., 2002; Tokede et al., 2013) By contrast, 18:2 *trans* fats have been more strongly associated with heart failure.(Baylin et al., 2003; Lemaitre et al., 2006b; Lemaitre et al., 2002) However, 18:2 *trans* fats, which result from industrial deodorization processes and are present in small amounts in most cooking oils, are much less likely to be affected by the neighborhood food environment or by policies banning the use of *trans* fats in restaurants.(Angell et al., 2009) Second, while the use of a proportion measure was a necessitated by our gas chromatography measurement technique, interpreting it is not straightforward because the measured value is affected both by the numerator (e.g. 18:1 *trans* fats) and the denominator (all circulating fatty acids). For example, a low proportion of 18:1 *trans* fats among all fatty acids may be due to higher consumption of butter rather than decreased consumption of partially hydrogenated vegetable oils. Indeed, higher consumption of alternate fat sources may explain our finding that more unhealthy food outlets were associated with a lower proportion of *trans* fats. We were unable to assess this hypothesis because only relative abundance measure of fatty acids were available to us; this is an area for future research. Finally, while fatty acids measured by gas chromatography reflect accumulations from several months of dietary habits rather than only recent consumption, (Seppänen-Laakso et al., 2002) we have only one address for each subject and so do not know what neighborhood conditions participants were exposed to over the time contributing to fatty acid concentrations.

This analysis had numerous strengths. The study population was well-characterized, and controls were population-based. That King County has high cardiac arrest survival rates enhanced our statistical power. Because our food environment data were linked to participants by calendar year of data collection, our data have stronger spatio-temporal correspondence than much prior cross-sectional work. Finally, our access to an objective measure of fatty acid concentrations allowed us to explore and fail to confirm a potential pathway linking the neighborhood environment to cardiac arrest.

However, our findings should be interpreted in light of several limitations. First, correlated spatial patterns among neighborhood retail environment characteristics limited the strength of our conclusions about specificity of associations with business types. Second, findings may not be generalizable to other geographic contexts or time periods. Although case ascertainment in CABS-R is ongoing, control recruitment was discontinued in 2006, limiting the types of comparisons that can be made for the most recent study years. Third, our coding of business registration data in terms of primary focus excluded from consideration a variety of establishments that sell food as part of their business, including wholesale warehouses, pharmacies, and gas stations, any of which may potentially be relevant to availability of unhealthy food and cardiovascular health. Additionally, deterministic classification of food outlets disregards the fact that many outlets classified as “healthy,” such as supermarkets, also sell food items that could be considered “unhealthy.”(Neckerman, 2014) Fourth, our food environment measures were based on year 2000 census tracts, a substantial oversimplification of the geographic context easily accessible to subjects. Potential sources of error include a mismatch between fixed geographic unit and participant-specific location, a mismatch between the count of stores and participants’ perceptions of the food environment, participants’ capacity to acquire food at contexts far from home, including their workplaces, participants’ residential moves over time, and broadly, the complex geography of modern life.(Foster and Hipp, 2011; Leal and Chaix, 2011) Measurement error due to food environment misspecification is likely non-differential with respect to diet and so is unlikely to account for the observed association between unhealthy food outlets and a favorable fatty acid biomarker profile. Nonetheless, we cannot rule out the possibility that the food environment misspecification biased the finding, and suggest that personalized food environment measures, perhaps selected through “-WAS” style techniques applied to the neighborhood environment (Mooney et al., 2017), are an import area for future work. Fifth, we were unable to disentangle the influence of the environment on health from health-relevant factors influencing neighborhood selection. For example, if people with limited time to prepare healthy foods both live in closer proximity to unhealthy food outlets *and* have less healthy lifestyles in general, then our estimate of the cardiovascular risk associated with proximity to unhealthy food outlets is overstated. Sixth, as noted above, our dietary biomarker was a proportional measure of trans fatty acids, which precludes analyses of total fat intake or of dietary components other than fatty acids. Sugars may be particularly interesting candidates, given the observed link between impaired fasting glucose and cardiac arrest.(Laukkanen et al., 2013) Seventh, we could not control for individual socio-economic status, which strongly determines health, likely including cardiac arrest risk.(Braveman and Gottlieb, 2014; Rajan et al., 2015) However, we did control for neighborhood socioeconomic status, which is strongly correlated with individual socioeconomic status and

has been used in much of the literature on socioeconomic status and cardiac arrest risk. (Bergström et al., 2015; Reinier et al., 2006; Reinier et al., 2011) Finally, our results are subject to residual confounding by other environmental and personal characteristics.

In conclusion, living in a denser retail environment was associated with higher cardiac arrest risk but lower trans fatty acids concentrations in RBC membranes, providing only partial support for the hypothesis that residing closer to unhealthy food outlets explains the link between dense environment and cardiac arrest. While our findings are preliminary, they suggest that other spatial correlates of dense retail environments not directly linked to food consumption, such as air pollution exposure (Link and Dockery, 2010) or stressful neighborhood conditions, (Mooney et al., 2016) may pose more promising directions for future research.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- Living near unhealthy food outlets was associated with greater cardiac arrest risk
- Living near unhealthy food outlets was associated with lower 18:1 *trans* fat levels
- Living near unhealthy food outlets was not associated with survival after arrest
- 18:1 *trans* fat concentrations appear not to link food environment to cardiac arrest

Figure 1.

Diagram of exclusion criteria resulting in subjects selected for the three primary analyses. Analysis 1 focuses on food environment and dietary biomarkers; analysis 2 focuses on food environment and cardiac arrest incidence, and analysis 3 focuses on Food environment and survival after cardiac arrest

Figure 2. Neighborhood food environments as related to dietary biomarkers of trans fat consumption, for 416 controls and 1570 cases living in King County, WA, 1990-2006. (Raw data in web appendix)

Figure 3.

Counts of healthy and unhealthy food outlets in 373 census tracts in Seattle, WA during year of ascertainment for 416 cases and 215 controls lived, 1990-2006.¹

¹Counts were jittered to increase figure legibility

Table 1.

Demographic and enrollment characteristics of controls and cases recruited in King County, WA from 1990-2010.

	Analysis 1 ¹	Analysis 2 ²		Analysis 3 ³
	Cases and Controls N=1,986	Controls N=215	Cases N=475	Cases N=1,648
<i>Dataset</i>				
First Year Enrolled	1990	1990	1990	1990
Last Year Enrolled	2006	2005	2006	2010
<i>Individual</i>				
Age, mean	66	57	63	66
Female, %	24	19	28	20
Arrest Witnessed, %	46	N/A	63	73
Survived 30 days after arrest, %	13	N/A	30	28
Neighborhood Identified, %	100	100	100	100
<i>Home Census Tract¹</i>				
Median Per-capita Income, \$	30,000	34,118	28,534	28,393
Healthy Food Outlet Count, mean (SD)	1.3 (1.7)	1.1 (1.6)	1.5 (2.2)	1.4 (1.9)
Unhealthy Food Outlet Count, mean (SD)	4.3 (5.3)	3.6 (4.4)	5.7 (7.2)	5.0 (6.0)
Healthy Proportion, mean (SD)	0.13 (0.16)	0.11 (0.14)	0.11 (0.12)	0.12 (0.15)

¹ Study participants for whom fatty acid biomarker data were available

² Seattle residents age 80 or younger, with no history of clinically diagnosed heart disease, and cardiac arrest incident at or prior to 2006

³ Cardiac arrest cases for whom data about whether their arrest was witnessed and bystanders performed CPR were available.

Table 2.

Relationship of prevalence of business types in home census tracts to cardiac arrest incidence for 475 cases and 215 controls who lived in the city of Seattle and matched the control sampling criteria, 1990-2006.

Exposure	Odds Ratio per standard deviation higher exposure ¹	95% Confidence Interval	
Healthy Food Sources ² in Home Census Tract	1.26	1.04	1.53
Unhealthy Food Sources ³ in Home Census Tract	2.29	1.19	4.41
Proportion of Food Sources categorized as Healthy in Home Census Tract	1.64	0.94	2.86

¹ All analyses control for age, year of event, and gender and use cluster robust standard errors.

² Supermarkets, Produce Markets, Natural Food Stores, Nut Stores, and Fish Markets

³ Fast Food Stores, Pizza Restaurants, Bakeries, Convenience Stores, and Meat Markets

Table 3.

Neighborhood environments as related to survival after cardiac arrest for 1,648 cases presenting with ventricular fibrillation for whom home census tract in King County, WA could be identified, 1990-2010

Exposure	Odds Ratio for survival per standard deviation higher exposure ¹	95% Confidence Interval	
Healthy Food Sources ² in Home Census Tract	1.00	0.92	1.09
Unhealthy Food Sources ³ in Home Census Tract	1.03	0.96	1.12
Proportion of Food Sources categorized as Healthy in Home Census Tract	0.90	0.80	1.01

¹ All analyses control for age, year of event, and gender and use cluster robust standard errors.

² Supermarkets, Produce Markets, Natural Food Stores, Nut Stores, and Fish Markets

³ Fast Food Stores, Pizza Restaurants, Bakeries, Convenience Stores, and Meat Markets