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ARTICLE

Contextualizing disability: a cross-sectional analysis of the association between the built environment and functioning among people living with spinal cord injury in the United States

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Abstract

Study design Secondary analysis of cross-sectional data from a multisite cohort study.

Objectives To analyze the association between the built environment and physical functioning reported by adults living with chronic spinal cord injury (SCI).

Setting Four US Spinal Cord Injury Model Systems centers in New Jersey, Colorado, Illinois, and Michigan.

Methods Participants were from the Spinal Cord Injury-Functional Index/Capacity (SCI-FI/C) development study. Survey data from $N = 402$ participants were geocoded for analysis. Geographic Information Systems (GIS) analysis was used to define five- and half-mile buffer areas around participants' residential addresses to represent the community and neighborhood environments, respectively, and to create measures of land use, residential density, destination density, and park space. The relationships between these built environment features and four domains of physical functioning—basic mobility, wheelchair mobility, self-care, and fine motor function—were modeled using ordinary least squares (OLS) regression.

Results People with paraplegia living in neighborhoods with more destinations and a nearby park reported higher levels of self-care functioning. For people with tetraplegia, living in a community with more destinations was associated with better wheelchair mobility and fine motor functioning, and living in a neighborhood with high land use mix was associated with higher fine motor functioning scores.

Conclusions The association between the built environment and functioning after SCI is supported and in need of further investigation. Understanding the environmental context of disability may lead to community-based interventions and effective public policy that will attenuate the experience of limitations and promote accessibility on a larger scale.

Introduction

Evidence of health disparities following traumatic spinal cord injury (SCI) supports the importance of contextual factors—framed by the International Classification of Disability and Functioning (ICF) model as personal characteristics and environmental conditions [1]—to the experience of disability [2, 3]. For instance, long-term improvements in physical functioning post injury are more likely to be reported by males [4, 5], non-Hispanic whites [6], and people from younger age groups [7]. This suggests that gaps emerge between historically advantaged and disadvantaged groups as people with SCI are exposed to differences in the physical and social conditions, resources, and opportunities present in their living circumstances. In recent years, a growing number of investigations in the general population demonstrate that differences in the

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places where people live are associated with differences in reported physical functional limitations among people with mobility impairments [8–11]. The purpose of this study is to understand the role of the environment in disability after SCI by investigating the association of the built environment and physical functioning among adults with traumatic SCI.

The ICF model indicates that impairments, activity limitations, and participation restrictions interact with environmental and personal contextual factors to produce disability [1]. People with SCI experience impairment to the upper and/or lower extremities which may lead to, among other limitations, difficulty with mobility and restricted involvement in social and productive activities, including work, recreation, and time with family and friends. This capacity to carry out daily activities can be modified by the conditions of the larger environment. For instance, although mobility is difficult for most people with SCI, a non-ambulatory person who uses a wheelchair and lives in a neighborhood with adequate sidewalks and transportation may experience limitations in mobility differently compared to a person with a similar injury living in a neighborhood that lacks these features. Similarly, living in a community with a greater density of places, such as grocery stores, recreational facilities, and cultural institutions, may foster more activity outside the home, and provide motivation for better self-care and other functional activities than living in a community with fewer opportunities for involvement.

Recent work supports the importance of the built environment factors and health and disability following SCI [12]. A recent qualitative study of people with disabilities, including SCI, identified several domains of environmental factors important to physical functioning and quality of life including the built, natural, and economic environment, transportation, assistive technology, information and technology access, social support and societal attitudes, and systems and policies [13]. A recent study of perceptions of community integration among people with SCI found that adults who identified their communities by physical features, such as the presence and accessibility of public space, were more likely to express dissatisfaction about their area of residence and quality of life [14]. This is unsurprising as the quality and presence of accessibility features in the built environment such as sidewalks, the architectural aspects of buildings, and the accessibility of public spaces are highly relevant to the range of daily activities engaged in by people with a physical disability. Research in the general population suggests that characteristics of the built environment such as better street connectivity, street conditions (e.g., intact sidewalks and curb cuts), and mixed land uses (e.g., areas combining residential and commercial land use) are associated with fewer self-care [15], mobility [16], and overall functional limitations [17]. Research in this area has typically involved measures of residential density, destination presence and convenience, land use patterns, aesthetics, and transportation networks that provide linkages between services and locations [18, 19].

Recent work has demonstrated that the built and economic aspects of communities and neighborhoods are associated with better quality of life and increased participation after SCI [20, 21]. This investigation builds upon this line of inquiry and assesses the role of the built environment in physical functioning. Maximizing physical functioning for people with chronic SCI is a challenge as individuals move forward with their lives in the community. This study combined survey information from an in-depth study of SCI-specific functional limitations with measures of environmental factors derived from administrative data. We hypothesized that built environment features such as mixed land use, more destinations, higher residential density, and the presence of recreational space would be associated with fewer reported activity limitations.

Methods

Materials

This investigation involved a secondary analysis of cross-sectional survey data collected for the development of the Spinal Cord Injury-Functional Index/Capacity (SCI-FI/C) instrument [22, 23]. The original purpose of the data was to develop and validate an SCI-specific measure of physical functioning to accurately assess changes post injury in both clinical and community settings. The SCI-FI/C sample consisted of 855 participants with a traumatic SCI, aged 18 years or older, and fluent in English from six SCI Model System centers in the United States. Data were collected in 2010–2011 by trained interviewers who assessed demographic and injury-related characteristics and functional capacity. The full details on the SCI-FI/C development, item content, and psychometric properties are provided in prior reports [22, 23].

Participants

The current study involved four of the sites from the original SCI-FI/C study—New Jersey, Colorado, Michigan, and Illinois. The SCI-FI/C participants were recruited from the Spinal Cord Injury Model Systems program. The subsample of participants recruited for this study involved the majority (72%) of the original SCI-FI/C sample ($n = 618$) and were representative of both the SCI-FI/C and the national Spinal Cord Injury Model Systems (SCIMS) participants across demographic and injury-related characteristics. These SCI-FI/C participants were contacted to provide consent to geocode their residential address data so that the SCI-FI/C survey could be linked to local area spatial and administrative information. Individuals who were hospitalized at the time of the SCI-FI/C survey ($n =$ 144) or declined participation ($n = 6$) were excluded from this analysis. Participants with addresses that could not be geocoded ($n = 66$) were also excluded from the current analysis. This yielded a final analytic sample of $N = 402$. Bivariate tests found no systematic differences by demographic or injury characteristics between the excluded cases and the final analytic sample.

The addresses were geocoded with a publically available Geocoder tool available through the US Census Bureau (https://geocoding.geo.census.gov/geocoder/). The geocodes were used to construct half- and five-mile address buffers to define the participants' residential neighborhood and community environments, respectively, using ArcMap with a Spatial Analyst extension. This approach is based on prior research from the transportation and urban planning literature reporting that small distances (i.e., 1 km or half mile) are generally perceived as neighborhoods, whereas relatively longer, "driving" distances are perceived as communities [24]. Geographic Information Systems (GIS) shapefile data on land use and land cover in 2010 were acquired from the United States Geological Survey (USGS). The USGS data are based on satellite imagery data indicating how land was used for housing, development, agriculture, open space, and natural areas [25]. Proportions of land usage were calculated within each buffer using Geospatial Modeling Environment. Data on the locations of local area destinations—specifically, recreation, cultural, retail, and religious facilities—were acquired from spatial data published by ArcGIS [26–30] and summed for each buffer. Census tract-level data on several key area economic indicators were extracted from the 2010 American Community Survey (ACS) 5-year pooled data [31]. Census tracts are small, statistical subdivisions of US counties based on population density and generally represent areas with a population of 1200 to 8000 people [32]. The sample included residents of 36 US states, 139 counties, and 385 Census tracts.

Measures

Dependent variables

Physical functioning limitations were measured by four unidimensional domains from the SCI-FI/C: *basic mobility* (54 items assessing capacity to transfer, change, and maintain body position), *wheelchair mobility* (56 items), *self-care* (90 items assessing capacity for bathing, eating, grooming, toileting, and sexual functioning), and *fine motor function* (36 items assessing capacity for hand use to manipulate objects), which have demonstrated good validity and reliability [22, 23]. Participants rated SCI-FI/C items using a 5-point ordinal scale indicating degree of difficulty doing a physical activity (0 = unable to do; 4 = without any difficulty) based on their capacity without assistance or use of adaptive equipment. Item responses were used to create item maps for each domain ordered along a continuum of difficulty using IRT analytic techniques explained in detail elsewhere in the literature [22, 23]. Final domain scores are represented as T-score distributions with a mean of 50 and standard deviation of 10 that are comparable for persons with paraplegia and tetraplegia. Higher scores corresponded with less difficulty.

Independent variables: the built environment

Land use mix was based on the USGS classifications of land use "intensity" as low, medium, or high. Low intensity referred to areas with a mixture of constructed materials and vegetation, where the majority of the housing were single-family units, and 20–49% of the coverage was impervious (e.g., pavement). Medium intensity designated greater coverage by impervious surfaces (50–79%) and a mixture of construction, vegetation, and single-family housing units. High intensity classified highly developed areas where people resided or worked in high numbers, impervious surfaces covered 80–100% of the total area, and the most common housing units were apartment complexes, row houses, and commercial/industrial buildings.

Destination density was based on counts of recreation, park, retail (plazas, shopping centers, malls), and religious locations. Total destination counts were calculated as well as specific subcategories of recreational sites and parks. Recreational destinations included places such as amusement parks, theaters, museums, zoos, casinos, stadiums, and country clubs. Subcategories of park sites included beaches. The summated destination counts were highly skewed at each spatial scale. Therefore, measures of destination, recreation, and park density at the community scale were constructed based on quartile and tertile scores. At the neighborhood scale, counts of recreation and park locations were measured using binary variables indicating "zero" vs. "at least 1" due to the presence of fewer of these destinations in smaller areas.

Independent variables: covariates

The SCI-FI/C assessed gender, race/ethnicity, and age using standard survey items. Participants self-reported both the neurological level (paraplegia/tetraplegia) and severity (complete/incomplete) of injury. A binary measure categorized people with relatively recent (1–2 years) vs. long-term(3 years or longer) injuries in the original data.

Table 1 Sample characteristics by injury type (mean (SD) or %), $N = 402$

		Total $N = 402$	Paraplegia $N = 189$	Tetraplegia $N = 213$	p Value
Demographic covariates					
Male (%)		78.1	78.8	77.5	$p = 0.740$
Age groups (%)	18–35 years	29.9	29	30.5	
	36–50 years	35.3	35.5	35.2	
	>50 years	34.8	35.5	34.3	$p = 0.947$
Race/ethnicity (%)	White	69.7	69.3	70	
	Black	15.2	14.3	16	
	Hispanic	8.9	10.1	7.9	
	Other	6.2	6.3	6.1	$p = 0.878$
Mean SES index score ± SD		−0.08 ± 3.65	−0.11 ± 3.63	−0.04 ± 3.68	$p = 0.852$
SCI covariates					
Complete (%)		42.3	52.9	42.3	$p = 0.033$
Injured 3 years or more (%)		49.8	55.6	52.5	$p = 0.196$
Community ambulation (%)		18.7	18	19.3	$p = 0.746$
Dependent variables					
Mean basic mobility ± SD		51.4 ± 10.3	55.8 ± 6.2	47.5 ± 11.7	$p < 0.001$
Mean wheelchair mobility ± SD		50.4 ± 10.6	57.0 ± 6.5	44.6 ± 10.1	$p < 0.001$
Mean fine motor ± SD		51.0 ± 9.0	57.3 ± 4.4	45.4 ± 8.3	$p < 0.001$
Mean self-care ± SD		51.3 ± 9.7	57.2 ± 4.6	46.1 ± 10.1	p < 0.001

A fifth SCI-FI/C domain was used to create a binary covariate differentiating persons who were non-ambulatory and those reporting community ambulation. Neighborhood socioeconomic status (SES) was measured by an index based on six Census tract economic indicators (household income, home values, percentages of residents receiving interest income, high school degrees, college degrees, and employed in high-status occupations). Higher scores represent higher SES.

Statistical analysis

All data analyses were conducted with Stata/SE version 15.0. Descriptive and bivariate statistics (i.e., Chi-squared tests for categorical variables and independent sample t-tests for continuous measures) were used to assess the distributions of key variables for the total sample and by injury level. Ordinary least squares (OLS) regression with robust standard errors estimated the associations between the built environment predictors and functional limitations controlling for age, gender, race/ethnicity, injury completeness, injury duration, community ambulation, and neighborhood SES. All analyses were stratified by paraplegia and tetraplegia as the SCI-FI/C calibrated item difficulty by level of injury, resulting in related but different items being administered to participants by level of injury [22, 23]. The built environment predictors were added to the adjusted models individually and the estimated relationships are reported in terms of unstandardized coefficients with associated p values and adjusted R^2 values. A series of post-estimation commands were used to test the parameter estimates for significant ($p < 0.05$) built environment predictors, including the Wald test, average marginal effects (AMEs) to show the magnitude of mean differences holding all covariate values constant, and Bonferroni adjusted 95% confidence intervals to assess the possibility of multiple comparison bias. Two post-hoc sensitivity analyses were performed to assess the effect of rural area residents ($n = 77$) and community ambulators ($n = 75$).

Results

The sample characteristics are presented in Table 1. The majority of the participants were male and non-Hispanic White, which is consistent with the overall SCI population in the United States [33]. The distribution of the three age groups shows equal representation of young, middle-aged, and older adults. Forty-two percent of the sample had complete injuries, half of the sample were injured for at least 3 years, and approximately 19% reported at least some community ambulation. Complete vs. incomplete injuries were modestly overrepresented in the paraplegia group ($X^2 = 4.56$, df = 1, $p = 0.03$). The distributions for the four domains measuring physical functioning differed significantly between the paraplegia and tetraplegia groups,

Table 2 Distributions of built environment characteristics of the residential communities (5 miles) and neighborhoods (half mile)

		%	Mean	SD	Minimum	Maximum
Community variables						
Land use mix	Low	76.6	—	—	—	—
	Medium	18.9	—	—	—	—
	High	4.5	—	—	—	—
Total destinations		—	203.7	270.9	0	1295
	≤25	22.4	12.4	8	0	25
	26–100	28.4	57.6	23	26	100
	101–250	22.6	163.8	42	102	246
	>250	26.6	554.3	310	253	1295
Total parks		—	50.7	57.9	0	256
	≤10	31.6	3.2	3	0	10
	11–50	28.9	24.1	11	11	50
	>50	39.5	108	52.5	51	256
Total recreation sites		—	19.5	33.9	0	270
	<10	42	4.4	3	0	10
	10–15	23.9	12.3	1.6	11	15
	>15	34.1	43	50	16	270
Neighborhood variables						
Land use mix	Low	56.5	—	—	—	—
	Medium	25.9	—	—	—	—
	High	17.7	—	—	—	—
Total destinations		—	3.5	5.7	0	34
	0	38.6	—	—	—	—
	1–2	26.6	1.3	0.5	1	2
	≥3	35.8	9	6.7	3	34
Total parks		—	0.8	1.3	0	9
	0	60.7	—	—	—	—
	At least 1	39.3	2	1.5	1	9
Total recreation sites		—	0.3	0.9	0	8
	0	81.6	—	—	—	—
	At least 1	18.4	1.7	1.6	1	8

which is consistent with prior reports using the SCI-FI/C [22, 23].

Table 2 summarizes the distributions of the built environment characteristics. At the community scale, the majority of the sample lived in "low intensity" communities, which means these participants lived in areas characterized predominantly by single-family homes. The counts of total destinations, parks, and recreational sites indicate a wide range in the number of destinations across the communities. At the neighborhood scale, there was more representation in the moderate (25.9%) and high intensity (17.7%) land use categories. The majority of people with SCI in this sample lived in places with few destinations, no local park, and no recreational area within a half mile of their home.

Associations between the built environment and physical functioning

Table 3 presents the results of the adjusted OLS regression models for each domain of functional limitations for people with paraplegia. At the community scale, several of the built environment predictors (e.g., greater land use mix and more parks and recreational sites) were associated with higher functioning (basic mobility, self-care, and fine motor). However, post-estimation analyses indicated that the magnitude of these effects were negligible (results not tabled). At the neighborhood scale, more land use mix and more destinations were positively associated with higher self-care functioning, and living in a neighborhood with a park was associated with better mobility and self-care. Although the results of the Wald test indicated that the effect of neighborhood land use differences on self-care scores was insignificant ($F(2, 175) = 2.56$, $p = 0.08$), the overall presence of more destinations in the neighborhood ($F(2, 175) = 8.46$, $p = 0.003$) and a park ($F(1, 176) = 8.70$, $p = 0.004$) were significantly associated with higher self-care functioning. For example, the average person with paraplegia living in a neighborhood with more than three destinations had a self-care score of 59.0 compared to a person living in a place with no (AME = 56.9) or few destinations (AME = 55.4). Similarly, the results of the Wald test ($F(1, 177) = 4.68$, $p = 0.03$) indicated that living in a neighborhood with a park was associated with higher basic mobility scores (AME = 56.9) compared to living in an area with no park (AME = 55.1) for the average person with paraplegia.

The results of the OLS regression analyses of the built environment characteristics and functioning for people with tetraplegia, adjusted for the covariates, are reported in Table 4. At the community scale, differences in the number of destinations were associated with each of the functioning domains. Post-estimation tests of these parameters indicated that the effect of destinations was significant in the model predicting wheelchair mobility ($F(3, 150) = 5.84$; $p = 0.008$) and fine motor functioning ($F(3, 199 = 3.25$; $p = 0.023$) (results not tabled). Holding the covariates constant, wheelchair functioning for a person with tetraplegia living in a community with the fewest destinations was noticeably lower (AME = 39.7) in comparison to the other quartiles (AME = 48.3, 26–100; AME = 44.9, 101–250; and AME = 43.8, >250 destinations). For fine motor functioning, scores were approximately three points lower for the average person living in a community with the fewest destinations (AME = 42.6) compared to people living in other areas (AME = 46.4, 26–100; AME = 46.0, 101–250; and AME = 45.8, >250 destinations). At the neighborhood scale, land use mix was associated with several domains of functioning (Table 4). Post-estimation testing indicated that the differences in average basic mobility and self-care

Table 3 Ordinary least squares regression models of the relationships between built environment characteristics and physical functioning among people with paraplegia ($N = 189$)[a]

Model		Basic mobility				Wheelchair				Self-care				Fine motor			
		b	p	95% CI	Adj R^2	**b**	p	95% CI	Adj R^2	**b**	p	95% CI	Adj R^2	**b**	p	95% CI	Adj R^2
I.	Base model				0.30				0.19				0.12				0.11
Community (5 miles) variables																	
II.	Land use mix[b]																
	Medium	−0.25	0.81	−2.60, 2.11	0.30	−2.34	0.12	−5.69, 1.02	0.20	0.74	0.44	−1.41, 2.89	0.13	−1.6	0.04	−3.26, 0.13	0.12
	High	2.38	0.18	−1.57, 6.32		−2.59	0.40	−9.48, 4.30		1.46	0.35	−2.06, 4.98		0.81	0.54	−2.19, 3.81	
III.	Total destinations[c]																
	26–100	−0.5	0.64	−3.06, 2.06	0.31	−1.4	0.29	−4.59, 1.79	0.18	−0.46	0.60	−2.59, 1.66	0.14	−0.1	0.90	−2.26, 2.04	0.10
	101–250	0.41	0.74	−2.55, 3.36		−1.08	0.52	−5.16, 3.01		0.33	0.73	−1.99, 2.65		−0.7	0.52	−3.13, 1.81	
	>250	2.08	0.11	−1.07, 5.22		0.05	0.97	−3.64, 3.75		1.76	0.08	−0.63, 4.15		0.03	0.98	−2.20, 2.25	
IV.	Total parks[d]																
	11–50	1.44	0.16	−0.89, 3.76	0.30	−0.16	0.91	−3.50, 3.18	0.18	0.21	0.83	−1.92, 2.37	0.14	−1.5	0.12	−3.65, 0.65	0.12
	>50	1.27	0.20	−0.94, 3.49		−0.73	0.52	−3.29, 1.82		1.53	0.04	−0.13, 3.19		−0.8	0.92	−1.88, 1.71	
V.	Total recreation sites[e]																
	10–15	0.37	0.74	−2.08, 2.82	0.31	0.65	0.68	−2.98, 4.29	0.18	0.11	0.90	−1.93, 2.15	0.14	−0.1	0.87	−2.17, 1.88	0.10
	>15	2.05	0.03	−0.12, 4.22		0.68	0.56	−1.95, 3.31		1.57	0.04	−0.18, 3.31		−0.1	0.91	−2.05, 1.86	
Neighborhood (half mile) variables																	
VI.	Land use mix[f]																
	Medium	−0.42	0.65	−2.50, 1.65	0.31	−1.23	0.35	−4.21, 1.75	0.19	0.21	0.80	−1.63, 2.04	0.15	−0.6	0.42	−2.42, 1.14	0.11
	High	1.73	0.11	−0.67, 4.13		0.63	0.66	−2.58, 3.84		2.02	0.03	0.00, 4.05		0.43	0.60	−1.42, 2.28	
VII.	Total destinations[g]																
	1–2	−1.41	0.15	−3.59, 0.78	0.31	−2.41	0.06	−5.34, 0.52	0.20	−1.54	0.05	−3.28, 0.22	0.20	−1.1	0.19	−2.91, 0.77	0.13
	≥3	1.19	0.25	−1.12, 3.51		−1.26	0.30	−3.98, 1.47		2.06	0.01	0.39, 3.73		1.07	0.18	−0.73, 2.87	
VIII.	Total parks[h]																
	At least one	1.82	0.04	0.08, 3.55	0.31	−0.95	0.41	−3.21, 1.30	0.19	2.06	0.00	0.77, 3.35	0.18	0.50	0.44	−0.78, 1.7	0.11
IX.	Total recreation sites[i]																
	At least one	0.61	0.76	−1.57, 2.79	0.30	−0.84	0.53	−3.54, 1.86	0.19	0.89	0.36	−1.00, 2.77	0.42	1.16	0.22	−0.69, 3.00	0.12

CI confidence interval

[a]Adjusted for age, male, race, complete, duration of injury, tract SES

Reference categories for community predictors: [b]low mix; [c]≤25 destinations; [d]<10 parks; [e]<10 recreation sites

Reference categories for neighborhood predictors: [f]low mix; [g]0 destinations; [h]0 parks; [i]0 recreation sites

Table 4 Ordinary least squares regression models of the relationships between built environment characteristics and physical functioning among people with tetraplegia ($N = 213$)[a]

Model		Basic mobility				Wheelchair				Self-care				Fine motor			
		b	*p*	95% CI	Adj R^2	**b**	*p*	95% CI	Adj R^2	**b**	*p*	95% CI	Adj R^2	**b**	*p*	95% CI	Adj R^2
I.	Base model				0.50				0.14				0.22				0.41
Community (5 miles) variables																	
II.	Land use mix[b]																
	Medium	1.19	0.34	−1.63, 4.01	0.50	−0.94	0.58	−4.79, 2.90	0.13	0.88	0.45	−1.77, 3.54	0.42	0.46	0.68	−2.00, 2.91	0.41
	High	3.52	0.27	−3.63, 10.67		0.08	0.98	−8.97, 9.13		3.42	0.28	−3.75, 10.58		1.72	0.44	−3.24, 6.68	
III.	Total destinations[c]																
	26–100	4.25	0.01	0.14, 8.36	0.51	8.66	0.00	2.09, 15.22	0.22	3.85	0.02	0.00, 7.75	0.43	3.77	0.00	0.65, 6.90	0.43
	101–250	2.31	0.22	−2.23, 6.86		5.19	0.06	−1.47, 11.84		2.19	0.20	−1.91, 6.29		3.41	0.03	−0.23, 7.05	
	>250	2.51	0.17	−1.85, 6.87		4.16	0.12	−2.35, 10.68		2.44	0.16	−1.70, 6.59		3.22	0.02	−0.21, 6.66	
IV.	Total parks[d]																
	11–50	2.26	0.15	−1.25, 5.77	0.50	3.56	0.12	−1.56, 8.67	0.16	2.3	0.13	−1.09, 5.70	0.42	2.57	0.03	−0.06, 5.20	0.42
	>50	−0.22	0.89	−3.80, 3.37		0.48	0.83	−4.44, 5.40		−0.01	1.00	−3.37, 3.35		0.94	0.44	−1.77, 3.65	
V.	Total recreation sites[e]																
	10–15	−2.33	0.12	−5.73, 1.07	0.50	−0.75	0.70	−5.18, 3.69	0.14	−1.51	0.30	−4.77, 1.75	0.42	−0.91	0.43	−3.48, 1.66	0.41
	>15	−1.1	0.43	−4.25, 2.05		0.72	0.71	−3.68, 5.12		−0.08	0.95	−2.72, 2.56		0.17	0.87	−2.23, 2.58	
Neighborhood (half mile) variables																	
VI.	Land use mix[f]																
	Medium	3.57	0.01	0.58, 6.56	0.51	1.00	0.52	−2.54, 4.523	0.15	2.61	0.04	−0.19, 5.42	0.43	3.3	0.00	0.92, 5.67	0.43
	High	1.25	0.40	−2.09, 4.60		−2.88	0.31	−9.22, 3.47		1.36	0.31	−1.65, 4.36		0.58	0.62	−2.07, 3.23	
VII.	Total destinations[g]																
	1–2	−0.29	0.85	−3.69, 3.12	0.50	1.34	0.51	−3.28, 5.95	0.14	0.38	0.80	−2.93, 3.68	0.42	0.84	0.47	−1.79, 3.47	0.41
	≥3	0.87	0.54	−2.34, 4.08		0.87	0.65	−3.37, 5.10		1.01	0.44	−1.91, 3.92		0.95	0.42	−1.72, 3.62	
VIII.	Total parks[h]																
	At least one	−1.26	0.30	−3.65, 1.13	0.50	−0.56	0.68	−3.25, 2.14	0.14	−0.69	0.53	−2.88, 1.49	0.42	−0.49	0.60	−2.33, 1.34	0.41
IX.	Total recreation sites[i]																
	At least one	−0.43	0.76	−3.23, 2.37	0.50	−0.24	0.88	−3.46, 2.97	0.14	0.43	0.75	−2.21, 3.07	0.42	0.09	0.94	−1.97, 2.14	0.41

CI confidence interval

[a]Adjusted for age, male, race, complete, duration of injury, neighborhood SES

Reference categories for community predictors: [b]low mix; [c]≤25 destinations; [d]<10 parks; [e]<10 recreation sites

Reference categories for neighborhood predictors: [f]low mix; [g]0 destinations; [h]0 parks; [i]0 recreation sites scores were not significant; however, the results of the Wald test supported the association between land use mix and fine motor functioning ($F(2, 200) = 4.03$, $p = 0.019$). That is, for the average person with tetraplegia living in a neighborhood with low intensity mix (e.g., only single-family homes), fine motor scores were lower compared to people living in more mixed-use areas (AME = 44.6, 47.9, and 45.1 for low, medium, and high mix intensity, respectively).

Sensitivity analyses

As a final step, we replicated the multivariate analyses after removing two potentially influential subgroups from the sample: community ambulators and rural area residents. In the analysis of non-ambulatory people only, the observed associations for both injury groups were robust. In the urban-only analysis, the observed associations between the neighborhood built environment characteristics and self-care for people with paraplegia were unchanged. However, the associations between community destinations and functioning in tetraplegia were no longer significant. The relationship between land use mix at the neighborhood scale and fine motor functioning was unchanged (results not tabled, coefficients available from the lead author by request).

Discussion

Environmental factors are important to the experience of disability. By combining several data sources and a rigorous analytic approach, we found that people with SCI living in places with mixed land use, more destinations, and parks reported fewer functional limitations across several domains. For those with paraplegia, living in neighborhoods with several destinations and a park was associated fewer self-care limitations. Higher wheelchair mobility and fine motor functioning was reported by people with tetraplegia with more destinations in the larger community— broadly defined as the number of commercial, cultural, and recreational sites—whereas fine motor functioning was also positively associated with living in neighborhoods with more mixed land use. These findings are consistent with previous research reporting that aspects of the built environment such as greater land use mix, density, and connectivity are associated with greater functional independence and activities related to self-care among older adults in the United States [15, 17].

Although this investigation was exploratory, based on empirical observation in other populations with mobility impairments, we hypothesized that indicators of more development and destinations in the local area would be associated with higher physical functioning, particularly in the mobility domains. Contrary to expectations, we found no association between wheelchair mobility and the built environment for persons with paraplegia. This may be due in part to the built environment measures used for this study. Indicators of land usage and destinations may not assess the aspects of the built environment that would drive mobility outside the home for people with SCI, such as the presence of accessibility features and quality of the built environment. In the current movement in public health in the United States to improve community walkability, knowledge of the specific features of neighborhoods could inform recommendations for infrastructure investments (e.g., sidewalk repair and ramps additions), as well as compliance with federal and local regulations guaranteeing full access for people with disabilities. Similarly, this information could inform future disability benefits and housing policies to help people with severe, chronic mobility impairments like SCI relocate to neighborhoods with better infrastructure and supportive features that would promote mobility, activity, and health.

The results of a sensitivity analysis excluding residents of rural areas suggested that the observed relationships between community destinations and functional limitations for people with tetraplegia were driven by differences between people living in rural and urban communities. Communities were defined for this investigation as the local “driveable” area within a 5-mile radius around the home. For people in rural areas, the distances traveled to access places that provide healthcare, amenities, and entertainment are likely far greater and pose additional challenges to people with SCI who do not always have access to reliable transportation. Fewer local destinations and the demand of traveling greater distances may lead to more perceived activity limitations, resulting in functional decline after SCI. Conversely, living in a high density, mixed-use environment may provide opportunities to be physically and socially active as well as more opportunities to live in accessible housing, which may enhance aspects self-care and fine motor functioning and promote further activity and mobility outside of the home. One factor that might be important to persons with tetraplegia living in places with more destinations is the availability of a larger community of people available to assist with access, thus enhancing activities among persons with SCI. In future studies, it would be worthwhile to examine how the built environment influences interactions between persons with SCI and others in the surrounding community.

Study limitations

This investigation has several limitations. Although several key relationships were identified, the amount of variance explained by the built environment was relatively small. In neighborhood research, smaller effect sizes are attributable to the fact that neighborhood and community exposures are comparatively distal relative to individual factors and supports on health outcomes. Although environmental effects are smaller, the influence of neighborhood context is distributed across large groups of people and may accumulate over time. The analysis of the link between several features of the built environment and physical functioning would be strengthened by longitudinal data that could be used to disentangle neighborhood selection effects, mechanisms, and change over time. The cross-sectional design of this study precludes the analysis of reverse causation, such as the selection of people into neighborhoods due to health and functioning-related factors. The SCI-FI/C instrument is subject to self-report bias. The strengths of the data obtained for the original SCI-FI/C development study, which included very detailed, SCI-specific information on functioning among a fairly large and diverse sample of community living adults, outweigh the limitations of these data. Similarly, the proxy built environment factors developed for this analysis were limited to available GIS data for a wide array of geographic locations. As noted by Magasi and colleagues [34], GIS data and methods are a powerful and insightful tool for assessing macro-level environmental factors. However, additional research is needed to develop data sources at a national level that tap the key features of the built environment observed to be relevant to individuals with mobility disabilities in studies of a single city or geographic area, such as street conditions and the accessibility of public spaces and buildings [16]. Although the sample used for this analysis was representative of persons with SCI in the national SCIMS database, SCI is in many ways a unique population and thus these findings may not be generalizable to all people with mobility impairments. As a final point, although the sample size was adequate to power the analysis, a larger sample would increase the potential to examine additional associations, such as conditional relationships, and to further explore subgroup differences between people who live in rural vs. urban areas.

Conclusions

The current study provides support for a link between the built environment and physical functioning following SCI. These findings further suggest a need to investigate the personal and environmental factors that shape health, functioning, and well-being over the long term in order to mitigate disability related to SCI. A better understanding of the specific features of communities and neighborhood locations that influence disability will help patients and their families plan for successful community living post SCI, as living in places with more opportunity for activity may promote physical functioning and lessen the experience of limitations after SCI.

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Author contributions ALB designed and implemented the study, conducted all data analyses, interpreted the results, and wrote the manuscript. DT and MS provided feedback on the study design, interpretation of the SCI-FI/C scores, and discussion of the results. AH, SC, and CK assisted with the study conceptualization, interpretation of results, and provided feedback on the final manuscript. RB assisted with the study implementation, contributed to the literature review, and initial drafts of the introduction. TR contributed to the extraction of GIS data, creation of built environment measures, and provided methodological feedback on the final report.

Compliance with ethical standards

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

Statement of ethics The original and current studies were approved by the Institutional Review Boards of all collaborating institutions. The authors certify that all applicable institutional and governmental regulations concerning the ethical use of personally identifiable data were followed during the course of this research.

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