Development and Validation of a Walkability Index from Google Street View Audits

by

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Abstract

Background: Walking promotes health and helps older adults age actively. However, with both cognitive and physical functions deteriorating with age, walking becomes a complex process that is dependent not only on the health of brain and body, but increasingly on the surrounding built and social environment. Built environment is related to physical activity as it can either foster or hinder mobility. The aim of this study is to create a valid scale that utilizes objectively assessed environmental characteristics to describe the walkability of a participant's environment.

Methods: We used historical neighborhood audits from a cohort of older adults in Pittsburgh, Pennsylvania from 2007 to construct and validate the scale using exploratory factor analysis. We then applied confirmatory factor analyses in a sample of older adults participating in a randomized control trial of a physical therapy intervention in Pittsburgh and recruited between 2016-2019.

Results: In a sample of 246 older adults in the greater Pittsburgh area, we identified 3 walkability factors. Factor 1 had demonstrated strong internal consistency (alpha=0.80) and consisted of mixed land use, commercial uses present, apartments present, educational facilities present, lighting present, and public recreation present. Factor 2 demonstrated fair consistency (alpha=0.57) but good face validity, including no undeveloped land, no slopes, no single-family homes, less than 6 stairs, good quality sidewalks, and benches present. Factor 3 had fair consistency (alpha=0.40) but without good face validity. Factor 1 was more strongly related to positive outlook of neighborhood as well as lower socioeconomic standing compared to Factor 2.

Conclusion: These findings could serve as a tool for identifying neighborhood factors related to walkability that could be targets for policy interventions. Moreover, the positive implications of a walkable neighborhood could be substantial for the health of the public, especially older adults.

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Preface

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1.0 Introduction: Mobility Framework and the Built Environment

Mobility is defined as individual's purposeful movement from one place to another where a change in environment may occur. There exists a wide spectrum that often conceptualizes mobility. It can range from being bed bound (immobile) to walking great distances across environments (Stavley et al., 1999). A conical model for mobility illustrates the seven life-space locations in ascending order from low to high mobility that includes bedroom, home, outdoors, neighborhood, service community, surrounding area, and world (respectively) (Webber al., 2010). Some fundamental contributors to mobility include cognitive, psychosocial, physical, financial, and environment. The importance of each factor is relative to individual context and can vary greatly. Life circumstances such as a recent fall, medical diagnosis, or one's financial status all play a role in mobility choice (Webber et al., 2010).

Each of these mobility determining factors are inherently linked to one another and a change in one can have a drastic impact on others. The environmental factor is often described as the space where people live and work in day-to-day, which can include residential buildings, sidewalks, and open spaces. Studies show that there exists a statistically positive relationship between the built environment and physical activity (Southworth, 2005; Saelens & Handy, 2008). People have lower body mass index (BMI) in more walkable areas, compared to a less walkable areas (Lawrence et al., 2006). Studies also suggest that built environment has some correlation with metabolic health as a more walkable environment with opportunities for activities promote physical activity and help reduce the burden of obesity and diabetes in the population (Howell & Booth, 2022).

1.1 Why Mobility Matters for Older Adults

Mobility is a fundamental aspect of daily life and can carry great weight regarding the health of an individual. It allows for older adults to continue to actively age while optimizing health and independence (WHO, 2007). Lack of mobility is associated with decreased quality of life, falling, and higher risk for mortality (Webber et al., 2010). Moreover, lack of mobility not only impacts physical health, but also mental health as immobility increases social isolation (Webber et al., 2010). A study that evaluated social engagement among older adults concluded that decreased life-space mobility was related to reduced social engagement such as participation in out-of-home activities (Rosso et al., 2013). Older adults who are well into their retirement no longer have workplace socialization opportunities, therefore the negative consequences such as depression and loneliness that follows social isolation may have a compounded impact on this demographic.

This decline of mobility is very prevalent in older adults, and walking as a form of exercise, can help reduce the negative effects of it. Older adults who walk at least the recommended amount of 150 minutes per week after a six year follow up had a significantly lower likelihood of metabolic syndrome or developing risk factors of metabolic syndromes, when compared to those who did not meet the required amount (Peterson at al., 2010). Similarly, another study with an eligibility criterion of women over the age of 65 who were functionally limited, uncovered that walking at least eight blocks every week for a one-year period helped maintain better functional capacity and walking ability at base line and at one-year follow-up, compared to women who did not walk eight blocks per week for a year (Simonsick et al., 2005). The ability to walk ¼ mile is a great indicator of functional status among older adults. Older individuals who cannot walk ¼ mile have a greater likelihood for mortality, more hospitalizations, and increased annual healthcare costs (Hardy et al., 2011). There is a difference of about $2,773 in health care costs for those who have difficulty walking ¼ mile, and those who have no difficulty walking that length (Hardy et al., 2011). The cyclical nature of this issue makes it more challenging as lack of mobility can lead to obesity or other diseases (Howell & Booth, 2022) that could in turn further limit mobility.

1.2 Barriers to Walking in Neighborhood

In theory, walking appears as an easy and effective way to exercise for people of all ages, especially older adults. However, several barriers exist that could make walking difficult. Walkability refers to the ease of walking in various areas on foot (Wang & Yang, 2019). Barriers exist in both objective form such as built structure, the social environment, weather, safety, and topography (Clark & Scott, 2016), and in subjective form such as perception of walkability. However, these barriers are not evenly distributed among older adults. For example, women tend to demonstrate more limitations and have higher risk of mobility disability when compared to men (Murtagh & Hubert, 2004; Statistics Canada, 2007). Culture also plays a role in imbalance of mobility limitation as it influences education, career, social relationships, and physical activity habits (Mollenkopf et al., 1997). A data report by CDC indicates that there are notable differences in inactivity levels between races in the US. Hispanic individuals have the highest prevalence of no physical activity, followed by non-Hispanic Black and non-Hispanic White individuals (Fulton, 2020). Moreover, mobility patterns also differ between rural and urban areas. Residents from rural areas are less active compared to urban area residents (Australian Institute of Health and Welfare, 2014). One of the reasons for this is that urban residents perceive their local area to be more walkable and therefore walk more (Berry et al., 2017).

The form of the built environment plays a crucial role in walkability of a neighborhood. Characteristics such as population density, land-use mix, street connectivity, and sidewalk availability have consistently been related to walking (Frank et al., 2010). The weather, such as extreme heat or cold, can make waking more challenging (McMillan, 2007). In addition, the topography of the neighborhood also plays a role in walkability. Places that have steep hills make it difficult to walk (Troped et al., 2001). Several studies also show that the safety of a neighborhood, captured in terms of crime rate, is associated with frequency of walking. High crime rates tend to discourage people from walking. (Gomez at al., 2004; Troped at al., 2001). Older adults may be more vulnerable to the poorly build neighborhood characteristics due to their reduced physical ability compared to younger population.

On a more subjective level, the aesthetics of the neighborhood also plays a role in increasing or decreasing desire to walk. Visibly appealing neighborhoods with trees and functional sidewalks promote walking (Ball et al., 2001). Personal social environment also plays a role, as those who have groups of people to walk with tend to walk more. Rather than just as a form of exercise or travel, walking can function as a social experience (Ball et al., 2001). It is important to note that even the subjective perceptions are defined by objective-built features, physical capacity, and mental willfulness.

1.3 Existing Assessment Measures

Similar to the dichotomization in barriers to walking, existing assessment measures also use objective and perceived environmental features to evaluate neighborhood walkability. Although an individual's socio-economic characteristics do play a significant role in decision making in regard to walking (Lee & Moudon, 2006), the built environment is often used to assess neighborhood characteristics because it is more tractable for policy interventions (Tribby et al., 2016). The self-reported surveys and interviews collected as part of perceived measures can have response bias and may be less reliable due to the changing nature of one's personal attitude and characteristics (Cerin et al., 2006). Although not always generalizable, self-reported surveys still play an important role in understanding characteristics of a particular neighborhood. While both subjective and objective measures are necessary, objective measures have advantages, particularly with regards to policy-level interventions. The objective measure of walkability of built environment is typically assessed at two levels: a disaggregate level that includes individual street block faces, and at spatially aggregate level (census) where evaluation occurs at a block group level (Tribby et al., 2016). Assessment measures built on these levels have highlighted the strengths and limitation of both measures.

1.3.1 Perceived Walkability Assessment

Perceived walkability, or how easy individuals find walking, has had limited research until recently. One study evaluating the effects of security and walkability concluded that in order to improve the well-being of a population, urban planning strategies should focus on creating appealing neighborhoods that boosts resident's perception of security. They assessed this using agreement rating on 7 statements (Lucchesi et al., 2020). A more robust perceived measure assessment tool often used by studies is Neighborhood Environment Walkability Scale (NEWS) (Saelens et al, 2003). This scale, along with its abbreviated version, NEWS-A (Cerin et al., 2006), obtains perceptions of built environment in an individual's local area. Specifically, it assesses 89 items in five areas of focus: land use, public transit, street characteristics, quality of environment for pedestrians, and places to walk and bicycle. The validity and reliability of it has been examined internationally (Cerin at al., 2006).

Similarly, Physical Activity Neighborhood Environment Scale (PANES), is also a self-report assessment on neighborhood environment walkability attributes. It is shorter than NEWS with only 17-items and has shown positive correlations with NEWS-A subscales (Sallis at al., 2010). Perceived walkability assessment is one way to address the gaps that might exist due to individual differences due to past experiences, culture, and personal values. However, they are prone to self-report biases and may not be comparable between various locations.

1.3.2 Objective Assessments: Evaluation Methods

Objective walkability assessments are often evaluated through geographical information system (GIS) methods using spatial data. They measure the topology for walking in various geographic areas by looking at composition, housing, and other neighborhood characteristics. GIS based measures also allow for one to retrospectively analyze and compare historical data. However, restrictions can exist in availability of data such as quality of sidewalk. Often, the data only encompasses macro-level environmental characteristics such as street connectivity rather than ‘micro-level’ characteristics such as quality metrics. GIS based methods could also be restricted to administrative boundaries (e.g., census tracts) which may be larger than desired and not as meaningful to an individual (Rosso et al., 2011). Another way of objectively assessing neighborhood walkability is through direct observation methods (Brownson et al., 2009). These types of assessments are conducted by trained surveyors or auditors who evaluate neighborhood characteristics. However, they can be more labor and time intensive, compared to GIS based assessments.

A common objective index is WalkScore, a web-based algorithm that is widely used and available in the United States, United Kingdom, Canada, and Australia. Data sources for this assessment include Google, Education.com, Open Street Map, the U.S. Census, Localeze, and places added by the WalkScore user community. It assigns a score of 0-100, with 0 being not walkable and 100 being highly walkable. A neighborhood is assessed by evaluating its proximity to 13 types of amenities such as grocery stores, restaurants, bars, schools, parks, etc. The closer the amenities, the higher the weight it is given. Generally, WalkScore scores are positively associated with walking rates (Herrmann et al., 2017). A study conducted among women in rural populations indicated that WalkScore appeared to be a relevant indicator of the presence of walkable amenities in rural areas, positively associated with perceived proximity of destinations, and the availability of street shoulders (Lo et al., 2019). Overall, WalkScore has shown strong validity and is commonly used for community assessment. One limitation of this tool, however, is that it does not account for characteristics such as safety, aesthetics, and physical activity resources (Lo et al., 2019).

1.4 Gaps in Knowledge

Walkability indices created so far have assessed walkability through perceived measurements and through census level (block group level or tract level). Perceived assessments are not always comparable across regions, and census level assessments may mask the smaller spatial variations that could affect day-to-day walkability. The third type is the objective assessments at a disaggregate level - individual street block faces. The biggest challenge of disaggregate level assessments is combining the individual segments into categories that are related to walkability (Tribby et al., 2016).

Disaggregated assessments are conducted by auditors through field surveys or through Google Street View images. However there exists a gap in the lack of summary measures from these individual audit assessments. A summary measure provides a more comprehensive evaluation. Despite the growing evidence that suggests that the individual neighborhood variables have explanatory power, they tend to be strongly correlated to one another in modelling context. This can lead to omission of few variables that are too correlated in research studies (Wong et al., 2011). Creating a single index that summarizes the correlated variables helps overcome this issue. For our study, we took literature, data availability, and theoretical justifications into consideration while developing the index. First, items were selected to be included in a factor analysis. Scree plots were used to determine the number of factors to include. Index validation was conducted through comparison with Health ABC demographic data, census data, EPA national walkability index, and Allegheny County survey data from Behavioral Risk Factor Surveillance System.

1.5 Public Health Significance

There are approximately 55 million older adults over the age of 65 in the US, representing 16% of overall population. This number is expected to increase to 21.6% in 2040 as the last cohort of baby boomers reach older adulthood (Mather et al., 2019). As 1/5th of Americans retire and spend more time at home, it is important that the built environment around their neighborhood provides ample support for mobility. Numerous studies so far have illustrated the plethora of health benefits that accompany older adults who live a mobile life.

Creating a valid and objective walkability index aids in understanding the walkability needs of a neighborhood. It also allows for comparisons to be made between various neighborhoods to gain a better understanding of what is lacking in specific areas. This knowledge and understanding could help lead policy interventions and influence decisions regarding mobility needs for older adults. Moreover, public policies on infrastructure could be guided with the use of neighborhood evaluation indices. With mobility playing a substantial role in disease prevention, evaluation of walkability by assessing the built environment can also help older adults decide what neighborhoods are walkable and help increase overall population mobility and improve public health.

2.0 Objective

The aim of this study was to create a valid index that uses objectively assessed environmental characteristics to describe the walkability of the local built environment.

3.0 Methods

3.1 Sample

Development of the walkability index utilized data from the Health, Aging, and Body Composition (Health ABC) study in which older Black and White adults were enrolled. Health ABC enrolled 3,075 participants from Pittsburgh, PA, and Memphis TN in 1997-1998. Participants had to be between the ages of 70-79 at enrollment, be without mobility disability, and have no plans to move from the area. Black individuals and men were oversampled.

Participants from the Pittsburgh site (n=1035) who attended the follow-up visit in 2006-2007 (visit 10) were considered for inclusion in a study to conduct virtual audits of neighborhood walkability. Participants were included if they had a valid address and still resided in the greater Pittsburgh region at the time of the follow-up visit (n=745).

Written informed consent was obtained at baseline from all participants, and protocols were approved by all involved institutional review boards.

3.1.1 Neighborhood Walkability

This study used Google Street View to evaluate residential characteristics and the predominant land use, types of residential and nonresidential uses, presence of recreational facilities, street characteristics, and quality of environment around the participant's residence. These areas of focus for evaluation were adapted from the Active Neighborhood Checklist (Hoehner et al., 2007). The Active Neighborhood Checklist was modified to remove items that were difficult to audit using Google Street View (graffiti and litter) or irrelevant to this study population of older adults (bicycle related items). A study that evaluated the interrater reliability of historical virtual audits using archived google street view imagery indicated that the prevalence and bias adjusted kappa (PABAK) of the 78-item modified checklist was .75, and 81% of the items had substantial agreement with PABAK$\geq$ .61 or almost perfect agreement with PABAK $\geq$ .81 (Harding et al., 2020). Only items with PABAK>0.60 were considered for inclusion in this factor analysis (see Table 1).

3.1.2 Adult Protocol

Google Street View provides 360^{o} panoramic street-level images. Since its launch in 2007, its features have improved to which time stamps of images are now available for comparison through its Google Maps Time Machine Feature (Raman, 2017).

The audits were conducted between June 2017 and July 2019 by two graduate students and one research assistant. All three auditors participated in a 2-hour training session that included the auditing platform, definitions of items on the Active Neighborhood Checklist, and practice navigation audits. After training, three auditors conducted a sample of audits independently and blind to the other auditors' results. Standardized protocols were established to reduce subjectivity between auditors. The audits were conducted on 660-ft of distance (1/8th- mile) on each side of each participant's residence, for a total of 1320-ft (1/4th- mile) audited per participant. While the Active Neighborhood Checklist was designed to audit single street segments, the ¼ mile distance was selected due to inconsistent distances between adjacent intersections across the greater Pittsburgh region, and because the mobility disability literature commonly uses the ability to walk ¼ mile as an indicator (Harding et al., 2020).

3.1.3 Individual Demographic and Health Characteristics

We conducted validation analysis using the following variables from Health ABC study data: age, gender, race, education, falls, financial status, functional status, and physical activity. The demographics variable included age, gender, race, and education and they are compared between the two factors of urbanicity and neighborhood quality. The variable falls constituted the number of self-reported falls within the past 12 months and was dichotomized into no falls and one or more falls. The variable finances (in US dollars) were categorized into 3 levels: less than 25,000 (K), 25K-50K, and more than 50K. Mobility disability was measured by whether or not the participant has difficulty walking a $1/4^{th}$ mile. Lastly, physical activity was defined as those who reported walking in the past week compared to those who did not.

3.1.4 Census Tract Data

The online Census Geocoder tool (U.S. Census Bureau) was used to obtain the census tract and census block that corresponded to each participant address. Neighborhood characteristics including median age, and neighborhood socioeconomic status (nSES), and population density. nSES was composed of median individual income, median household income, median value of housing units, percentage of households receiving interest/dividend/net rental income, percentage of adults with high school education, percentage of adults with a bachelor's degree, and percentage of adults in managerial/professional occupations) (Rosso et al., 2016). Population densities were obtained at census tract-level for each address from the 2010 US Census.

The National Walkability Index was designed by the Environmental Protection Agency (EPA) to measure the relative walkability of neighborhoods at a community level, utilizing three variables: intersection density, proximity to transit stops, and diversity of land uses (employment mix, employment, and household mix) (Thomas & Zeller, 2021). Using these variables, block groups were ranked depending on their quantile position. Scores range from 1 to 20, with higher values indicating greater walkability. Data were linked with Health ABC data by census tract.

3.1.5 Neighborhood Perception

The 2009-2020 Allegheny County Health Survey, modeled after the CDC's Behavioral Risk Factor Surveillance System (BRFSS), assessed perceptions of participants neighborhoods. Participants were asked about as ease of neighborhood walkability, how often others were seen exercising outside, and perceived safety walking during day or night (Table 4). A total of 3,592 adults, or 66% of all survey respondents, provided valid responses to these questions of neighborhood perception. Of these survey respondents, 19% identified as AA and 62% reported a household income of less than $50,000. Only a third (1795) of these survey participants were 65 years of age or older.

As BRFSS's Allegheny County Health Survey (ACHS) data were available at the ZIP code level, ZIP code was used to match ACHS survey data to Health ABC participants. Due to the ACHS survey itemization, with lower scores indicating more walkability, negative values indicated a positive correlation between the survey question and the factors. Survey response from 728 people were included in the final analysis.

3.2 Statistical Analysis

3.2.1 Construction of Walkability Index

To construct the walkability index, we included items based on theoretical justifications, existing literature, and availability of data. Variables included qualitative (e.g., type of structure) and quantitative (e.g., number of steps leading up to the house) measurements (see Table 1 for list of included variables and definitions) and were assessed for factorial validity. Scree plots were used to determine the appropriate number of factors to include. We assessed internal consistency of the factors using Cronbach's alpha.

3.2.2 Validation

Construct validity was tested by assessing associations of identified factors with 1) individual demographic, socioeconomic, health and behavior variables from Health ABC; 2) census-derived neighborhood variables; 3) the National Walkability Index; and 4) neighborhood perception from the Behavioral Risk Factor Surveillance System survey for Allegheny County. Associations were assessed using Spearman's correlations for continuous variables and ANOVA for categorical variables.

3.2.3 Confirmatory Factor Analysis

We used a confirmatory factor analysis on comparable data from the Program to Improve Mobility in Aging (PRIMA) study (Brach et al., 2020). The PRIMA study evaluated a novel physical therapy intervention to improve walking in older adults. The participants of PRIMA (n = 248) were recruited between 2018-2019 through the Pittsburgh Pepper Center Research Registry and had gait speeds between 0.6-1.2 m/s. Neighborhood audits were conducted in a similar manner to those conducted for Health ABC study participants, with the audit distance reduced to 1/8 mile centered on the participant's home. Confirmatory factor analysis was conducted using the factors identified from the Health ABC data. Cronbach's alphas, factor loadings and model fit statistics were examined.

Table 1 Variables Derived from Google Street View Audits Used to Create Walkability Factors and their Definitions

Variable	Definitions
Residential/mixed land use	Predominant land use was all residential or residential mixed with commercial, institutional, or industrial buildings. Dichotomized into predominantly mixed or nonresidential and predominantly residential
Predominant land use undeveloped	Predominant land use is natural space that is not maintained by public or private entities
Predominant land use commercial	Predominant land use is any building that is not solely residential, including college and universities, churches, and retail stores
Single family homes	Presence of stand-alone residential buildings with no more than two front entrances
Apartments	Presence of residential buildings that have more than 4 units
Public Recreation	Presence of public recreational facilities and equipment (including in the school yard if publicly accessible) including, park, off-road walking/biking trail, sport/playing field or court, playground, outdoor pool.
Any service/retail present	Presence of places such as community centers, restaurants, banks, post offices, salons, grocery stores, gas stations, etc.
Educational facilities	Presence of elementary, middle, high schools, or colleges or universities
Street size	Size of street for the majority of the audit. Options: Audit is primarily through a parking lot, no marked lanes, 2 or more marked lanes
Safe intersections	Presence of intersections that had a crosswalk or a walk signal present

Bench	Presence of public benches along the sidewalk, including at transit stops
Lighting	Presence of lamp posts intended to light the sidewalk
Tree shade	Presence of tree shade that would cover the sidewalk or other walking area at approximately noon. Options: None or few <25% shade, some or more shade
Steepest slope	A flat/gentle slope would hardly be noticeable to most individuals. A moderate to steep slope could act as a barrier to most individuals and walking on it may increase some individuals' heart rates.
Sidewalk quality	Either no sidewalk or unwalkable sidewalk or sidewalk is present and walkable
Stairs at entrance	Presence of 6 or more stairs leading up to the entrance of the house

4.0 Results

The analytic sample of Health ABC (Table 2) consisted of 745 participants ranging from 78-89 years old (mean= 82, SD=2.7). The sample was 57.2% female and 38.5% Black. Approximately 28% of our sample reported having fallen more than once during the past twelve months and 66% had mobility disability, reporting difficulty walking 1/4 mile. Over 45% of participants reported not walking in the past week.

The exploratory factor analysis of the walkability variables in Health ABC using a 3-factor model produced the best fit; 41% of the variance was explained with 3 factors, whereas with 4 factors, the percent explained only increased by about 7%. This analysis described variability among variables that were correlated. Factor one (urbanicity), consisted of mixed land use, commercial uses present, apartments present, educational facilities present, pedestrian lighting present, and public recreation present demonstrated strong internal consistency (Cronbach alpha=0.82). Factor two (quality of neighborhood), consisting of no undeveloped land, no slopes, no single-family homes, presence of less than 6 stairs at participant's home entrance, good quality sidewalks, and benches present had a moderate Cronbach alpha of 0.51. Lastly, factor 3 included no undeveloped land, no abandoned homes, and no abandoned buildings and had a moderate Cronbach alpha of 0.52 (Table 3). Given the low internal consistency combined with a lack of face validity for the items included in factor 3, we opted to not assess validity of this factor further. The variables that fall under factors 1 and 2 were also more supported by literature and theoretical justifications, compared to factor 3.

Urbanicity did not differ by gender (p=0.8; Table 2). On average, White participants had a higher urbanicity value (0.0653) than Black participants (-0.104). Urbanicity was higher for those who had less than high school education (0.115) compared to those with post-secondary education (0.057) with the lowest values among those who were high school graduates (-0.128). Those with higher incomes had higher urbanicity values. Urbanicity was not significantly different based on reported falls or ability of walk a 1/4th mile but was higher for those who reported walking in the past week (0.122) compared to those who reported no walking (-0.117). Higher urbanicity was also related to higher nSES (p=0.09), higher National Walkability Index (p <.0001), and greater population density (p<0.0001).

Neighborhood quality did not differ by gender (p=0.1; Table 2). Black participants had a lower neighborhood quality value (-0.514) compared to white participants (0.336). Neighborhood quality was higher for those post-secondary education (p=0.24), compared to high school graduates (-0.12) with the lowest values for those with education less than high school (-0.45). Higher income was associated with higher quality of neighborhood. Neighborhood quality was not significantly different based on reported falls or ability to walk a 1/4th mile. Neighborhood quality was higher for those who reported walking in the past week (0.096) compared to those who reported no walking (-0.084). Better neighborhood quality was also related to higher nSES (p<.0001), higher National Walkability Index (p <.0001), and lower population density (p=0.0006).

Perception of the environment from an independent sample (BRFSS) was significantly related to both factors (Table 4). Urbanicity showed significant correlation with people's perception of available opportunities to be physically active (-0.23, p<.0001), pleasantness to walk (-0.17, p<.0001), and not feeling safe walking in their neighborhood (0.16, p<.0001). Significant, moderate correlations were also present between urbanicity and ease of walking to places (-0.40, p<.0001), seeing other people walking (-0.30, p<.0001), and often noticing other people exercising in the neighborhood (-0.37, p<.0001). Busy roads and urbanicity had significant low correlations (0.11, p =0.003). Quality of neighborhood did not show significant correlations with ease of walking in neighborhood (0.04, p=0.298) and noticing other people walking in neighborhood (-0.01, p= 0.875). However, significant correlations were observed between quality of neighborhood and having opportunities to be physically active (-0.20, p<.001), pleasantness in walking (-0.16, p<.0001), noticing other people exercising (-0.13, p=0.0004), feeling safe walking in neighborhood (-0.22, p<.0001). Higher neighborhood quality was related to lower likelihood of reporting that busy roads make it unsafe to walk in their neighborhood (-0.28, p<.0001).

A confirmatory factor analysis was conducted with the PRIMA study which had comparable study participants with similar age (mean=77.4, SD=6.6) and geographic location (greater Pittsburgh area). In the PRIMA sample, urbanicity again had strong internal consistency (Cronbach alpha=0.77), but factor 2 had a poor Cronbach alpha of 0.24.

Table 2 Demographic and Health Characteristics of the Health ABC Sample (n=745) and their Associations with the Walkability Factors

Health ABC Characteristics	**Sample**	**Urbanicity (Factor 1)**		**Neighborhood Quality (Factor 2)**	
	mean (SD) or n (%)	**Mean (SD) or rho**	**p-value**	**Mean (SD) or rho**	**p-value**
Age (years)	82.39 (2.74)	0.07	0.04	0.05	0.2
Gender					
Male	316 (42.8%)	-0.011(0.999)	0.8	0.069(0.958)	0.1
Female	422 (57.2%)	0.008(1.002)		-0.0514(1.028)	
Race					
White	454 (61.5%)	0.065(1.076)	0.02	0.34(0.577)	<.0001
Black	284 (38.5%)	-0.10(0.856)		-0.54(1.266)	
Education					
Less than high school	111 (15.1%)	0.12(0.923)		-0.45(1.297)	
High School graduate	272 (36.9%)	-0.13(0.914)		-0.12(0.999)	

Post-secondary	354 (48.0%)	0.057(1.073)	0.03	0.24(0.816)	<.0001
Finances ($)					
Less than 25K	264 (42.3%)	-0.043(0.912)	0.006	-0.25(1.136)	<.0001
25K up to 50K	200 (31.1%)	-0.097(0.987)		0.11(0.908)	
50K	160 (25.6)	0.22(1.144)		0.35(0.559)	
Number of falls (past 12 months)					
No falls	468 (72.0%)	0.019(0.997)	0.8	-0.026(0.998)	0.1
1 or more	182 (28.0%)	0.0016(1.061)		-0.12(0.989)	
Physical Function: Difficulty walking a 1/4th mile					
No	296 (65.6%)	0.0003(1.006)	0.5	0.0084(1.005)	0.8
Yes	155 (34.4%)	-0.065(1.017)		0.039(0.966)	
Physical Activity: walk at least 10 times, past 12 months (and past week)					
no walking past week	296 (45.5%)	-0.12(0.957)	0.003	-0.084(1.092)	0.02
walked past week	355 (54.5%)	0.12(1.049)		0.096(0.903)	
nSES	0.037(5.039)	0.06	0.09	0.34	<.0001
National Walkability Index	13.776(2.940)	0.55	<.0001	-0.19	<.0001
Population Density (people/square mile)	7612 (7044)	0.48	<.0001	-0.13	0.0006

Table 3 Definitions of the Factors Identified through Exploratory Factor Analysis

	Audit Items	Raw Cronbach's alpha
Factor 1 (urbanicity)	mixed land use, commercial uses present, apartments present, educational facilities present, lighting present, and public recreation present	0.82

Factor 2 (neighborhood quality)	no undeveloped land, no slopes, no single-family homes, less than 6 stairs, good quality sidewalks, and benches present	0.51
Factor 3 (abandoned properties)	No undeveloped land, no abandoned home, no abandoned buildings	0.52

Table 4 Comparison of Walkability Factors with Average Perception of Neighborhood Characteristics from the Behavioral Risk Factor Surveillance System (BRFSS) at the ZIP Code Level (n=728)

Survey Question	**Urbanicity (Factor 1)**	**Neighborhood Quality (Factor 2)**
	rho, p-value	rho, p-value
My neighborhood offers opportunities to be physically active	-0.23 <.0001	-0.20 <.001
It is pleasant to walk in my neighborhood	-0.17 <.0001	-0.16 <.0001
In my neighborhood it is easy to walk to places	-0.40 <.0001	0.04 0.298
I often see other people walking in my neighborhood	-0.30 <.0001	-0.01 0.875
I often see other people exercising in my neighborhood	-0.37 <.0001	-0.13 0.0004
I feel safe walking in my neighborhood, day, or night	0.16 <.0001	-0.22 <.0001
Busy roads make it unsafe to walk in my neighborhood	0.11 0.003	-0.28 <.0001

5.0 Discussion

Several walkability indices exist that rely on self-reported (Cerin et al., 2006) or macro-level (e.g., census) data (Thomas & Zeller, 2021). Here, we developed and validated walkability indices derived from micro-level audited data. We identified two factors (urbanicity and neighborhood quality) with fair to good internal consistency and good face validity. We demonstrated that higher urbanicity was related to ease, opportunity, and safety of neighborhood walkability, noticing others walking, sociodemographic characteristics, and physical activity, but was not related to physical function. Higher neighborhood quality was related to sociodemographic characteristics, physical activity, opportunity and safety of neighborhood walkability, but was not related to physical function, perception of walkability, or noticing other people walk in neighborhood. Macro-level measures are commonly used in walkability indices, including items such as household and job density, land-use mix, and design (Cervero & Kockelman, 1997), or residential density and other aspects of the built environment (Ewing & Cervero, 2010). However, micro-level walkability items (e.g., sidewalk quality, stairs at entrances) are frequently identified by older adults as contributors to falls (Chippendale & Raveis, 2017) and are related to walking behaviors among older adults (Rosso et al., 2021).

We did not observe associations between our factors and either falls or reported difficulty in walking a 1/4th mile. This could be due to the fact that both of these variables are more contingent on an older adult's physical ability rather than the built environment. Factors such as muscle weakness, comorbidities, and lack of physical mobility may contribute to increased risk of falling (Deandrea et al., 2010). In contrast, both greater urbanicity and better neighborhood quality were related to greater likelihood of reporting walking in the past week. As people age, neighborhood characteristics, such as good quality sidewalks, become essential to safety (Buffel et al., 2012; Mahmood et al., 2012). One reason neighborhood characteristics are more important to older adults than other age groups may be the increase in time spent at neighborhood following retirement (Gefenaite et al., 2020). Urban neighborhoods may support walking across the lifespan, but it may not always be safe or easy to walk in these environments (Suarez-Balcazar, 2020) which supports our identification of two distinct walkability factors:urbanicity and neighborhood quality.

Lower socioeconomic status is associated with lack of physical activity (Ford et al., 1991; Mackenbach et al., 2008) and the environment in which an individual resides plays a substantial role in one's ability to walk. Neighborhood socioeconomic status (nSES) was not significantly related to urbanicity (0.063, $p=0.09$) in our analyses, but was associated with the quality of neighborhood (0.340, $p<.0001$). Census results indicate that rural areas have higher median household income than urban counterparts (Guzman et al., 2021). However, this does not account for generational wealth or other sources of income. This gap could account for the lack of association between nSES and urbanicity. On the other hand, neighborhood quality was statistically associated with nSES, possibly indicating the availability of high-quality resources in wealthier areas. Good quality sidewalks and presence of benches (items within factor 2) both require funding and extra resources that communities with lower nSES may not have. Studies show that neighborhoods with lower SES indicators, such as poverty and vacant homes, have significantly worse sidewalk quality than wealthier neighborhoods (Rajaee et al., 2021).

Correlations with the National Walkability Index show that the quality of neighborhood is associated with greater walkability. The variables that were used to construct the Neighborhood Walkability Index include intersection density, proximity of transit stops, and diversity of land uses. Qualities more often present in urban areas receive higher walkability scores in this index

(Thomas & Zeller, 2021). Similarly, population density was positively and significantly correlated with urbanicity, but negatively and significantly correlated with neighborhood quality. It is important to note that many urban areas with high values in National Walkability Index and with higher population density are areas whose residents are more likely to be racial minorities. People with lower incomes who have consequently experienced historical disinvestments may explain the negative associations with neighborhood quality. A 2018 report indicated that racial and ethnic minorities make up about 43% of urban areas, but only 22% of rural areas (USDA, 2022).

Both urbanicity and neighborhood quality were significantly related in the expected direction with nearly all measures of neighborhood perception from the BRFSS survey data. The smallest geographic unit for BRFSS was the ZIP code level, whereas our indices were built using a 1/4-mile distance. Despite the discrepancy in geographic unit, significant associations existed between the indices and most ACHS variables, although this discrepancy may have led to the small correlation coefficients we observed.

5.1 Strengths and Limitations

One limitation with our study is that our data is from a cohort of older Pittsburgh residents, and therefore may not be applicable to other geographies or for younger adults/children. Validation tests (as done with our PRIMA study) to neighborhoods from various parts of the United States and for different age groups should be considered. Second, Google Street View images may be prone to blurry images or visual obstructions, particularly for the older images used in this study. The feature also does not always allow an individual to zoom in on a home with clarity. However, we demonstrate that walkability factors can be constructed even from these older images, allowing for application to completed, historical cohorts, as in this study with the Health ABC cohort. Urbanicity had a much higher alpha compared to neighborhood quality. This could be because of potential error in measurement because due to the scale, coding, and availability of images and differences in this error across different items included in our audits.

Despite the challenges, our study had notable strengths. The data used to construct the indices spanned urban, suburban, and exurban areas and is therefore generalizable beyond city neighborhoods. The data for the exploratory analysis cohort was from 2007, but the validity test we conducted was from a more recent study completed in 2019. Despite the time difference, the indices displayed good consistency between cohorts. Another strength was the inclusion of self-reported neighborhood characteristics from an external sample collected in 2010.

This is the first study to use micro-index (at residential level) audit data to construct walkability indices. Our two identified indices of urbanicity and neighborhood quality show good face validity and internal consistency and could be applied to various existing geographic indices. Future research can attempt to validate the indices with data from other regions to determine if they are robust to regional differences and in neighborhoods beyond the greater Pittsburgh area. These indices, urbanicity and neighborhood quality, can be used to attest the features of neighborhoods and aid in policy making to ascertain what features could help increase mobility within the older adult population and help improve the overall public health.

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