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Neighborhood influences on recreational physical activity and survival after breast cancer

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Abstract

Purpose Higher levels of physical activity have been associated with improved survival after breast cancer diagnosis. However, no previous studies have considered the influence of the social and built environment on physical activity and survival among breast cancer patients. **Methods** Our study included 4,345 women diagnosed with breast cancer (1995–2008) from two population-based studies conducted in the San Francisco Bay Area. We examined questionnaire-based moderate/strenuous recreational physical activity during the 3 years before diagnosis. Neighborhood characteristics were based on data from the 2000 US Census, business listings, parks, farmers' markets, and Department of Transportation. Survival was evaluated using multivariable Cox proportional hazards models, with follow-up through 2009.

Results Women residing in neighborhoods with no fast-food restaurants (vs. fewer fast-food restaurants) to other restaurants, high traffic density, and a high percentage of foreign-born residents were less likely to meet physical activity recommendations set by the American Cancer Society. Women who were not recreationally physically active had a 22 % higher risk of death from any cause than women that were the most active. Poorer overall survival

was associated with lower neighborhood socioeconomic status (SES) (p trend = 0.02), whereas better breast cancer-specific survival was associated with a lack of parks, especially among women in high-SES neighborhoods.

Conclusion Certain aspects of the neighborhood have independent associations with recreational physical activity among breast cancer patients and their survival. Considering neighborhood factors may aide in the design of more effective, tailored physical activity programs for breast cancer survivors.

Keywords Breast cancer · Built environment · Neighborhood · Physical activity · Socioeconomic status

Introduction

Worldwide, breast cancer is the most common cancer and the leading cause of cancer death for women [1]. Although 5-year relative survival after breast cancer is approximately 90 % [2], survivors have been found to be at an increased risk of recurrence, second cancers, and premature death [3–5]. Therefore, it is critical to identify modifiable factors that can reduce morbidities and improve survival for all women after breast cancer diagnosis. Higher levels of physical activity have been associated with a 30 % reduction in mortality risk after breast cancer diagnosis [6], as well as reduced risk of recurrence, and improved quality of life and physical functioning [7]. We previously reported that any (vs. no) recreational activity during the 3 years before breast cancer diagnosis was associated with a 34 % lower risk of death for women with estrogen receptor-positive tumors [8].

Research to date suggests that elements of the social and built environment influence physical activity levels [9–12]. The built environment comprises the man-made, physical

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attributes of a person's surroundings, such as spatial configuration of streets, the transportation structure, commuting patterns, availability of health-promoting resources (e.g., parks, farmers' markets), and the number of walkable destinations. These attributes can provide opportunities and/or barriers for healthful behaviors (e.g., physical activity and diet) that can influence health outcomes [13]. The social environment includes the socioeconomic and demographic aspects of a neighborhood and has been associated with opportunities for education, employment, social support, stress and coping, factors that can shape health behaviors and outcomes [14–17]. To our knowledge, no previous studies have considered the associations between recreational physical activity and survival after breast cancer while accounting for measures of the social and built environment. Identifying the environmental barriers and facilitators to physical activity may help to inform and improve interventions for increasing physical activity levels.

Combining interview data from San Francisco Bay Area breast cancer patients with data on neighborhood characteristics, we examined the relationship between recreational physical activity and measures of the neighborhood environment. Additionally, we examined associations of physical activity and neighborhood environment with survival after breast cancer diagnosis.

Materials and methods

Subjects

This analysis includes data from two population-based studies that were harmonized and pooled to create the Neighborhoods and Breast Cancer Study (NABC). The two studies include the San Francisco Bay Area Breast Cancer Study (SFBCS), a case–control study of breast cancer in African American, Hispanic, and non-Hispanic white women [18, 19]; and the Northern California site of the Breast Cancer Family Registry (NC-BCFR) [20, 21]. Both studies identified women newly diagnosed with a first primary invasive breast cancer through the Greater Bay Area Cancer Registry and screened cases by telephone to establish study eligibility and self-identified race/ethnicity (participation was 84 % in the SFBCS and 83 % in the NC-BCFR among cases contacted).

In SFBCS, eligible cases were aged 35–79 years who lived in Alameda, Contra Costa, San Mateo, San Francisco, or Santa Clara counties at the time of diagnosis. They included all Hispanics diagnosed between 1 April 1995 and 30 April 2002, all African Americans diagnosed between 1 April 1995 and 30 April 1999, and a random 10 % sample of non-Hispanic whites diagnosed between 1 April 1995 and 30 April 1999. Of 2,571 cases selected into the case–control study, 2,258 (88 %) completed the in-person interview.

In NC-BCFR, eligible cases were aged 18–64 years who lived in Alameda, Contra Costa, Marin, San Mateo, San Francisco, Santa Clara, Santa Cruz, and Monterey counties at the time of diagnosis. They included cases of any race/ethnicity diagnosed from 1 January 1995 to 30 September 1998; Hispanic, African American, and Asian American (Chinese, Filipina, and Japanese) cases diagnosed from 1 October 1998 to 30 April 2002; Hispanic and African American cases diagnosed from 1 May 2002 to 31 December 2008. Cases were enrolled in the NC-BCFR if they had indicators of increased genetic susceptibility [20, 21]. Cases not meeting these criteria were randomly sampled (2.5 % of non-Hispanic whites and 33 % of other racial/ethnic groups). Of 4,708 cases selected into NC-BCFR, 3,631 (77 %) completed the in-person interview.

For cases that participated in both studies ($n = 339$), we used data from the SFBCS interview. We limited our analytic sample to cases with a first primary invasive breast cancer, who completed the questionnaire themselves within 5 years of diagnosis, had a geocodeable address and had follow-up information from the cancer registry. We excluded cases with Native American or mixed race/ethnicity ($n = 10$) or unknown physical activity ($n = 8$). The remaining 4,345 cases were interviewed on average 20.2 months (standard deviation = 8.8 months; range = 0.3–60.0 months) after diagnosis. Study participants provided written informed consent and all protocols were approved by the Institutional Review Board of the Cancer Prevention Institute of California.

Data collection

For both studies, trained interviewers administered similar, structured questionnaires at the participant's home in English, Spanish, or Chinese. Data were harmonized according to common definitions and included age at diagnosis, race/ethnicity, education, first-degree family history of breast cancer, personal history of benign breast disease, years since last pregnancy, pre-diagnosis oral contraceptive use, pre-diagnosis menopausal hormone therapy use, grams per day of alcohol intake 1 year prior to diagnosis, and body mass index (BMI) 1 year prior to diagnosis.

Assessment of physical activity has been described elsewhere [8, 19]. Briefly, lifetime histories of strenuous and moderate recreational activities were available from both studies and combined for these analyses. SFBCS assessed lifetime recreational physical activity performed at least 1 h per week for at least 4 months per year; for each activity, information was collected on type of activity, the age the activity started and stopped, months per year performed, and hours per week performed. NC-BCFR assessed lifetime histories of moderate (e.g., brisk walking,

hiking, cycling on level streets) and strenuous (e.g., swimming laps, aerobics, running, cycling on hills) activities; for each type of activity, information was collected on the average number of hours per week (0.5, 1, 1.5, 2, 3, 4–6, 7–10, ≥ 11 , or do not know) and months per year (1–3, 4–6, 10–12, or don't know) at specific ages, including during the 3 years before diagnosis. We estimated average recreational physical activity during the 3 years before diagnosis because prior research has shown associations between recent physical activity and survival [22], and this time frame corresponded most closely with the measurement of our neighborhood characteristics. Three physical activity variables were considered. For the first variable, the average hours per week and months per year of moderate and strenuous physical activities during the 3 years before diagnosis were summed and categorized into the following: (1) meeting physical activity recommendations by the American Cancer Society (ACS) [23] (at least 150 min of moderate intensity, 75 min of strenuous intensity, or an equivalent combination of moderate/strenuous activity per week); (2) not meeting the recommendations, but performing some moderate or strenuous physical activity; or (3) performing no moderate or strenuous physical activity. For the second variable, recent moderate and strenuous activities were weighted by metabolic equivalents (MET) (8.5 for strenuous activity and 5.4 for moderate activity) [24] and summed to obtain MET hours per week of activity during the 3 years before diagnosis, as done previously [8]. For the third variable, we considered hours per week of moderate and strenuous activity not weighted by MET.

For each participant, we obtained cancer registry information routinely abstracted from the medical record at diagnosis [25], including tumor histological subtype (ductal, lobular, or mixed/other), histological grade, estrogen receptor (ER) and progesterone receptor (PR) status, AJCC (American Joint Committee on Cancer) stage, time to first and second subsequent tumors, first-course treatment (chemotherapy, radiation, and surgery), marital status and vital status (routinely determined by the cancer registry through hospital follow-up and database linkages) as of 31 December 2009 and, for the deceased, the underlying cause of death.

Geocoding

Residential address at the time of diagnosis was geocoded to a latitude/longitude coordinate and then assigned a 2000 census block group. Addresses were standardized to conform to U.S. Postal Service specifications using ZP4 software (ZP4. Monterey, CA: Semaphore Corp., 2011). Batch geocoding was performed using ArcGIS with both current address point and street geocoding reference files (ArcGIS. Redlands, CA: Environmental Systems Research Institute,

Inc., 2011). Manual review was performed to geocode addresses that did not batch geocode, resulting in 97 % of addresses being assigned a latitude and longitude.

Social environment

For neighborhood-level socioeconomic status (SES), we used a previously validated composite SES measure of seven indicator variables at the census block group (education index, median household income, percent living 200 % below poverty level, percent blue-collar workers, percent older than 16 in workforce without job, median rent, median house value) [26]. Neighborhood immigrant population was characterized at the block group level with percentage of foreign-born residents.

Built environment

We derived information on neighborhood amenities including business listings from Walls & Associates' National Establishment Time-Series Database (which utilizes data from Dunn and Bradstreet) [27], farmers' markets listings from the California Department of Food and Agriculture [28], and parks from the NavTeq's NavStreets database [29]. Using ArcGIS software, neighborhood amenities within a 1,600-m network distance [30] from a case's residence at diagnosis were summed. To do this, we first constrained the search space by selecting all neighborhood amenities within a 1,600-m linear distance of residence, then computed the actual network distance between the residence and every neighborhood amenity. If the network distance was $\leq 1,600$ m, then the neighborhood amenity was included in analyses. We considered businesses active 1 year before diagnosis, during the year of diagnosis, or 2 years after diagnosis. The number of recreational facilities included places where recreational activities could take place (e.g., fitness centers). The Restaurant Environment Index is the ratio of the number of fast-food restaurants to other restaurants, and the Retail Food Environment Index [31] is the ratio of the number of convenience stores, liquor stores, and fast-food restaurants to supermarkets and farmers' markets. Parks included beaches, recreation areas, and parks. We determined the number of parks with an access point (e.g., vehicular entry point/parking lot or edge of smaller park) within 1,600-m network distance of a participant's residence.

Neighborhood density was characterized at the census block group level by population density (the number of people/m²) and percentage of total housing units that are not single-family dwellings. Population-based commuting characteristics from the census were summarized by typical travel time to work (% traveling ≥ 60 min/day). Data on traffic counts from the California Department of Transportation [32]

were used to obtain traffic density within a 500-m buffer of each case's residence, using methods described previously [33].

Statistical analysis

To evaluate the association of personal and neighborhood characteristics with physical activity guidelines [23], we used logistic regression to calculate odds ratios (ORs) and 95 % confidence intervals (CIs). To evaluate the association of physical activity and neighborhood characteristics with overall and breast cancer-specific survival, we used Cox proportional hazards regression to calculate hazard ratios (HRs) and 95 % CI. Base models for both logistic and Cox proportional hazards regression models included age at diagnosis, study, race/ethnicity, stage at diagnosis, and clustering by block group. Neighborhood factors that were associated with survival or physical activity in the base models were included in the fully adjusted model. Logistic models also included potential confounding variables significantly associated with physical activity (education, pre-diagnosis BMI, pre-diagnosis menopausal hormone therapy use, pre-diagnosis alcohol intake). In the fully adjusted Cox models, the confounding variables included personal factors (marital status, education, history of benign breast disease, years since last full-term pregnancy, pre-diagnosis oral contraceptive use, pre-diagnosis menopausal hormone therapy use, pre-diagnosis alcohol intake, pre-diagnosis BMI), tumor characteristics, and treatment. Correlation among the neighborhood variables was assessed, and only uncorrelated neighborhood factors (<0.50 Spearman correlation coefficient) that were significantly associated with the outcomes in univariate models were included in the multivariate models. There were insufficient numbers of cases within each neighborhood unit (block group) to warrant multilevel modeling (55 % of block groups had one case and 80 % of block groups had two or fewer cases).

For deceased cases, survival time was measured in days from the date of interview to the date of death of any cause for overall survival and to the date of death from breast cancer for breast cancer-specific survival. For breast cancer-specific survival, patients who died from other causes were censored at the time of death. Patients alive at the study end date (31 December 2009) were censored at this date or at date of last follow-up (i.e., last known contact). The proportional hazards assumption was tested for physical activity and neighborhood variables using significance tests of interactions with the timescale, and visual examination of scaled Schoenfeld residual plots; there was no evidence that these variables violated the assumption of proportional hazards.

We performed stratified analyses according to age at diagnosis (<50 or ≥ 50 years), BMI (<25.0 , 25.0 – 29.9 ,

≥ 30 kg/m²), ER status (ER+, ER–, unknown), and race/ethnicity. Tests for heterogeneity across strata were conducted using likelihood ratio tests comparing models with and without an interaction term between physical activity and the stratified variable; no significant interactions were found (data not shown). Tests for trend were used to evaluate associations between survival and increasing physical activity and ordinal categories of neighborhood characteristics. p values <0.05 were considered statistically significant, and all tests of significance were two-sided. Analyses were performed using SAS version 9.3 (SAS Institute, Cary, NC).

Results

The majority of breast cancer cases were between 40 and 64 years of age, Hispanic, college educated, and had a normal pre-diagnostic BMI (<25 kg/m²; Table 1). Sixty-six percent of the cases reported moderate or strenuous recreational physical activity during the 3 years prior to diagnosis, with 38 % reporting some recreational strenuous physical activity and 45 % meeting the physical activity recommendations set by the ACS. More than half of the cases lived in high-SES (quintiles 4 and 5) or more densely populated neighborhoods (quartiles 3 and 4), similar to the underlying population of incident breast cancer cases in this region (data not shown). The majority of women lived in neighborhoods where there were few convenience or liquor stores, and fast-food restaurants in comparison with supermarkets and farmers' markets, as well as few fast-food restaurants in comparison with other types of restaurants. Most women had at least one park within a 1-mile (1.6 km) walking distance to their residence at diagnosis.

Recent recreational physical activity

In the fully adjusted model, not meeting recreational activity recommendations was associated with diagnosis with AJCC stage IV disease, Hispanic and Asian American race/ethnicity, lower education, being obese, and residence in neighborhoods with a high percentage of foreign-born residents, no fast-food restaurants (vs. fewer fast-food restaurants) to other restaurants, and high traffic density (Table 2). There was also borderline significant evidence that meeting recreational physical activity recommendations was associated with being overweight and residing in neighborhoods without convenience or liquor stores and fast-food restaurants (vs. neighborhoods with all types of retail food environment, including supermarkets and farmer's markets). Number of parks and recreational facilities were not associated with physical activity levels in the fully adjusted model.

Table 1 Distribution of demographic, breast cancer, and neighborhood characteristics of study participants with breast cancer, San Francisco Bay Area, 1995–2008 ($n = 4,345$)

Characteristics	<i>N</i>	%
Study		
San Francisco Bay Area Breast Cancer Study	1,941	44.7
Northern California site of the Breast Cancer Family Registry	2,404	55.3
Age at diagnosis (years)		
<35	292	6.7
35–44	856	19.7
45–54	1,435	33.0
55–64	1,224	28.2
≥65	538	12.4
AJCC stage at diagnosis		
I	1,893	43.6
II	1,933	44.5
III	311	7.2
IV	78	1.8
Unknown	130	3.0
Estrogen receptor (ER) and progesterone receptor (PR) status		
ER– and PR–	917	21.1
ER+ or PR+	3,011	69.3
Unknown	417	9.6
Race/ethnicity		
Non-Hispanic white	1,057	24.3
African American	984	22.7
Hispanic	1,659	38.2
Asian American	645	14.8
Education		
Less than high school	838	19.3
High school graduate	776	17.9
Some college	1,397	32.2
College graduate or post graduate	1,302	30.0
Unknown	32	0.7
Pre-diagnosis body mass index (kg/m²)		
<25.0	1,836	42.3
25.0–29.9	1,252	28.8
≥30.0	1,203	27.7
Unknown	54	1.2
Recent recreational physical activity (MET hours/week)^a		
0	1,458	33.6
Quartile 1: <11.92	760	17.5
Quartile 2: 11.92–17.88	685	15.8
Quartile 3: 17.89–39.68	717	16.5
Quartile 4: >39.68	725	16.7
Met physical activity recommendation^b		
No physical activity	1,458	33.6
Did not meet, but had some physical activity	948	21.8
Met goal	1,939	44.6

Table 1 continued

Characteristics	<i>N</i>	%
Neighborhood socioeconomic status^c		
Quintile 5 (high)	1,675	38.6
Quintile 4	1,067	24.6
Quintile 3	770	17.7
Quintile 2	586	13.5
Quintile 1 (low)	247	5.7
Percentage of foreign-born residents in census block group^d		
Quartile 1: <15.9	1,092	25.1
Quartile 2: 15.9–26.3	1,084	25.0
Quartile 3: 26.4–41.5	1,085	25.0
Quartile 4: >41.5	1,084	25.0
Population density in census block group (people/1,000 m²)^e		
Quartile 1: <1.08	638	14.7
Quartile 2: 1.08–2.56	898	20.7
Quartile 3: 2.57–4.28	1,203	27.7
Quartile 4: >4.28	1,606	37.0
Percentage of non-single-family units in census block group^d		
Quartile 1: <3.6	1,085	25.0
Quartile 2: 3.6–23.3	1,088	25.0
Quartile 3: 23.4–51.8	1,086	25.0
Quartile 4: >51.8	1,086	25.0
Restaurant Environment Index within 1,600 m of residence at diagnosis^a		
No fast-food restaurants	1,132	26.1
≤Median (≤0.11)	1,393	32.1
>Median (>0.11) ^f	1,497	34.5
No restaurants	323	7.4
Retail Food Environment Index within 1,600 m of residence at diagnosis		
No convenient stores, liquor stores, and fast-food restaurants	572	13.2
<1	2,671	61.5
≥1 ^e	727	16.7
No retail food outlets	375	8.6
Number of parks within 1,600 m of residence at diagnosis^g		
0	661	15.2
1–2	2,079	47.9
≥3	1,605	36.9
Traffic density within 500 m of residence at diagnosis (vehicle miles traveled per square mile)^d		
Quartile 1: <31,280	1,041	24.0
Quartile 2: 31,281–60,581	1,044	24.0
Quartile 3: 60,582–99,608	1,049	24.1
Quartile 4: >99,608	1,045	24.1
Unknown	166	3.8
Percentage of residents in census block group who traveled ≥60 min to work^d		
Quartile 1: <6.4	1,088	25.0

Table 1 continued

Characteristics	N	%
Quartile 2: 6.4–10.4	1,093	25.2
Quartile 3: 10.5–16.0	1,077	24.8
Quartile 4: >16.0	1,087	25.0
Number of recreational facilities within 1600 m of residence ^d		
Quartile 1: <2	1,226	28.2
Quartile 2: 2–3	1,003	23.1
Quartile 3: 4–7	1,097	25.3
Quartile 4: >7	1,019	23.5
Vital status		
Deceased	915	21.1
Alive	3,430	78.9
Cause of death		
Breast cancer	569	62.2
Other cancer	103	11.3
Circulatory disease	82	9.0
Other causes	137	15.0
Unknown cause	24	2.6

AJCC American Joint Committee on Cancer

^a Based on the quartile distribution among all cases with nonzero values in study population

^b Physical activity recommendation: at least 150 min of moderate intensity, 75 min of strenuous intensity, or an equivalent combination of moderate/strenuous activity per week

^c Based on the quintile distribution for block groups in California

^d Based on the quartile distribution among all cases in study population

^e Based on the quartile distribution for block groups in California

^f Includes those who have a numerator value >0 and a denominator = 0

^g Based on the tertile distribution among all cases with nonzero values in study population

Overall survival

After adjustment for personal, tumor, treatment, and neighborhood characteristics (Table 3), Hispanic and Asian American women had better survival than non-Hispanic white women, whereas African American and non-Hispanic white women had similar overall survival. Women who were not recreationally physically active in the 3 years prior to diagnosis had a 22 % HR 1.22, 95 % CI 0.98–1.52) higher risk of death from any cause than women that were the most active. Results were similar and statistically significant when considering hours per week of moderate or strenuous physical activity not weighted for MET [fully adjusted HR 1.27 (95 % CI 1.02–1.59); comparing women with no physical activity to those with the most activity] and meeting physical activity recommendations [fully adjusted HR 1.22 (95 % CI 1.03–1.44) comparing women with no physical activity to those

Table 2 Association of neighborhood characteristics with not meeting recreational physical activity recommendations^a: ORs with 95 % CIs, San Francisco Bay Area, 1995–2008

	Base model ^b		Fully adjusted model ^c	
	ORs	95 % CIs	ORs	95 % CIs
AJCC stage at diagnosis				
I	1.00		1.00	
II	1.17	1.02–1.34	1.10	0.96–1.26
III	1.29	1.01–1.66	1.15	0.89–1.49
IV	1.99	1.22–3.26	1.68	1.01–2.80
Unknown	1.18	0.81–1.71	1.12	0.76–1.66
<i>p</i> trend ^d		<0.01		0.04
Race/ethnicity				
Non-Hispanic white	1.00		1.00	
African American	1.52	1.27–1.82	1.12	0.90–1.38
Hispanic	2.02	1.71–2.38	1.31	1.08–1.58
Asian American	2.42	1.93–3.02	1.99	1.55–2.56
Education				
Less than high school	2.25	1.82–2.77	1.83	1.45–2.30
High school graduate	1.44	1.19–1.75	1.31	1.07–1.59
Some college	1.25	1.06–1.47	1.16	0.98–1.37
College graduate or post graduate	1.00		1.00	
Unknown	5.03	1.78–14.26	3.85	1.33–11.13
<i>p</i> trend ^d		<0.01		<0.01
Pre-diagnosis BMI (kg/m ²)				
<25.0	1.00		1.00	
25.0–29.9	1.26	1.07–1.47	1.15	0.98–1.35
≥30.0	1.78	1.51–2.10	1.56	1.31–1.85
Unknown	1.85	1.03–3.30	1.52	0.81–2.84
<i>p</i> trend ^d		<0.01		<0.01
Neighborhood socioeconomic status ^e				
Quintile 5 (highest)	1.00		1.00	
Quintile 4	1.44	1.22–1.70	1.15	0.96–1.37
Quintile 3	1.36	1.12–1.65	0.92	0.74–1.15
Quintile 2	1.38	1.13–1.70	0.81	0.63–1.05
Quintile 1 (lowest)	1.70	1.27–2.28	0.97	0.68–1.37
<i>p</i> trend		<0.01		0.18
Percentage of foreign-born residents in census block group ^f				
Quartile 1: <15.9	1.00		1.00	
Quartile 2: 15.9–26.3	1.24	1.04–1.48	1.12	0.93–1.34
Quartile 3: 26.4–41.5	1.34	1.12–1.60	1.12	0.92–1.37
Quartile 4: >41.5	1.76	1.46–2.12	1.34	1.08–1.66
<i>p</i> trend		<0.01		0.01
Percentage of non-single-family units in census block group ^f				
Quartile 1: <3.6	1.00		1.00	
Quartile 2: 3.6–23.3	1.07	0.90–1.27	0.97	0.81–1.16
Quartile 3: 23.4–51.8	1.30	1.09–1.56	1.06	0.86–1.31
Quartile 4: >51.8	1.18	0.99–1.41	0.89	0.72–1.11
<i>p</i> trend		0.02		0.50

Table 2 continued

	Base model ^b		Fully adjusted model ^c	
	ORs	95 % CIs	ORs	95 % CIs
Restaurant Environment Index within 1,600 m of residence at diagnosis ^g				
No fast-food restaurants	0.90	0.77–1.06	1.30	1.01–1.68
≤Median (≤0.11)	1.00		1.00	
>Median (>0.11) ^h	1.06	0.91–1.24	1.15	0.96–1.39
No restaurants	0.67	0.51–0.87	1.17	0.78–1.75
<i>p</i> trend ⁱ		0.06		0.53
Retail Food Environment Index within 1,600 m of residence at diagnosis				
No convenience stores, liquor stores and fast-food restaurants	0.71	0.59–0.85	0.77	0.58–1.01
<1	1.00		1.00	
≥1 ^h	0.88	0.74–1.05	0.95	0.79–1.16
No retail food outlets	0.65	0.52–0.82	0.85	0.59–1.21
<i>p</i> trend ⁱ		1.00		0.36
Population density in census block group (people/1,000 m ²) ^k				
Quartile 1: <1.08	1.00		1.00	
Quartile 2: 1.08–2.56	1.11	0.89–1.37	1.00	0.79–1.26
Quartile 3: 2.57–4.28	1.20	0.98–1.48	0.96	0.75–1.22
Quartile 4: >4.28	1.57	1.29–1.92	1.18	0.90–1.53
<i>p</i> trend		<0.01		0.23
Traffic density within 500 m of residence at diagnosis (vehicle miles traveled per square mile) ^f				
Quartile 1: <31,280	1.00		1.00	
Quartile 2: 31,281–60,581	1.16	0.98–1.37	1.09	0.91–1.31
Quartile 3: 60,582–99,608	1.37	1.15–1.63	1.24	1.02–1.51
Quartile 4: >99,608	1.39	1.17–1.66	1.28	1.03–1.60
Unknown	0.77	0.55–1.08	0.82	0.57–1.18
<i>p</i> trend ^h		<0.01		0.02
Number of parks within 1,600 m of residence at diagnosis ^l				
0	0.81	0.67–0.98	1.05	0.85–1.31
1–2	0.95	0.83–1.08	1.01	0.87–1.17
≥3	1.00		1.00	
<i>p</i> trend		0.04		0.67
Number of recreational facilities within 1600 m of residence at diagnosis ^f				
Quartile 1: <2	1.00		1.00	
Quartile 2: 2–3	1.09	0.92–1.29	0.96	0.80–1.16
Quartile 3: 4–7	1.06	0.89–1.25	0.91	0.74–1.11
Quartile 4: >7	1.14	0.96–1.36	0.96	0.75–1.23

Table 2 continued

	Base model ^b		Fully adjusted model ^c	
	ORs	95 % CIs	ORs	95 % CIs
<i>p</i> trend		0.19		0.59

AJCC American Joint Committee on Cancer, *BMI* body mass index
^a Meeting physical activity recommendation was defined as at least 150 min of moderate intensity, 75 min of strenuous intensity, or an equivalent combination of moderate/strenuous activity per week
^b Adjusted for continuous age at diagnosis, study, race/ethnicity, AJCC stage, and clustering by block group; estimates for race/ethnicity not adjusted for race/ethnicity and estimates for AJCC stage not adjusted for AJCC stage
^c Adjusted for base model^b and pre-diagnosis menopausal hormone therapy use (never, former, current, unknown), grams per day of alcohol intake in reference year (0, <5, 5–9, 10–14, ≥15, unknown), and all variables in the table
^d Does not include unknown category
^e Based on the quintile distribution for block groups in California
^f Based on the quartile distribution among all cases in study population
^g Based on the median among all cases with nonzero values in study population
^h Includes those who have a numerator value >0 and a denominator = 0
ⁱ Does not include no restaurants category
^j Does not include no retail food outlets category
^k Based on the quartile distribution for block groups in California
^l Based on the tertile distribution among all cases with nonzero values in study population
 Bold values indicate statistically significant *p* < 0.05

meeting physical activity recommendations] (data not shown in tables). Poorer overall survival was associated with lower neighborhood SES (*p* trend = 0.02) and residence in more densely populated neighborhoods, although the trend for population density was not significant in the fully adjusted model. Associations of better overall survival with residence in neighborhoods with no parks were only marginally significant in the fully adjusted models. Additional analyses stratified by neighborhood SES showed that the inverse association was present only among women who resided in high-SES (quintiles 4, 5) neighborhoods [HR 0.68 (95 % CI 0.49–0.96) comparing no parks vs. ≥3 parks], while no association was seen among women in lower-SES (quintiles 1–3) neighborhoods [HR 1.05 (95 % CI 0.67–1.25)] (data not shown in tables).

Table 3 Association of neighborhood variables and recent recreational physical activity with overall survival: estimated HRs with 95 % CIs, San Francisco Bay Area, 1995–2008

	Base model ^a		Fully adjusted model ^b	
	HRs	95 % CIs	HRs	95 % CIs
Race/ethnicity				
Non-Hispanic white	1.00		1.00	
African American	1.46	1.22–1.75	1.07	0.85–1.35
Hispanic	0.79	0.66–0.95	0.58	0.46–0.71
Asian American	0.92	0.72–1.19	0.70	0.53–0.94
Recent recreational physical activity (MET hours/week)^c				
0	1.33	1.08–1.64	1.22	0.98–1.52
Quartile 1: <11.92	1.14	0.90–1.44	1.09	0.86–1.40
Quartile 2: 11.92–17.88	0.93	0.72–1.22	0.89	0.68–1.17
Quartile 3: 17.89–39.68	1.04	0.80–1.34	1.08	0.84–1.39
Quartile 4: >39.68	1.00	1.00		
<i>p</i> trend		<0.01		0.05
Neighborhood socioeconomic status^d				
Quintile 5: >0.84 (high)	1.00		1.00	
Quintile 4: 0.23–0.84	1.09	0.90–1.32	1.00	0.81–1.23
Quintile 3: –0.32 to 0.22	1.32	1.08–1.61	1.16	0.91–1.48
Quintile 2: –0.90 to –0.31	1.64	1.30–2.05	1.32	1.01–1.73
Quintile 1: <–0.90 (low)	1.85	1.39–2.46	1.33	0.94–1.89
<i>p</i> trend		<0.01		0.02
Percentage of foreign-born residents in census block group^e				
Quartile 1: <15.9	1.00		1.00	
Quartile 2: 15.9–26.3	0.91	0.75–1.11	0.85	0.70–1.04
Quartile 3: 26.4–41.5	1.04	0.86–1.25	0.89	0.72–1.09
Quartile 4: >41.5	1.23	1.02–1.49	1.03	0.81–1.30
<i>p</i> trend		0.02		0.79
Percentage of non-single-family units in census block group^e				
Quartile 1: <3.6	1.00		1.00	
Quartile 2: 3.6–23.3	1.09	0.89–1.34	1.03	0.84–1.27
Quartile 3: 23.4–51.8	1.25	1.03–1.53	1.08	0.87–1.35
Quartile 4: >51.8	1.30	1.07–1.57	1.16	0.92–1.47
<i>p</i> trend		<0.01		0.21
Restaurant Environment Index within 1,600 m of residence at diagnosis^e				
No fast-food restaurants	0.92	0.78–1.10	1.06	0.83–1.36
≤Median (≤0.11)	1.00		1.00	
>Median (>0.11) ^f	1.11	0.94–1.31	1.12	0.93–1.36
No restaurants	0.85	0.65–1.12	1.22	0.76–1.96
<i>p</i> trend ^g		0.04		0.49
Retail Food Environment Index within 1,600 m of residence at diagnosis				
No convenient stores, liquor stores and fast-food restaurants	0.92	0.75–1.13	1.18	0.88–1.59
<1	1.00		1.00	
≥1 ^f	0.95	0.80–1.14	1.03	0.84–1.27
No retail food outlets	0.78	0.60–1.01	1.15	0.72–1.83
<i>p</i> trend ^h		0.84		0.70
Population density in census block group (people/1,000 m²)ⁱ				
Quartile 1: <1.08	1.00		1.00	
Quartile 2: 1.08–2.56	1.28	0.98–1.66	1.26	0.95–1.69
Quartile 3: 2.57–4.28	1.51	1.18–1.94	1.50	1.11–2.01
Quartile 4: >4.28	1.54	1.21–1.96	1.18	0.86–1.61

Table 3 continued

	Base model ^a		Fully adjusted model ^b	
	HRs	95 % CIs	HRs	95 % CIs
<i>p</i> trend		<0.01		0.53
Traffic density within 500 m of residence at diagnosis (vehicle miles traveled per square mile)^c				
Quartile 1: <31,280	1.00		1.00	
Quartile 2: 31,281–60,581	1.13	0.93–1.39	1.01	0.82–1.24
Quartile 3: 60,582–99,608	1.37	1.13–1.66	1.18	0.95–1.47
Quartile 4: >99,608	1.27	1.05–1.54	1.12	0.88–1.43
Unknown	1.07	0.73–1.57	1.29	0.86–1.94
<i>p</i> trend ^j		<0.01		0.19
Percentage of residents in census block group who traveled ≥60 min to work^c				
Quartile 1: <6.4	1.00		1.00	
Quartile 2: 6.4–10.4	1.12	0.92–1.36	1.09	0.89–1.32
Quartile 3: 10.5–16.0	1.21	1.00–1.47	1.19	0.97–1.47
Quartile 4: >16.0	1.06	0.87–1.30	1.08	0.87–1.33
<i>p</i> trend		0.42		0.36
Number of parks within 1,600 m of residence at diagnosis^k				
0	0.75	0.61–0.94	0.78	0.59–1.03
1–2	0.93	0.80–1.07	0.96	0.83–1.12
≥3	1.00		1.00	
<i>p</i> trend		0.02		0.11
Number of recreational facilities within 1,600 m of residence at diagnosis^e				
Quartile 1: <2	1.00		1.00	
Quartile 2: 2–3	1.04	0.87–1.26	0.95	0.77–1.17
Quartile 3: 4–7	1.23	1.03–1.46	1.19	0.96–1.47
Quartile 4: >7	1.09	0.90–1.33	0.99	0.76–1.29
<i>p</i> trend		0.14		0.48

^a Adjusted for continuous age at diagnosis, study, race/ethnicity, AJCC stage, and clustering by block group; estimates for race/ethnicity not adjusted for race/ethnicity

^b Adjusted for base model^a and histological grade (1, 2, 3 or 4, unknown), joint ERPR status (ER–PR–, ER+ or PR+, unknown), marital status (single, married, separated/divorced, widowed, unknown), education (less than high school, high school graduate, vocational/technical school or some college, college graduate or graduate school, unknown), history of benign breast disease (no, yes, unknown), years since last full-term pregnancy (<2, 2–4, ≥5, unknown), pre-diagnosis oral contraceptive use (never, ever, unknown), pre-diagnosis menopausal hormone therapy use (never, former, current, unknown), grams per day of alcohol intake in reference year (0, <5, 5–9, 10–14, ≥15, unknown), pre-diagnosis BMI (<25.0, 25.0–29.9, ≥30.0, unknown), type of surgery (none, lumpectomy, mastectomy, unknown), chemotherapy (no, yes, unknown), first subsequent primary tumor (no, yes), second subsequent primary tumor (no, yes), time to first and second subsequent primary tumor (months, continuous), and all variables in the table

^c Based on the median among all cases with nonzero values in study population

^d Based on the quintile distribution for block groups in California

^e Based on the quartile distribution among all cases in study population

^f Includes those who have a numerator value >0 and a denominator = 0

^g Does not include no restaurants category

^h Does not include no retail food outlets category

ⁱ Based on the quartile distribution for block groups in California

^j Does not include unknown category

^k Based on the tertile distribution among all cases with nonzero values in study population

Bold values indicate statistically significant $p < 0.05$

Table 4 Association of neighborhood variables and recent recreational physical activity with breast cancer-specific survival: estimated HRs with 95 % CIs, San Francisco Bay Area, 1995–2008

	Base model ^a		Fully adjusted model ^b	
	HRs	95 % CIs	HRs	95 % CIs
Race/ethnicity				
Non-Hispanic white	1.00		1.00	
African American	1.47	1.16–1.85	1.14	0.84–1.54
Hispanic	0.77	0.61–0.97	0.60	0.45–0.79
Asian American	1.04	0.77–1.40	0.79	0.57–1.10
Recent recreational physical activity (MET hours/week)^c				
0	1.06	0.82–1.36	0.99	0.76–1.30
Quartile 1: <1.96	0.93	0.69–1.24	0.87	0.64–1.18
Quartile 2: 1.96–2.99	0.89	0.65–1.20	0.80	0.58–1.11
Quartile 3: 3.00–6.38	0.96	0.72–1.29	0.98	0.73–1.31
Quartile 4: >6.38	1.00		1.00	
<i>p</i> trend		0.59		0.90
Neighborhood socioeconomic status^d				
Quintile 5: >0.84 (high)	1.00		1.00	
Quintile 4: 0.23–0.84	1.06	0.84–1.35	1.02	0.78–1.32
Quintile 3: –0.32 to 0.22	1.13	0.88–1.45	1.07	0.79–1.45
Quintile 2: –0.90 to –0.31	1.48	1.11–1.98	1.29	0.90–1.85
Quintile 1: <–0.90 (low)	1.68	1.15–2.45	1.43	0.90–2.29
<i>p</i> trend		<0.01		0.09
Percentage of foreign-born residents in census block group^e				
Quartile 1: <15.9	1.00		1.00	
Quartile 2: 15.9–26.3	0.78	0.61–0.99	0.74	0.57–0.96
Quartile 3: 26.4–41.5	0.90	0.71–1.14	0.80	0.62–1.04
Quartile 4: >41.5	1.11	0.88–1.39	1.01	0.74–1.37
<i>p</i> trend		0.30		0.93
Percentage of non-single-family units in census block group^e				
Quartile 1: <3.6	1.00		1.00	
Quartile 2: 3.6–23.3	1.16	0.90–1.49	1.19	0.92–1.53
Quartile 3: 23.4–51.8	1.17	0.92–1.49	1.14	0.87–1.51
Quartile 4: >51.8	1.19	0.94–1.51	1.25	0.93–1.68
<i>p</i> trend		0.17		0.19
Restaurant Environment Index within 1,600 m of residence at diagnosis^e				
No fast-food restaurants	1.00	0.80–1.23	1.12	0.83–1.51
≤Median (≤0.11)	1.00		1.00	
>Median (>0.11) ^f	1.04	0.85–1.28	1.05	0.82–1.35
No restaurants	0.99	0.70–1.41	1.44	0.83–2.49
<i>p</i> trend ^g		0.72		0.69
Retail Food Environment Index within 1,600 m of residence at diagnosis				
No convenient stores, liquor stores and fast-food restaurants	1.01	0.78–1.30	1.13	0.79–1.62
<1	1.00		1.00	
≥1 ^f	1.03	0.82–1.28	1.10	0.85–1.43
No retail food outlets	0.91	0.66–1.27	1.18	0.69–2.02
<i>p</i> trend ^h		0.81		0.89
Population density in census block group (people/1,000 m²)ⁱ				
Quartile 1: <1.08	1.00		1.00	
Quartile 2: 1.08–2.56	1.48	1.07–2.05	1.50	1.04–2.15
Quartile 3: 2.57–4.28	1.51	1.10–2.07	1.59	1.09–2.31
Quartile 4: >4.28	1.56	1.15–2.12	1.32	0.87–2.00

Table 4 continued

	Base model ^a		Fully adjusted model ^b	
	HRs	95 % CIs	HRs	95 % CIs
<i>p</i> trend		0.01		0.47
Traffic density within 500 m of residence at diagnosis (vehicle miles traveled per square mile)^c				
Quartile 1: <31,280	1.00		1.00	
Quartile 2: 31,281–60,581	1.05	0.82–1.35	0.95	0.73–1.24
Quartile 3: 60,582–99,608	1.39	1.10–1.76	1.29	0.98–1.68
Quartile 4: >99,608	1.08	0.84–1.38	1.00	0.73–1.37
Unknown	1.03	0.64–1.68	1.27	0.76–2.14
<i>p</i> trend ^j		0.17		0.45
Percentage of residents in census block group who traveled ≥60 min to work^c				
Quartile 1: <6.4	1.00		1.00	
Quartile 2: 6.4–10.4	1.23	0.96–1.56	1.20	0.93–1.54
Quartile 3: 10.5–16.0	1.18	0.92–1.50	1.17	0.89–1.52
Quartile 4: >16.0	1.13	0.89–1.45	1.09	0.84–1.42
<i>p</i> trend		0.41		0.61
Number of parks within 1,600 m of residence at diagnosis^k				
0	0.79	0.60–1.04	0.69	0.48–0.99
1–2	0.98	0.82–1.17	0.99	0.82–1.21
≥3	1.00		1.00	
<i>p</i> trend		0.15		0.10
Number of recreational facilities within 1,600 m of residence at diagnosis^e				
Quartile 1: <2	1.00		1.00	
Quartile 2: 2–3	0.92	0.72–1.16	0.85	0.65–1.12
Quartile 3: 4–7	1.17	0.94–1.46	1.13	0.86–1.48
Quartile 4: >7	1.03	0.81–1.30	1.01	0.72–1.44
<i>p</i> trend		0.38		0.50

^a Adjusted for continuous age at diagnosis, study, race/ethnicity, AJCC stage, and clustering by block group; estimates for race/ethnicity not adjusted for race/ethnicity

^b Adjusted for base model^a and histology (ductal, lobular, other), histological grade (1, 2, 3 or 4, unknown), joint ERPR status (ER–PR–, ER+ or PR+, unknown), marital status (single, married, separated/divorced, widowed, unknown), education (less than high school, high school graduate, vocational/technical school or some college, college graduate or graduate school, unknown), history of benign breast disease (no, yes, unknown), years since last full-term pregnancy (<2, 2–4, ≥5, unknown), pre-diagnosis oral contraceptive use (never, ever, unknown), pre-diagnosis menopausal hormone therapy use (never, former, current, unknown), grams per day of alcohol intake in reference year (0, <5, 5–9, 10–14, ≥15, unknown), pre-diagnosis BMI (<25.0, 25.0–29.9, ≥30.0, unknown), type of surgery (none, lumpectomy, mastectomy, unknown), chemotherapy (no, yes, unknown), first subsequent primary tumor (no, yes), second subsequent primary tumor (no, yes), time to first and second subsequent primary tumor (months, continuous), and all variables in the table

^c Based on the median among all cases with nonzero values in study population

^d Based on the quintile distribution for block groups in California

^e Based on the quartile distribution among all cases in study population

^f Includes those who have a numerator value >0 and a denominator = 0

^g Does not include no restaurants category

^h Does not include no retail food outlets category

ⁱ Based on the quartile distribution for block groups in California

^j Does not include unknown category

^k Based on the tertile distribution among all cases with nonzero values in study population

Bold values indicate statistically significant *p* < 0.05

Breast cancer-specific survival

Although the associations with neighborhood characteristics were generally similar for overall and breast cancer-specific survival, there was no association between recreational physical activity and breast cancer-specific survival (Table 4). Results were similar for hours per week of moderate or strenuous physical activity not weighted by MET [fully adjusted HR 1.04 (95 % CI 0.80–1.37) comparing women with no physical activity to those with the most activity] and meeting physical activity recommendations [fully adjusted HR 1.06 (95 % CI 0.85–1.31) comparing women with no physical activity to those meeting physical activity recommendations] (data not shown in tables). Hispanic women had better survival than non-Hispanic white women. Although the trends were not statistically significant, residence in more densely populated neighborhoods was associated with poorer survival, whereas residence in neighborhoods with more foreign born was associated with better survival. Living in neighborhoods without parks was associated with better breast cancer-specific survival. As with overall survival, the association was only seen among women living in high-SES neighborhoods [HR 0.54 (95 % CI 0.34–0.85) comparing no parks vs. ≥ 3 parks], while no association was seen among women living in lower-SES neighborhoods [HR 1.28 (95 % CI 0.52–1.21)] (data not shown in tables).

Discussion

In the present study, certain aspects of the neighborhood environment have independent associations with physical activity among breast cancer patients and their survival. Among a racially/ethnically diverse population of women with breast cancer, meeting recreational physical activity recommendations varied by neighborhood factors, including percentage of foreign-born residents, the presence of fast-food restaurants and convenience or liquor stores, and traffic density, as well as race/ethnicity, education level, and BMI, as reported previously [12, 34–37]. After adjustment for neighborhood, personal, tumor, and treatment characteristics, recent recreational physical activity was associated with better overall survival after breast cancer diagnosis. While in fully adjusted multivariable models, physical activity, and neighborhood associations with survival were attenuated, our findings suggest that residing in neighborhoods of lower SES, which are more densely populated, or with more parks may be associated with poorer survival. Given the recognized benefits of physical activity among breast cancer survivors, our results support the importance of considering and understanding

the role of specific neighborhood social and built environment factors on physical activity and survival.

Our findings of poorer survival among women residing in neighborhoods with lower SES are consistent with numerous studies [38–40]. However, ours is the first study to suggest that higher population density may be associated with poorer survival. Higher population density has been associated with bladder [41] and lung [42] cancer mortality; both traffic-related air pollution, which has been associated with mortality [43], and noise have been cited as potential contributing factors.

In contrast to our hypothesis that greater numbers of parks would be associated with better survival, we found that women residing in neighborhoods without parks had better survival, but this association was limited to women living in high-SES neighborhoods. We also hypothesized that parks and other recreational facilities would provide opportunities for exercise; however, we did not find that the number of parks and recreational facilities were associated with meeting physical activity recommendations, consistent with some [36, 37], but not all [44, 45] studies. While no prior study has considered an association between parks and survival after breast cancer diagnosis, it is possible that the quality, safety, and type of park, factors we could not measure, are more relevant to physical activity and survival. Additional research into the specific attributes of parks and other, unmeasured neighborhood factors associated with the number of parks is needed to understand this unexpected association with survival.

We also found that women residing in neighborhoods with more foreign-born residents had better breast cancer-specific survival, even after adjusting for race/ethnicity and individual-level nativity of study participants (data not shown). In previous analyses specific to Asian American and Hispanic breast cancer patients, we did not find survival to be associated with living in an ethnic enclave, a composite measure that includes percentage of foreign-born residents [39, 40]. Neighborhoods with a higher percentage of foreign born, however, have been found to have healthier food environments, but worse environments related to physical activity (lower walkability and safety and fewer resources for recreational exercise), suggesting that attributes of these neighborhoods both hinder and facilitate healthy behaviors [46]. This study also found lower weekly physical activity levels among Hispanics, but not Chinese, living in these neighborhoods, consistent with our finding of lower physical activity among those who live in neighborhoods with the highest percentage of foreign-born residents [46]. Therefore, future studies will need to explore specific factors that influence survival in neighborhoods with a high percentage of foreign-born residents.

We also found that higher traffic density was associated with not meeting recreational physical activity recommendations,

possibly because higher traffic density may reduce pedestrian safety. Previous studies, however, have not found consistent associations with traffic volume and speed; it is hypothesized that the combination of high traffic volume and speed, factors that are difficult to measure, poses a barrier for physical activity [47]. In terms of retail food environment, women living in neighborhoods without unhealthy retail food outlets (no convenience, liquor stores, and fast food) versus a mix of retail food outlets that include supermarkets and farmers' markets were more likely to meet physical activity recommendations. On the other hand, living in a neighborhood with only healthier restaurants (no fast-food restaurants) was associated with not meeting physical activity recommendations, a finding counter to our hypothesis. When considering these neighborhoods further, we found that neighborhoods with fewer fast-food restaurants to other restaurants had a much larger number of total restaurants (mean = 21 restaurants) than neighborhoods with no fast-food (mean = 2 restaurants) or neighborhoods with a higher ratio of fast food to other restaurants (mean = 5 restaurants), suggesting that neighborhoods with a large variety of predominately healthy restaurants may promote physical activity. Additionally, as with parks, further research that can incorporate information on the quality of restaurants and supermarkets (i.e., cost, availability of fresh produce) and account for other attributes of neighborhoods associated with these types of food establishments is warranted.

Our finding of recent, pre-diagnosis recreational physical activity being associated with better overall survival is consistent with prior studies [6, 22, 48–51]. A meta-analysis found that pre-diagnosis physical activity reduced all-cause mortality by 18 %, but not breast cancer-specific mortality [22], similar to the findings in our study. We did not find differences by ER status, unlike our previous report that included a subset of the breast cancer cases included in this analysis, [8] or by BMI, as found in a meta-analysis [22]. We also found that the poorer survival often seen in African Americans compared to non-Hispanic whites [38, 52] did not persist after adjustment for personal, tumor, treatment, and neighborhood characteristics. While it was not physical activity or neighborhood characteristics that attenuated the African American/non-Hispanic white survival differences (data not shown), it was beyond the scope of this paper to determine what factors attenuated these differences and will be the focus of future analyses. We also found that Hispanics and Asian Americans generally had better survival than non-Hispanic whites, consistent with an analysis in elderly women that controlled for treatment, screening, co-morbidities, and tumor severity [53].

Several potential limitations need to be considered when interpreting our results. We assessed self-reported, pre-diagnosis recreational physical activity rather than physical activity after diagnosis, which has been found to have

stronger associations with survival than physical activity prior to diagnosis [22]. In addition, the time frame of neighborhood data did not correspond exactly to the time frame of the physical activity measurement, but was nevertheless relevant to the survival period. Some data suggest that, for most women, levels of activity after treatment are similar to their pre-diagnostic levels [54, 55], although declines in activity have been noted 10 years after diagnosis [56]. If women in the most active group decreased their physical activity levels over time, then our physical activity findings could have been underestimated. The focus on recreational activity may have introduced some exposure misclassification, given that non-recreational physical activity may be more common in Hispanics and African Americans [19]. In the SFBCS, we found no association of occupational or household-related activity with survival (data not shown). While we cannot rule out misclassification of physical activity levels, either by race/ethnicity or by longer time between diagnosis and study interview, a self-reported lifetime physical activity questionnaire comparable to the one in the SFBCS study [19] was found to be reliable (correlation of 0.72) [57]. A further limitation is that our results may not be generalizable to other geographic regions, although our study population is representative of women diagnosed with breast cancer in the San Francisco Bay Area. We also lacked information on co-morbidities, which could influence all-cause mortality [58, 59].

Although the databases we utilized to determine neighborhood amenities allowed us to feasibly characterize neighborhoods, there is limited information on the quality and validity of these data. In addition, as no prior studies, to our knowledge, have used NavTeq data for parks, we cannot rule out misclassification of the parks data. Similar to most studies on this topic, we did not have longitudinal data to consider residential mobility or information on why individuals selected to live in neighborhoods with certain attributes. We also had no information on perceived built environment (e.g., safety), which is likely to affect the behavior [11]. Lastly, even though we did not find heterogeneity of neighborhood associations by race/ethnicity, women in different racial/ethnic groups may be more likely to engage in certain types of activities, for which particular neighborhood characteristics (e.g., utilitarian walking in neighborhoods with more destinations) may be more relevant.

Despite these limitations, our study is among the first to consider physical activity, a potentially modifiable prognostic factor, and measures of the social and built environment with survival after breast cancer diagnosis. The study's strengths include the inclusion of large number of racial/ethnically diverse women from two population-based breast cancer studies. The two studies asked about many of

the same exposures, and findings did not differ by study (data not shown). Our study utilized individual-level interview data, clinical cancer registry data, and neighborhood data that allowed us to consider types of breast cancer, subgroups of patients, and a number of potential confounding variables. We considered a large number of established and objectively measured elements of the neighborhood social and built environment that were not subject to recall bias. Bias due to differential follow-up was minimized by linking data from both studies to the population-based cancer registry. Further, we adjusted for any survival bias by left-truncating all cases at the time of interview.

In our study, elements of the social and built environment have independent associations with recent recreational physical activity in a diverse cohort of breast cancer patients and their survival. Meeting recreational physical activity recommendations varied by the percentage of foreign-born residents, the presence of fast-food restaurants and convenience or liquor stores, and traffic density in neighborhoods. In addition, residing in lower SES or more densely populated neighborhoods may be associated with poorer survival and residing in neighborhoods with more foreign-born residents and no parks may be associated with better survival. The associations of social and built environment with recent recreational physical activity, which was associated with better overall survival, highlight the importance of considering aspects of the social and built environment in future studies of physical activity and breast cancer survival and in future efforts to design more effective physical activity programs for breast cancer survivors.

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Conflict of interest The authors declare that they have no conflict of interest.

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