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Residential mobility and chronic disease among World Trade Center Health Registry enrollees, 2004–2016

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ABSTRACT

Residential mobility is hypothesized to impact health through changes to the built environment and disruptions in social networks, and may vary by neighborhood deprivation exposure. However, there are few longitudinal investigations of residential mobility in relation to health outcomes. This study examined enrollees from the World Trade Center Health Registry, a longitudinal cohort of first responders and community members in lower Manhattan on September 11, 2001. Enrollees who completed ≥2 health surveys between 2004 and 2016 and did not have diabetes (N = 44,089) or hypertension (N = 35,065) at baseline (i.e., 2004) were included. Using geocoded annual home addresses, residential mobility was examined using two indicators: moving frequency and displacement. Moving frequency was defined as the number of times someone was recorded as living in a different neighborhood; displacement as any moving to a more disadvantaged neighborhood. We fit adjusted Cox proportional hazards models with time-dependent exposures (moving frequency and displacement) and covariates to evaluate associations with incident diabetes and hypertension. From 2004 to 2016, the majority of enrollees never moved (54.5%); 6.5% moved ≥3 times. Those who moved ≥3 times had a similar hazard of diabetes (hazard ratio (HR) = 0.78; 95% Confidence Interval (CI): 0.40, 1.53) and hypertension (HR = 0.99; 95% CI: 0.68, 1.43) compared with those who never moved. Similarly, displacement was not associated with diabetes or hypertension. Residential mobility was not associated with diabetes or hypertension among a cohort of primarily urban-dwelling adults.

1. Introduction

Neighborhoods have been shown to impact health (Roux and Mair, 2010). A substantial body of literature links features of the built environment, defined as the human-made or modified spaces in which we live, work, and congregate, with health outcomes (Jackson, 2003; Renalds et al., 2010). Furthermore, over time, as neighborhoods change, residents move or stay, which has also been the focus of recent health research (Hirsch et al., 2014; Lim et al., 2017; Ludwig et al., 2011; Rachele et al., 2018). Specifically, residential mobility in the context of gentrification (Glass, 1964) has been of interest (Cole et al., 2017; Lim et al., 2017), due to the potential for an increase in residential displacement (Kennedy and Leonard, 2001; Zuk et al., 2015), whereby the original residents of a community are displaced to more disadvantaged neighborhoods (Ding et al., 2016), potentially leading to adverse health outcomes (Fullilove and Wallace, 2011).

Residential mobility has the potential to affect health through various potential pathways. First, residential mobility leads to changes to the physical built environment, which implicates shifts in resource availability (Drewnowski et al., 2019). For example, moving to a different neighborhood alters the surrounding environment such that access to goods, services, and public resources change, including walkability and access to supermarkets with fresh food. Specifically, moves to more disadvantaged neighborhoods may confer heightened risk due to

Abbreviations: 9/11, September 11, 2001; WTC, World Trade Center; PUMA, public use microdata area; PTSD, posttraumatic stress disorder; HR, hazard ratio; CI, Confidence Interval.

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decreased resources and increased exposure to crime or dangerous environments (Morris et al., 2018). The Moving to Opportunity study provides an example of how participants who were randomly assigned the opportunity to move to a less disadvantaged neighborhood (via a housing relocation voucher) experienced improvements in mental health, obesity, type 2 diabetes, and asthma (Katz et al., 1999; Leventhal and Brooks-Gunn, 2003; Ludwig et al., 2011).

A second potential pathway through which residential mobility could influence health is through a disruption of social ties and networks. The conceptual model of how social networks impact health proposed by Berkman and colleagues (Berkman et al., 2000) posits that macro-level social conditions shape the nature and degree of social networks which influence social support, influence, and engagement; which then go onto impact health through behavioral modifications, psychological well-being, and physiologic conditions. More generally, social ties and social capital are hypothesized to serve as buffers to life's stressors (Price et al., 2018; Wind and Villalonga-Olives, 2019), which may affect individuals' ability to '[conserve resources]' when faced with adversity, leading to stress and vulnerability to stress-related disorders. Therefore, individuals living in communities with lesser degrees of social capital; or those who experience losses of social capital due to forced or voluntary moves may be at heightened risks of adverse health outcomes through this pathway (Villalonga-Olives and Kawachi, 2017).

Lastly, high levels of residential mobility may serve as a marker of housing instability (Clark, 2010), which can be driven by multiple stressors such as difficulty paying the mortgage or rent or overcrowding (Carrion et al., 2015; Vijayaraghavan et al., 2013). More generally, residential mobility, even including moves to lower poverty neighborhoods, have been shown to induce stress (Keene and Geronimus, 2011; Srinivasan et al., 2003).

Changes to the built environment have the potential to affect healthy behaviors, which may go on to affect chronic disease risk (Laraia et al., 2012; Li et al., 2009; Sallis et al., 2012). For example, residents living in neighborhoods with lower densities of resources such as parks, recreational activity centers, and grocery stores have been shown to have decreased levels of physical activity and poorer diet quality (Caspi et al., 2012; Drewnowski et al., 2019; Duncan et al., 2005, 2015; Hickson et al., 2011; Jiao et al., 2015). These potentially modifiable risk factors, including but not limited to obesity, sedentary behaviors, and poor diet - although correlated with socioeconomic position - have independently been linked with common chronic diseases, such as diabetes and hypertension (Brummett et al., 2011; Forman et al., 2009; Stringhini et al., 2012). Our hypothesis was that residential mobility and/or displacement in the context of gentrification and the resulting changes in the built environment along with the disruption of social ties and increased stress, could influence risk factors for chronic disease and ultimately the risk of developing diabetes and/or hypertension (Gebreab et al., 2017).

Although several studies have assessed the potential health effects of neighborhood characteristics, gentrification, residential mobility, and related changes to the built environment (Gibbons and Barton, 2016; Lovasi et al., 2009), most have been cross-sectional in design. However, because gentrification and any potentially related residential mobility or displacement are dynamic processes that inherently occur over time, there is a need for longitudinal studies that can measure neighborhood change, individuals' moving patterns, and disease occurrence over time (Tulier et al., 2019).

The purpose of this study was to examine the associations between residential mobility over time and chronic disease incidence between 2004 and 2016 in a cohort of primarily urban-dwelling adults who were exposed to the World Trade Center (WTC) terrorist attacks on September 11, 2001 (9/11). First, we estimated the associations between moving frequency and diabetes and hypertension. Second, we focused on a particular moving pattern potentially related to gentrification: displacement, and estimated its associations with diabetes and hypertension.

2. Methods

2.1. Study population and design

The World Trade Center Health Registry (Registry) is a prospective cohort study of individuals exposed to the WTC terrorist attacks on 9/11 and included those who worked, lived, or went to school in lower Manhattan, defined as south of Canal Street, at the time or participated in the rescue and recovery efforts (Farfel et al., 2008). In 2003–2004, 71, 426 individuals were enrolled and completed a baseline questionnaire (Wave 1). Subsequently, three follow-up surveys were administered: Wave 2 (2006–2007), Wave 3 (2010–2011), and Wave 4 (2015–2016). Response rates among adults for each of the follow-up surveys were as follows: Wave 2: 67.5%; Wave 3: 62.2%; Wave 4: 52.8%. Questionnaires asked about a variety of topics including demographics, physician-diagnosed health conditions, and mental health symptoms through the use of validated survey instruments.

For this analytic study, enrollees who were less than 18 years of age at Wave 1 (N = 2757), those who withdrew from the Registry through 2018 (N = 926), and those who completed Wave 1 only (13,404) were excluded. This sample was then separated into two subgroups: those without prevalent diabetes at baseline (i.e., 2004; N = 44,089) and those without prevalent hypertension at baseline (N = 35,065). Separate analyses were conducted for these two outcomes in each of these subgroups.

2.2. Measures

Annual address data was collected through yearly communications with enrollees. Addresses were geocoded to the level of public use microdata areas (PUMAs). PUMAs are statistical geographic areas defined by the US Census and are designed to have approximately 100,000 residents (Kurban et al., 2011). In this study, a PUMA was considered to be a "neighborhood". Moving was defined as having an address change indicating relocation to a different neighborhood (i.e., PUMA) across consecutive years. Although it is possible that enrollees may have moved multiple times in one year, address data were only collected once per year.

Of all moving events, we identified displacement in the context of the level of neighborhood gentrification over time using the following multi-tiered approach. First, at the neighborhood level, we measured gentrification and neighborhood types within the New York City metropolitan area by calculating a composite measure of neighborhood disadvantage based on US Census and American Community Survey data that was originally developed by Ross and Mirowsky (2001). Specifically, we defined objective neighborhood disadvantage in an individual's census tract using the following formula:

$$(H_{FPT} + F_{HH}) - (A_C + H_{OO})$$

Where H_{FPT} = % of households with incomes below the federal poverty threshold.

F_{HH} = % of female-headed households with children
A_C = % of adults over age 24 years with college degrees
H_{OO} = % of housing units that are owner-occupied

In this study, this index was calculated for each neighborhood (i.e., PUMA) in the New York City metropolitan area and year of data (2000 Census data and single year data from the American Community Survey for 2005–2015). Higher index values indicated greater neighborhood disadvantage.

Linear regression models were then fit to measure the change in the index over time between 2000 and 2015. Neighborhoods were subsequently categorized into four groups based on their baseline neighborhood deprivation (i.e., intercept) and change over time (i.e., slope):

consistently non-deprived, gentrifying, consistently deprived, and declining (Poirot E et al., unpublished manuscript). Consistently non-deprived neighborhoods had low baseline indexes (intercepts ≤80th percentile) and little to no change over time (slopes ≤20th percentile or not statistically significant); gentrifying neighborhoods had high baseline indexes (intercepts >80th percentile) and rapid negative changes in the index (slopes ≤20th percentile; i.e., less neighborhood deprivation) over time; consistently deprived neighborhoods had high baseline indexes (intercepts >80th percentile) and little to no change over time (slopes >80th percentile or not statistically significant); and declining neighborhoods had low baseline indexes (intercepts ≤80th percentile) and further positive changes in the index (slopes >80th percentile; i.e., more neighborhood deprivation) over time. The distribution of neighborhood types in the New York City metropolitan area is shown in Fig. 1 (Poirot E et al., unpublished manuscript).

Second, after classifying neighborhood types, we defined individual residential displacement using individual-level annual address data. Among those with at least 2 annual geocoded addresses in the New York City metropolitan area, displacement was defined as ever moving from a non-deprived or gentrifying neighborhood to a deprived or declining neighborhood between 2004 and 2016. The comparison group for the displaced, referred to as those "not displaced", was defined as those who lived in non-deprived or gentrifying neighborhoods and never moved. This was chosen in an effort to approximate a similar experience to that of the "displaced" since they started in the same types of neighborhoods.

All covariates and outcomes of interest were derived from survey responses. Both diabetes and hypertension outcomes were assessed through separate questions that asked whether the enrollee had ever received a physician diagnosis of each condition, and if so, when. Posttraumatic stress disorder (PTSD) symptoms were assessed as a covariate in relation to both outcomes due to the literature showing a relationship between mental health symptoms and both diabetes (Kibler et al., 2009) and hypertension (Egede and Dismuke, 2012) as well as housing instability (Tsai and Rosenheck, 2015). PTSD symptoms were measured using the stressor-specific PTSD Checklist (PCL)-17 (Ruggiero et al., 2003), which references the events of 9/11 in the re-experiencing and avoidance symptom clusters. The PCL is a self-administered questionnaire that queries the severity of PTSD symptoms based on *DSM-IV* criteria (American Psychiatric Association, 1994). Enrollees rated the degree to which these symptoms bothered them, ranging from 1 = *not at all* to 5 = *extremely*, and the scores from the 17 items were summed. Total scores ≥44 were considered to be indicative of probable PTSD.

2.3. Statistical analysis

Residential mobility was considered in two ways: moving frequency and potentially gentrification-related displacement (hereafter referred to as displacement). Moving frequency was categorized into the following categories based on US Census data (Census, 2016; Jelleyman and Spencer, 2008): 0 moves (i.e., never movers), 1–2 moves, and ≥3 moves to different neighborhoods (i.e., frequent movers) between 2004 and 2016. Extended Cox proportional hazards models were fit to estimate the associations between moving frequency and time to diabetes diagnosis and moving frequency and time to hypertension diagnosis (Kleinbaum and Klein, 2010). In addition, separate models were fit with displacement as the exposure. The analytic sample for the analysis with displacement as the exposure was restricted to those who had at least two years of recorded addresses in the New York City metropolitan area (i.e., so they had the opportunity to be displaced). The displaced (i.e., those who ever moved from a non-deprived or gentrifying neighborhood to a deprived or declining neighborhood between 2004 and 2016) were compared to the not displaced (i.e., those who lived in non-deprived or gentrifying neighborhoods and never moved). Therefore, anyone who moved in other patterns other than 'displaced' or anyone who lived in

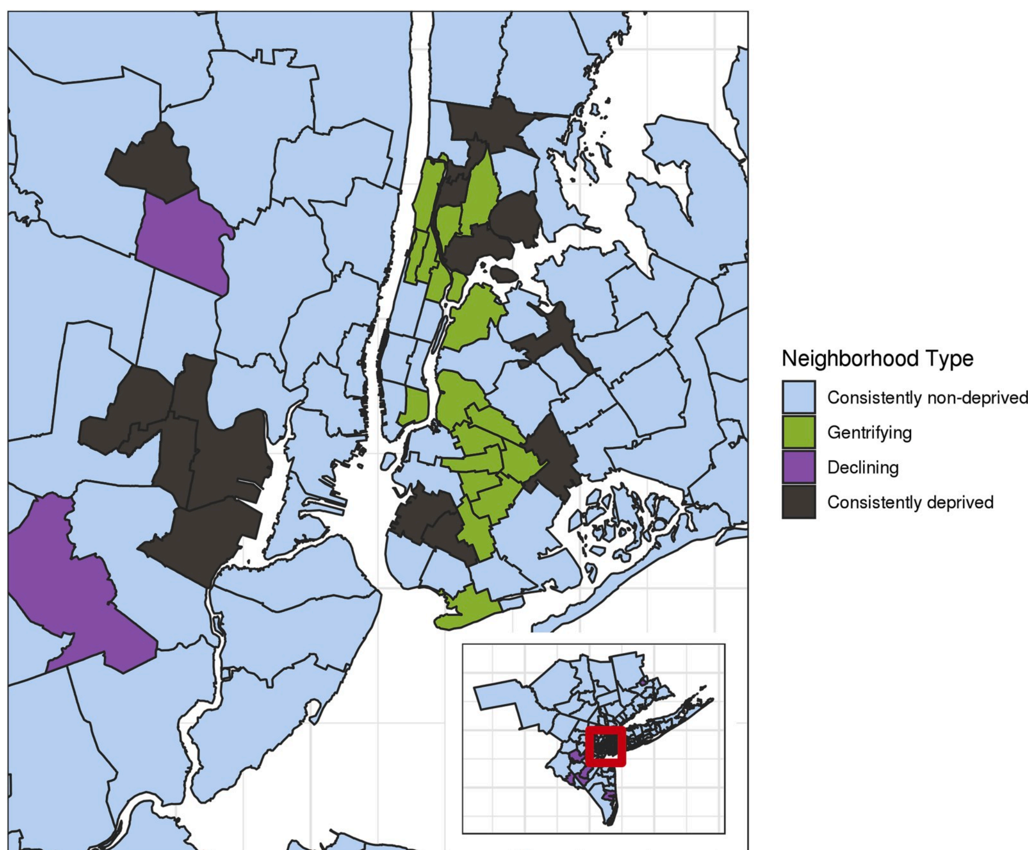

Fig. 1. Neighborhood types as defined by public use microdata areas within the New York city metropolitan area, 2000–2015.

deprived or declining neighborhoods at baseline and never moved were excluded from analyses with displacement as the exposure. Both moving frequency and displacement were considered as time-varying exposures (Kleinbaum and Klein, 2010).

The accrual of follow-up time began in 2004 (i.e., baseline) and continued until a report of the outcome, loss to follow-up (i.e., last survey Wave completed), or the end of follow-up (i.e., 2016); whichever occurred first. All models controlled for factors hypothesized to be potential confounders based on the literature and our conceptualized directed acyclic graph (Greenland et al., 1999): sex, race/ethnicity, age at baseline, income, marital status, employment status, education level, and probable PTSD at baseline. Income, marital status, employment status, and education level were considered as time-varying covariates.

Lastly, we conducted five sensitivity analyses. First, when estimating the association between displacement and each outcome, we considered an alternative comparison group for the displaced. The original comparison group was made up of persons who lived in gentrifying or non-deprived neighborhoods and never moved. However, in an attempt to address the potential for a "healthy mover" effect (McNamee, 2003), we ran models with an alternative comparison group: those who moved in all other patterns other than displaced. The second sensitivity analysis assessed the impact of controlling for living in public housing provided by the New York City Housing Authority (NYCHA) in statistical models. Living in NYCHA housing may reduce the degree of residential mobility and displacement, and has been found to be associated with several health outcomes (Bahchieva and Hosier, 2001; Lim et al., 2019; Mehta et al., 2018). In the third sensitivity analysis, we examined potential effect measure modification in the associations of moving frequency on

Table 1
Participant characteristics by residential mobility activity among those without prevalent diabetes at baseline, world trade center health registry, 2004–2016.

	Total Sample (N = 44,089)[a] N (%)[e]	Moving Frequency			Displacement	
		Never Moved	Moved 1–2 times	Moved ≥3 times	Displaced[b]	Not displaced[c,d]
		N = 24,027	N = 17,217	N = 2845	N = 714	N = 20,222
		N (%)[f]	N (%)[f]	N (%)[f]	N (%)[f]	N (%)[f]
Incident diabetes						
No	40620 (92.1)	22046 (54.3)	15904 (39.2)	2670 (6.6)	655 (3.4)	18599 (96.6)
Yes	3469 (7.9)	1981 (57.1)	1313 (37.8)	175 (5.0)	59 (3.5)	1623 (96.5)
Age at Wave 1 (years)						
18-35	10523 (23.9)	3636 (34.6)	5635 (53.5)	1252 (11.9)	302 (9.0)	3059 (91.0)
36-42	11234 (25.5)	6112 (54.4)	4485 (39.9)	637 (5.7)	171 (3.2)	5256 (96.8)
43-51	12180 (27.6)	7778 (63.9)	3889 (31.9)	513 (4.2)	158 (2.3)	6570 (97.7)
≥52	10152 (23.0)	6501 (64.0)	3208 (31.6)	443 (4.4)	83 (1.5)	5337 (98.5)
Sex						
Male	26739 (60.7)	15071 (56.4)	10130 (37.9)	1538 (5.8)	353 (2.7)	12710 (97.3)
Female	17350 (39.4)	8956 (51.6)	7087 (40.8)	1307 (7.5)	361 (4.6)	7512 (95.4)
Race/Ethnicity						
NH White	30290 (68.7)	16838 (55.6)	11578 (38.2)	1874 (6.2)	308 (2.1)	14112 (97.9)
NH Black	4683 (10.6)	2586 (55.2)	1786 (38.1)	311 (6.6)	145 (6.2)	2200 (93.8)
Hispanic	5186 (11.8)	2598 (50.1)	2227 (42.9)	361 (7.0)	183 (7.9)	2146 (92.1)
Asian	2402 (5.5)	1299 (54.1)	944 (39.3)	159 (6.6)	51 (4.1)	1191 (95.9)
Other	1528 (3.5)	706 (46.2)	682 (44.6)	140 (9.2)	27 (4.5)	573 (95.5)
Education[g]						
≤High school	20067 (45.9)	11470 (57.2)	7409 (36.9)	1188 (5.9)	374 (3.8)	9562 (96.2)
College	14640 (33.5)	7618 (52.0)	5993 (40.9)	1029 (7.0)	227 (3.4)	6469 (96.6)
Graduate school	9032 (20.7)	4854 (53.7)	3595 (39.8)	583 (6.5)	110 (2.6)	4119 (97.4)
Income[g]						
≤$25,000	3942 (8.9)	1815 (46.0)	1686 (42.8)	441 (11.2)	118 (7.3)	1502 (92.7)
$25,0001-≤$75,000	18176 (41.2)	9315 (51.2)	7552 (41.5)	1309 (7.2)	380 (4.8)	7515 (95.2)
$75,0001-≤$150,000	16137 (36.6)	9566 (59.3)	5808 (36.0)	763 (4.7)	167 (2.0)	8229 (98.0)
>$150,000	5834 (13.2)	3331 (57.1)	2171 (37.2)	332 (5.7)	49 (1.6)	2976 (98.4)
Employment Status[g]						
Employed	38129 (86.9)	20858 (54.7)	14910 (39.1)	2361 (6.2)	605 (3.3)	17698 (96.7)
Unemployed	5731 (13.1)	3158 (55.1)	2130 (37.2)	443 (7.7)	106 (4.0)	2513 (96.0)
Marital Status[g]						
Married/cohabitating	28230 (64.6)	16799 (59.5)	10087 (35.7)	1344 (4.8)	350 (2.4)	14027 (97.6)
Divorced/separated	4840 (11.1)	2349 (48.5)	2093 (43.2)	398 (8.2)	112 (5.4)	1960 (94.6)
Widowed	705 (1.6)	440 (62.4)	223 (31.6)	42 (6.0)	6 (1.6)	361 (98.4)
Never married	9931 (22.7)	4363 (43.9)	4565 (46.0)	1003 (10.1)	240 (5.9)	3803 (94.1)
PTSD at Wave 1						
No	36637 (85.3)	20174 (55.1)	14180 (38.7)	2283 (6.2)	556 (3.2)	16853 (96.8)
Yes	6334 (14.7)	3293 (52.0)	2554 (40.3)	487 (7.7)	147 (4.8)	2888 (95.2)
Lower Manhattan Resident on 9/11						
No	37280 (84.6)	20795 (55.8)	14292 (38.3)	2193 (5.9)	615 (3.5)	17133 (96.5)
Yes	6809 (15.4)	3232 (47.5)	2925 (43.0)	652 (9.6)	99 (3.1)	3089 (96.9)

Abbreviations: NH: Non-Hispanic; PTSD: posttraumatic stress disorder.

[a] Those ≥18 years at Wave 1, who did not withdraw from the Registry, who completed at least one follow-up survey between 2006 and 2016, without prevalent diabetes at baseline (2004).

[b] Defined as those who lived in gentrified or non-deprived neighborhoods at some time during follow-up and moved to deprived or declining neighborhoods.

[c] Defined as those who lived in gentrified or non-deprived neighborhoods at baseline and never moved.

[d] Displaced and non-displaced do not sum to the total noted in the Total Sample column because these two groups do not include anyone who had <2 annual geocoded addresses in the New York City metropolitan area (N = 5507), anyone who moved in other patterns other than 'displaced' (N = 16,403), or anyone who lived in deprived or declining neighborhoods at baseline and never moved (N = 1243).

[e] Percents shown are column percents.

[f] Percents shown are row percents.

[g] Counts refer to status at Wave 1. In the model, these covariates vary over time.

both outcomes by age at baseline, race/ethnicity, education level attained, and household income in order to explore if the impact of moving on chronic disease varied across life stages (i.e., age) or demographic subgroups (i.e., race/ethnicity, education, and income). Previous literature has documented an increased vulnerability to the changing social and environmental conditions of neighborhoods among minorities (Gibbons and Barton, 2016) and those of low socioeconomic status (Pearsall, 2010), as well as younger individuals (Price et al., 2018). This analysis was conducted by including cross-product terms between moving frequency and each demographic characteristic (i.e., age, race/ethnicity, income, and education) in separate models for each outcome. Fourth, we calculated the number of moves to different discrete addresses, ignoring the distinction between neighborhoods. Models were fit using this as the exposure instead of the number of moves to different neighborhoods. Finally, the last sensitivity analysis examined the potential impact of attrition from the cohort by calculating and applying inverse probability of attrition weighting to models using stabilized weights (Weuve et al., 2012).

All analyses were conducted using SAS 9.4 software (Cary, NC). Statistical significance was determine using two-sided p-value <0.05.

3. Results

Among the sample without prevalent diabetes at baseline (N = 44,089), nearly half (45.5%) moved at least once during follow-up (Table 1). However, moving three or more times was rare (6.5%). Younger enrollees were more likely to move frequently compared with those who were older (11.9% of those aged 18–35 years vs. 4.4% aged ≥52 years moved ≥3 times). Hispanics and those of other race (vs. non-Hispanic Whites), females (vs. males), those of lower household income at baseline (≤$25,000 vs. more), those who were unemployed at baseline (vs. employed), those who were never married at baseline (vs. married), those with probable PTSD at baseline (vs. no PTSD), and those who were residents in lower Manhattan on 9/11 (vs. lived elsewhere) were also more likely to frequently move. These same trends were also observed among the sample without prevalent hypertension at baseline (Supplemental Table 1; note that the population sample size differs in Supplemental Table 1 due to the exclusion of those with prevalent hypertension at baseline).

Although moving at least once was common, displacement was rare (1.6%, Table 1). Similar demographics to those associated with frequent moving also predicted displacement in bivariate analyses, although lower Manhattan residents (as of November 9, 2001) were not more likely to be displaced than those who lived elsewhere (3.1% vs. 3.5%, respectively).

In bivariate analyses, the overall incidence of diabetes decreased as moving frequency increased (Table 2). For example, those who moved ≥3 times (i.e., frequent movers) were slightly less likely to develop diabetes than those who never moved (6.2% vs. 8.2%, respectively; Table 2). After adjustment for covariates, moving frequency was not associated with diabetes incidence. Similarly, displacement was not associated with diabetes incidence (hazard ratio (HR) = 0.81, 95% Confidence Interval (CI): 0.33, 1.98). This result did not change when the comparison group for the displaced was altered from those who lived in gentrifying or non-deprived neighborhoods and never moved to all other movers.

Although residential mobility was not associated with diabetes, several covariates exhibited expected associations with diabetes incidence. In the adjusted model, older age at baseline was associated with an increased hazard of diabetes (for those aged ≥52 years vs. 18–35 years, HR = 3.41, 95% CI: 2.75, 4.22; Table 2). Females were less likely to develop diabetes compared with men. Those of non-White races/ethnicities (vs. White), those with a high school education only (vs. graduate school), those with household incomes ≤$150,000 (vs. >$150,000), and those with probable PTSD at baseline (vs. no PTSD) had greater risks of diabetes over follow-up.

Table 2
Adjusted[a] hazard ratios (HR) and 95% confidence intervals (CI) for The association between moving frequency and covariates and diabetes incidence, world trade center health registry, 2004–2016.

	Diabetes (N = 3469)	No diabetes (N = 40,620)	HR (95% CI)
	N (%)	N (%)	
Moving frequency			
0 times	1981 (8.2)	22046 (91.8)	1.00 (Reference)
1–2 times	1313 (7.6)	15904 (92.4)	1.06 (0.88, 1.28)
≥3 times	175 (6.2)	2670 (93.8)	0.78 (0.40, 1.53)
Age at Wave 1 (years)			
18-35	359 (3.4)	10164 (96.6)	1.00 (Reference)
36-42	758 (6.7)	10476 (93.3)	1.82 (1.46, 2.27)
43-51	1213 (10.0)	10967 (90.0)	2.66 (2.16, 3.28)
≥52	1139 (11.2)	9013 (88.8)	3.41 (2.75, 4.22)
Sex			
Male	2206 (8.3)	24533 (91.7)	1.00 (Reference)
Female	1263 (7.3)	16087 (92.7)	0.76 (0.67, 0.86)
Race/Ethnicity			
NH White	1902 (6.3)	28388 (93.7)	1.00 (Reference)
NH Black	565 (12.1)	4118 (87.9)	1.72 (1.45, 2.03)
Hispanic	581 (11.2)	4605 (88.8)	1.57 (1.32, 1.85)
Asian	289 (12.0)	2113 (88.0)	2.45 (1.99, 3.02)
Other	132 (8.6)	1396 (91.4)	1.30 (0.94, 1.81)
Education[c]			
≤High school	2045 (10.2)	18022 (89.8)	1.53 (1.27, 1.83)
College	884 (6.0)	13756 (94.0)	1.05 (0.87, 1.28)
Graduate school	509 (5.6)	8523 (94.4)	1.00 (Reference)
Income[c]			
≤$25,000	338 (8.6)	3604 (91.4)	1.29 (0.95, 1.75)
$25,0001-≤$75,000	1656 (9.1)	16520 (90.9)	1.70 (1.34, 2.16)
$75,0001-≤$150,000	1201 (7.4)	14936 (92.6)	1.53 (1.21, 1.93)
>$150,000	274 (4.7)	5560 (95.3)	1.00 (Reference)
Employment Status[c]			
Employed	2906 (7.6)	35223 (92.4)	0.93 (0.79, 1.09)
Unemployed	545 (9.5)	5186 (90.5)	1.00 (Reference)
Marital Status[c]			
Married/cohabitating	2238 (7.9)	25992 (92.1)	1.00 (Reference)
Divorced/separated	508 (10.5)	4332 (89.5)	1.07 (0.91, 1.27)
Widowed	104 (14.8)	601 (85.2)	1.25 (0.88, 1.76)
Never married	591 (6.0)	9340 (94.0)	0.80 (0.67, 0.96)
PTSD at Wave 1			
No	2565 (7.0)	34072 (93.0)	1.00 (Reference)
Yes	783 (12.4)	5551 (87.6)	1.43 (1.25, 1.65)

Abbreviations: HR: hazard ratio; CI: Confidence Interval; NH: Non-Hispanic; PTSD: posttraumatic stress disorder.

[b]Estimates for displacement are from a separate model controlling for all other covariates that follow in the table.
[a] Adjusted for all covariates listed in the table: age, sex, race/ethnicity, education, income, employment status, marital status, and PTSD at Wave 1.
[c] Counts refer to status at Wave 1. In the model, these covariates vary over time.

Analyses of hypertension incidence had similar results to those of diabetes incidence. Although those who frequently moved were slightly less likely to develop hypertension over time compared with never movers (18.1% vs. 23.6%, respectively; Table 3), moving frequency was not associated with hypertension in the adjusted model. Likewise, displacement was not associated with hypertension incidence (HR = 0.87, 95% CI: 0.50, 1.52), and these results did not vary when the alternative comparison group was examined in sensitivity analyses. The same factors identified as predictors of diabetes incidence were similarly associated with hypertension incidence. Older age at baseline, non-White race/ethnicity, lower education, lower household income, and probable PTSD at baseline were associated with increased hazards of hypertension (Table 3). In addition, those who were employed over time were more likely to develop hypertension compared with those who were not employed (HR = 1.14, 95% CI: 1.02, 1.27).

The main findings did not change when we controlled for living in NYCHA housing. Furthermore, neither the association between moving frequency and diabetes incidence nor that between moving frequency and hypertension incidence varied across strata of age at baseline, race/ethnicity, education, or income level (data not shown). In addition, results did not change when the moving frequency analysis was conducted examining the number of moves to different discrete addresses instead of the number of moves to different neighborhoods (data not shown). Lastly, the Registry cohort experienced significant attrition over time. Specifically, those who dropped out after Wave 1 compared with those who continued to participate in additional Wave surveys were more likely to be young (30.5% vs. 21.2% between ages 18–35), non-White (50.7% vs. 33.0%), and have lower household income (19.7% vs. 10.1% with household incomes ≤$25,000). However, when we applied inverse probability of attrition weights to our analysis, results did not change (data not shown).

4. Discussion

In a longitudinal cohort study of survivors of the 9/11 terrorist attacks in New York City, measures of residential mobility (i.e., moving frequency and displacement) were not associated with the incidence of diabetes or hypertension over time. Results remained unchanged after considering an alternative reference group for the displaced, evaluating the potential for different estimates across several demographic subgroups, examining the number of moves to different addresses regardless of neighborhood changes, and quantitatively assessing the potential impact of cohort attrition. Although there was no association with moving patterns, several covariates were identified as risk factors for both diabetes and hypertension including older age, male sex, non-White race/ethnicity, lower education and household income levels, and PTSD symptoms, which is consistent with the literature (Centers for Disease Control and Prevention, 2011; Matthews et al., 1989; Winkleby et al., 1990).

There are various potential pathways through which residential mobility could adversely impact health: unfavorable changes to the built environment and subsequent impacts on opportunities for healthful behaviors; disruption of social ties and/or a loss of social capital; increased stress due to either of these sets of changes; among others. While these negative consequences conceptually have the potential to affect health behaviors and stress and subsequently disease risk (Roux and Mair, 2010), we did not observe an association between moving frequency or displacement and either diabetes or hypertension incidence. This null finding may be due to several reasons. First, we

Table 3
Adjusted[a] hazard ratios (HR) and 95% confidence intervals (CI) for The association between moving frequency and covariates and hypertension incidence, world trade center health registry, 2004–2016.

	Hypertension (7,749)	No Hypertension (27,316)	HR (95% CI)
	N (%)	N (%)	
Moving frequency			
0 times	4397 (23.6)	14208 (76.4)	1.00 (Reference)
1–2 times	2917 (20.7)	11146 (79.3)	0.93 (0.82, 1.06)
≥3 times	435 (18.1)	1962 (81.9)	0.99 (0.68, 1.43)
Age at Wave 1 (years)			
18-35	1287 (13.4)	8322 (86.6)	1.00 (Reference)
36-42	2037 (21.2)	7582 (78.8)	1.40 (1.26, 1.57)
43-51	2529 (26.7)	6927 (73.3)	1.83 (1.65, 2.04)
≥52	1896 (29.7)	4485 (70.3)	2.27 (2.02, 2.54)
Sex			
Male	5034 (24.6)	15405 (75.4)	1.00 (Reference)
Female	2715 (18.6)	11911 (81.4)	0.67 (0.62, 0.72)
Race/Ethnicity			
NH White	4904 (20.3)	19297 (79.7)	1.00 (Reference)
NH Black	1036 (31.5)	2257 (68.5)	1.45 (1.31, 1.62)
Hispanic	1059 (24.6)	3247 (75.4)	1.12 (1.00, 1.24)
Asian	434 (21.4)	1598 (78.6)	1.13 (0.97, 1.32)
Other	316 (25.6)	917 (74.4)	1.17 (0.96, 1.43)
Education[c]			
≤High school	4091 (26.6)	11281 (73.4)	1.40 (1.26, 1.55)
College	2225 (18.5)	9777 (81.5)	1.10 (0.99, 1.23)
Graduate school	1338 (18.1)	6041 (81.9)	1.00 (Reference)
Income[c]			
≤$25,000	691 (21.2)	2564 (78.8)	1.13 (0.95, 1.34)
$25,0001- ≤$75,000	3390 (23.6)	10978 (76.4)	1.26 (1.11, 1.43)
$75,0001- ≤$150,000	2881 (22.7)	9838 (77.3)	1.20 (1.07, 1.36)
>$150,000	787 (16.7)	3936 (83.3)	1.00 (Reference)
Employment Status[c]			
Employed	6710 (21.9)	23934 (78.1)	1.14 (1.02, 1.27)
Unemployed	978 (23.2)	3232 (76.8)	1.00 (Reference)
Marital Status[c]			
Married/ cohabitating	5127 (23.0)	17150 (77.0)	1.00 (Reference)
Divorced/ separated	922 (25.6)	2677 (74.4)	1.04 (0.93, 1.16)
Widowed	154 (35.6)	279 (64.4)	1.27 (0.97, 1.64)
Never married	1454 (17.3)	6960 (82.7)	0.92 (0.83, 1.01)
PTSD at Wave 1			
No	6196 (21.0)	23330 (79.0)	1.00 (Reference)
Yes	1322 (28.3)	3347 (71.7)	1.18 (1.08, 1.30)

Abbreviations: HR: hazard ratio; CI: Confidence Interval; NH: Non-Hispanic; PTSD: posttraumatic stress disorder.

[b]Estimates for displacement are from a separate model controlling for all other covariates that follow in the table.

[a] Adjusted for all covariates listed in the table: age, sex, race/ethnicity, education, income, employment status, marital status, and PTSD at Wave 1.

[c] Counts refer to status at Wave 1. In the model, these covariates vary over time.

examined this question in a specific population who were present in lower Manhattan on 9/11. The Registry cohort is mostly non-Hispanic White, college-educated, and the vast majority employed. It is possible that in this context, residential mobility is not associated with poor health outcomes overall. While we attempted to examine whether moving frequency may have differentially affected certain subgroups, perhaps the more vulnerable moreso than others, we did not detect any differences across strata of age, race/ethnicity, household income, or education. Second, both frequent moving and potentially gentrification-related displacement were rare in this cohort, which not only limited our power, but may also provide insight into the residential dynamics of this particular cohort. In other words, it may be that the particular measures of residential mobility examined in this study were not the most relevant to this particular population in the study timeframe.

The study of neighborhood-level changes, such as gentrification, in relation to individual health outcomes is challenging. The hypothesized causal framework for this study question was such that changes to the built environment, namely neighborhood characteristics, would influence stress levels and risk behaviors for metabolic and cardiovascular disease, such as physical activity and obesity, which would then go onto influence disease risk (Ewing et al., 2014). However, several studies have noted that individuals tend to "self-select" into neighborhoods that cater to their preferences, such as walkability (Frank et al., 2007; James et al., 2015). However, this type of self-selection would be expected to inflate associations between neighborhood factors and health outcomes (Jokela, 2014), and our findings were consistently null, with point estimates less than 1. Another potential complication is referred to as the "healthy mover" effect. This refers to the observation that those who move at all may be in better health than those who do not move (McNamee, 2003). One way we tried to evaluate this was by changing the comparison group for those who were displaced from those who were living in gentrifying or non-deprived neighborhoods and never moved to those who moved in all other patterns other than the displaced. However, results did not change. Finally, we attempted to measure residential displacement in the context of gentrification. However, we note that there are many reasons for displacement, with gentrification-related pressures being only one potential option. In addition, we did not have information on whether these moves were voluntary or forced, which would have added more depth to our study.

Our study benefited from several strengths. We had longitudinal data on a closed and well-defined cohort over 12 years. Because gentrification is a dynamic and multidimensional process that occurs over time and has impacts that vary over time, this type of design was essential to assess health impacts of gentrification (Tulier et al., 2019). Furthermore, we were able to respond to recent calls for following individuals through "time and space" in the study of residential mobility (Coulter et al., 2015; Coulter and van Ham, 2013). In particular, this allowed us to implement a statistical method that accommodated time-varying exposures and covariates (Morris et al., 2018). We further identified factors hypothesized to be potential confounders, such as demographic characteristics, and avoided controlling for factors that could be on the causal pathway, such as exercise, nutrition, or obesity (Laraia et al., 2012; Sallis et al., 2012). Another strength is that we were able to pair objective population-level data (i.e., US Census and American Community Survey data) with individual-level data on address history and health outcomes. In addition to evaluating moving frequency over time, this allowed us to also evaluate the types of moves (i.e., displacement), as well.

We also note some limitations of this work. One major limitation is that we did not have information on reasons for moving or reasons for moving to particular neighborhoods. This is a common limitation of studies of this kind (Findlay et al., 2015; James et al., 2015). Future studies should consider integrating this information. To that end, this may be a suitable topic for qualitative assessments of motives for moving. Another limitation is that the address information we used was not originally collected for research purposes. Annual "snapshots" of address data were collected on Registry enrollees. Thus, only one address per year was recorded over time; allowing for a maximum of one move per year. It is therefore possible that this measure of moving frequency did not adequately capture all of the potentially relevant residential mobility that may have truly occurred. Furthermore, it is also possible that those with the highest degree of housing insecurity (i.e., those who became homeless; those with insecure housing) were lost to follow-up. However, we were unable to test the extent to which this could have occurred due to the nature of the address data collection. Furthermore, the WTCHR experienced a substantial degree of non-random attrition over time. However, when we quantitatively assessed its potential impact on our results, there were no notable differences. Lastly, we had crude, self-reported information on disease outcomes with no measure of severity, such as glycemic control (Tabaei et al., 2017). Future directions of this work may include evaluating more objective endpoints such as mortality data linked through the National Death Index and/or hospitalization data collected by the New York State Statewide Planning and Research Cooperative System.

5. Conclusion

This study documented residential mobility and its potential consequences on chronic disease among a cohort of individuals exposed to the 9/11 disaster in a dynamic urban environment between 2004 and 2016. Moving frequency and displacement were not associated with diabetes or hypertension. This area of research has implications for public health. The built environment constitutes a complex exposure that has been shown to influence health (Srinivasan et al., 2003). Although in this study there was no apparent association between residential mobility and the chronic disease outcomes studied, it has been shown that community resources impact opportunities for healthy behaviors, which over time can affect health outcomes. From a public health perspective, this indicates that regional programs and policies, such as those related to affordable housing in cities, should consider the potential downstream effects on health. Further research is needed to better understand the drivers behind certain individuals moving to neighborhoods with varied characteristics or resources. This information could identify whether 'forced' moves, or those that destroy social ties for example, have deleterious effects compared with other types of moves. In addition, research using large, administrative databases for outcome ascertainment, especially in cohorts that also have rich individual-level covariate data, may be warranted.

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Appendix A. Supplementary data

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