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Systematic review of walkability indices used in studies assessing adults' walking for transportation

By

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Degree to be awarded: Master of Public Health

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An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
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Abstract

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Neighborhood environmental characteristics are associated with physical activity behaviors of residents. Many studies have examined the association between components of built environment and health behaviors. Both the obesity and the climate change crisis require creative solutions to encourage people to move more and pollute less. Increasing active transportation is one method to increase physical activity and decrease transportation-related emissions (a major contributor to greenhouse gas pollution). This systematic review evaluated which walkability indices were used in studies on the association between walkability and walking for transportation. The protocol was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). Four scientific databases were searched. One reviewer conducted screening, data extraction, and quality assessments. Articles were included if the independent variable assessed was an objective walkability index and if the outcome assessed walking for utilitarian purposes/transportation. Study populations were adults in developed countries. 28 articles met inclusion criteria. Studies were cross-sectional (n = 23) and cohort-based (n = 5). Studies were in Canada (n = 11), the United States (n = 7), Australia (n = 4), Belgium (n = 3), Sweden (n = 2), and Japan (n = 1). Walkability indices included the Walk Score (n = 16), a GIS-derived index developed by Frank and colleagues (n = 8), cluster-derived walkability (n = 2), SPACES instrument (n = 1), validated paper map data (n = 1), and the EPA Walkability Index (n = 1). All studies found a significant association between walkability and walking for transportation in at least one of their outcomes. No negative associations were reported, but some non-significant positive associations were. Results showed that the Walk Score index was the most common index used. Walk Score has been validated for accuracy as a walkability index in the United States, Canada, Australia, New Zealand, and Japan. The index was enhanced in 2011 to incorporate improved walking distance estimates, intersections, block length, and amenity weighting. To promote use of comparable indices in future studies, efforts should be made to validate Walk Score in additional countries or establish correlation between Walk Score and GIS measures of walkability.

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Table of Contents

Chapter 1: Introduction

As the obesity and metabolic syndrome epidemic continues to expand in the United States and around the world, many different approaches have been researched and implemented to improve access to determinants of health like nutrition and physical activity. Recent public health and built environment research has shown associations and plausible mechanisms through which neighborhood and street characteristics influence physical activity. At the same time, climate change, driven by human activity-related greenhouse gas emissions, is another looming worldwide crisis. Motorized transportation, especially in non-developing countries whose road networks were built with automobiles as a priority, is a major contributor to greenhouse gas emissions. It is increasingly important to implement programs that combine the public health benefits of physical activity with the climate change benefits of alternative transportation, but unifying research in this field is lacking. In the last 20 years, a body of research has developed on the association between built environment and physical activity, including active transportation. Built environment, especially walkability, is assessed through many different mechanisms, sometimes combined into a single index of walkability. To advance research on walkability and transportation, it is important to understand how walkability is assessed in studies on the association between walkability and walking for transportation.

Problem statement: To date, no systematic review has compiled which walkability indices are used in studies looking at the association between walkability and transportation walking in adult populations in non-developing countries. **Purpose statement:** This review will improve understanding of which walkability indices are used, in which circumstances, and what associations and results are seen in these studies, to advance the field of built environment and physical activity research. **Research question:** Which walkability indices are used in studies

assessing associations between walkability and walking for transportation? **Significance statement:** The understanding of which indices are used, their circumstances of use, and recommendations for future studies, can inform the methodology of research at the intersection of public health and built environment, and improve understanding of the existing research in the field.

Chapter 2: Comprehensive Review of the Literature

Studies examining associations between various aspects of the built environment and health-related behaviors, have become increasingly prevalent in urban planning and public health academia over the last 20 years. Built environment consists of measurements like land use patterns; density and distribution of buildings related to housing and services; the transportation system; and infrastructure that supports driving, walking, biking, and other modes of transportation (Handy et al., 2002). As the obesity epidemic increases around the world, strategies and solutions related to the built environment – neighborhoods that make physical activity attractive and safe – have become more popular.

While 2 billion people worldwide are overweight or obese as defined by BMI (World Health Organization, 2020), many people in these categories are metabolically healthy, without insulin resistance, high blood pressure, or dyslipidemia (components of "metabolic syndrome") (Caballero, 2019). Up to one quarter of people of "normal weight" (BMI below 25) may have metabolic syndrome or precursors, while half of those categorized as overweight and a third of those categorized as obese may be metabolically healthy (Wildman et al., 2008), despite excess weight frequently being implicated as a risk factor for chronic disease development. One proposed mechanism to prevent the onset of metabolic syndrome is physical activity. Physical activity has been shown to be a protective mechanism against the development of metabolic syndrome regardless of body weight. A study in the Netherlands found that there was no risk difference in development of cardiovascular disease in people with obesity and overweight when they had high levels of physical activity (Koolhaas et al., 2017). A large body of literature has come to the same conclusion, that higher levels of physical activity are associated with improved cardiovascular and insulin function (Armstrong et al., 2015; Henriksen, 2002; Manson et al., 2002; Myers et al., 2019; Roberts et al., 2013; Williams, 2013).

At the same time, the need to address human-driven sources of climate change, including transportation-related greenhouse gases, has spurred growth in the alternative transportation field like walking and biking (Prior et al., 2018). Active transportation can both reduce carbon emissions as well as improve population health through better mental health and chronic disease outcomes (Prior et al, 2018). With automobile accidents and health effects from air pollution also major contributors to worldwide morbidity and mortality (NHTSA, 2018; Orru et al., 2017), strategies to reduce the number of cars on roads are increasingly important for public health and urban planning. Some of the approaches to improving street walkability, such as increasing trees and other greenery along routes, can improve the physical experience of walking via aesthetics and shade canopy, and at the same time remove greenhouse gases from the atmosphere and improve drainage during flooding events (Prior et al., 2018; US EPA, 2013). The combination of both the public health and built environment rationale for active transportation is a burgeoning field of research, and it can benefit from increased interaction and collaboration between both fields to strengthen common goals.

When studying the influence of the built environment on physical activity, it is difficult to execute high-quality research studies, because the requirements of a randomized control trial do not lend themselves well to studies of neighborhood environments, in which it is difficult and unethical to manipulate subjects' living circumstances. Natural experiments in which participants move to neighborhoods of different walkability levels are important for establishing a causational link between walkability and physical activity; however, most studies in the field are cross-sectional. Cross-sectional studies tend to analyze health behaviors like physical activity measurements at a single point in time by comparing residents who live in neighborhoods with different environmental variables, such as residential density, street connectivity, access to services, and overall walkability metrics (Saelens et al., 2003). Natural experiments lend themselves to higher-quality longitudinal studies but remain more rare than single timepoint cross-sectional studies in the field of built environment and health research.

This systematic review gathers and synthesizes evidence of studies on the association between objectively measured walkability indices and walking for transportation, an important niche in the larger body of built environment and physical activity research. While no systematic review has assessed this exact relationship, a wide variety of systematic reviews on related topics exist, and they are outlined and described below. A summary table is also provided at the end of this section in Table 1.

Smith et al. (2017)'s systematic review examined built environment and physical activity across age groups, with 28 studies located mostly in the United States as well as Australia, Belgium, England, Scotland, and New Zealand. The results showed a positive effect of street walkability components (measured with public transit, destination accessibility, land-use mix, recreation facility density, residential density, and street connectivity); parks and playgrounds (measured as installation, renovation, and access to these amenities); and infrastructure (like bike lanes, crosswalks, greenways, traffic calming features, and wayfinding), on active transportation, physical activity, and use of community amenities (Smith et al., 2017). The authors found some evidence that built environment improvements might benefit wealthier and white residents more than lower income and minority residents (Smith et al., 2017). Among other opportunities to improve the quality of evidence in the field of built environment and health behavior, authors suggested using valid and reliable measurement tools across studies.

McCormack and Shiell (2011) conducted a systematic review on the association between built environment and physical activity among adults. They examined 33 studies located primarily in the United States but also Canada, Australia, the United Kingdom, and the Netherlands. The review found that land use mix, connectivity, and population density were the most important determinants of physical activity, and that the built environment was more strongly associated with transportation walking than any other type of physical activity assessed (McCormack & Shiell, 2011).

. Mayne et al. (2015)'s systematic review examined 37 studies looking at associations between policy and built environment and BMI, diet, and physical activity, all in natural or quasi-natural experimental settings. Most studies were in the United States, with evidence also coming from Australia, the United Kingdom, Canada, Chile, and New Zealand. For interventions related to physical activity, stronger associations with the built environment were seen around active transportation improvements, as well as studies with a longer time to follow up (Mayne et al., 2015). However, the greatest effect sizes were seen in studies on associations between nutrition interventions and health outcomes, rather than built environment interventions.

Grasser et al. (2013)'s systematic review of GIS-based walkability measurements examined which ones were associated with active transportation, weight, and walking and biking for transportation, in adult populations. The study reviewed 19 projects (with 34 publications) and concluded that population density, intersection density, and composite walkability indices were more frequently associated with active transportation as an outcome, with inconclusive evidence around weight as an outcome; and land use mix was not as strong an independent variable as the other three. Walking for transport was the outcome variable with the most consistent evidence for an association with built environment. The authors noted that most studies were in the United States, with a need to replicate studies in other countries and improve comparability of GIS-based measures of walkability (Grasser et al., 2013).

Two articles were found that reviewed other systematic reviews (Dixon et al., 2021; Saelens & Handy, 2008). Saelens and Handy (2008) reviewed both systematic reviews as well as individual studies on the topic of built environment characteristics correlated with walking behavior. The authors concluded that despite a lack of prospective studies to establish a causal link, the correlations seen in cross-sectional studies provided compelling evidence for the causative role of built environment influencing walking and should be considered a strong evidence base to support built environment policy change to improve physical activity (Saelens & Handy, 2008). The reviews found evidence that greater mixed land use, proximity to destinations, population density, aesthetic qualities, safety, sidewalks, and street connectivity were all correlated with walking; with differences in which qualities influenced walking for exercise and transportation (Saelens & Handy, 2008). The authors recommended the development of better conceptual models and greater specificity in behaviors and environments being studied.

Dixon et al. (2021)'s scoping review of reviews synthesized results from existing reviews of the association between built environment and diet, physical activity, and weight. Across 74 studies, findings were mixed, but higher levels of physical activity were associated with higher levels of walkability overall (Dixon et al., 2021). The authors suggested improving future research quality through longitudinal rather than cross-sectional studies, and that the field should come to a consensus around how to define and measure the built environment (Dixon et al., 2021).

In response to the preponderance of evidence on this topic in the US and Australia, the systematic review by Van Holle et al. (2012) summarized European studies on the relationship between built environment and physical activity in adults. The authors reviewed 70 articles (from 66 study samples) and found a positive relationship between different types of physical activity and walkability; access to shops, services, and workplaces; and a composite index of environmental quality (Van Holle et al., 2012). The included studies were located most frequently in the United Kingdom, Belgium, and the Netherlands, with data from 27 countries overall. Outcome measures included total physical activity, leisure time physical activity, total walking and cycling, recreational walking and cycling, general active transportation, walking for transportation, and cycling for transportation. 11 studies (including Sundquist et al., 2011, Van Dyck et al., 2009, and Van Dyck et al., 2010) looked at the outcome of walking for transportation and found evidence for physical environment correlations of walkability.

The systematic review by Hilland et al. (2020) looked at socioeconomically disadvantaged adults and correlates of walking. 35 studies were included, mostly in the United States as well as Scotland, Australia, and Canada; all studies assessed outcomes of overall walking, leisure-time walking, and walking for transportation. The authors found positive associations between these outcomes and various socioeconomic measurements. Objective and perceived walkability and perceived safety were associated with walking for transportation (Hilland et al., 2020). The authors suggested a need for more longitudinal studies in this area.

Farkas et al. (2019) conducted a systematic review of associations between objectively measured built environment and walking in Canadian adults, finding 25 articles. One conclusion was that overall walkability and land use mix were associated with transportation walking (Farkas et al., 2019).

Three studies looked at built environment and older adults (Barnett et al., 2017; Cerin et al., 2017; Rachele et al., 2019). Barnett et al. (2017) conducted a systematic review and meta-analysis of associations between built environment and physical activity of older adults. The study reviewed 100 articles and found 26 environmental attributes that were significantly positively correlated with physical activity. The strongest associations included walkability, safety from crime, access to destinations, recreational facilities, parks, commercial destinations, greenery and aesthetics, walk-friendly infrastructure, and public transport (Barnett et al., 2017).

Cerin et al. (2017) conducted a systematic review of correlations between perceived and objective physical environment and older adults' active travel, with a meta-analysis of 42 studies. More studies were in North America than any other continent, followed by Europe, Asia, Oceania, South America, and Africa. Neighborhood physical environment characteristics of the studies included residential density, walkability, street connectivity, access to services and destinations, pedestrian and cycling infrastructure, aesthetics, and safety and traffic; outcomes were walking for transport (within the neighborhood and any amount), combined walking and cycling for transport, and cycling for transport (Cerin et al., 2017). Walking for transportation was the most frequently assessed outcome and the authors found adequate evidence of a positive association between that and density, walkability, connectivity, access to services and destinations, land use mix, and pedestrian features; with more limited correlations between built environment characteristics and cycling for transportation and combined active transportation.

Rachele et al. (2019)'s systematic review of 23 articles looked at associations between built environment (measurement included walkability, residential density, street connectivity, land use mix, public transport, pedestrian infrastructure, aesthetics, safety and traffic) and physical function (typically objective and self-reporting ability to perform certain tasks) among middle aged and older adults. The authors concluded that the strongest evidence was for a positive association between pedestrian infrastructure and aesthetics with physical function; with weaker evidence for land use mix, safety from crime, and traffic; and a lack of adequate information for walkability, density, connectivity, and public transport (Rachele et al., 2019). Most studies were in the United States, with one study each from Australia, the United Kingdom, Germany, Ireland, Netherlands, Brazil, Finland, Japan, and Sweden.

The study by Yang et al. (2021) reviewed recent literature (13 studies) that looked at the association between walkability and weight behaviors or outcomes in children. Evidence was split, with eight studies finding a positive association between walkability and physical activity and weight, while five did not. This study examined how and why different walkability indices were used and suggestions for use in research. The authors found that most studies used subjective indices, either the Neighborhood Environment Walkability Scale for Youth (NEWS-Y), or some components (nine to choose from) of that scale, plus one study used Walk Score (an objective measurement of walkability), and one the density of various community and streetscape amenities around a school (Yang et al., 2021). Outcomes included physical activity, physical fitness, active transportation, BMI, and body fat.

These systematic reviews provide a broad overview of the state of research surrounding systematic literature reviews on built environment and health behavior. While several reviews researched similar questions to the present one, including a focus on walkability indices, non-developing country locations, active transportation and walking outcomes, and adult populations, none answered the exact question of this systematic review. Many authors of the reviews pointed to a need for consensus around how walkability is measured in studies assessing associations between built environment and physical activity, especially when research is trying to elucidate a causal pathway and link between the two. Brief descriptions of reviewed studies are summarized in the following Table 1.

Table 1: Reviews of Similar Topics

Study	Number of articles	Location	Outcomes
Barnett et al. 2017	100 studies	Australia, Belgium, Brazil, Canada, China, Colombia, Czech Republic, Poland, Slovakia, Hong Kong, China, Iceland, Iran, Ireland, Japan, Lithuania, Malaysia, Netherlands, Norway, Singapore, South Africa, South Korea, Thailand, United Kingdom, United States	26 environmental attributes significantly positively correlated with physical activity. Strongest associations for walkability, safety from crime, access to destinations, recreational facilities, parks, commercial destinations, greenery and aesthetics, walk-friendly infrastructure, and public transport.
Cerin et al. 2017	42 studies	North America, Europe Asia, Oceania, South America, Africa (countries not named)	Walking for transportation was most frequently assessed outcome. Evidence of a positive association between that and density, walkability, connectivity, access to services and destinations, land use mix, and pedestrian features. More limited correlations between built environment characteristics and cycling for transportation and combined active transportation.
Dixon et al. 2021	(Review of reviews) 74 articles	Most evidence from United States	Higher levels of physical activity were associated with higher levels of walkability.
Farkas et al. 2019	25 studies	Canada	Overall walkability and land use mix were associated with transportation walking.
Grasser et al. 2013	19 projects, 34 articles	Most in United States, others not reported	Population density, intersection density, and composite walkability indexes were more frequently associated with active transportation as an outcome, with inconclusive evidence around weight as an outcome. Walking for transport was the outcome variable with the most consistent evidence for an association with built environment.

Study	Number of articles	Location	Outcomes
Hilland et al. 2020	35 studies	United States, Scotland, Australia, Canada	Objective and perceived walkability, and perceived safety, were associated with walking for transportation.
Mayne et al. 2015	37 studies	United States, Australia, United Kingdom, Canada, Chile, and New Zealand	For interventions related to physical activity, stronger associations were seen around active transportation improvements as well as studies with a longer time to follow up. The greatest effects were seen from nutrition interventions, with limited evidence around BMI.
McCormack & Shiell 2011	33 studies	United States, Canada, Australia, United Kingdom, Netherlands	Land use mix, connectivity, and population density were the most important determinants of physical activity. Built environment was more strongly associated with transportation walking than any other type of physical activity.
Rachele et al. 2019	23 studies	United States, Australia, United Kingdom, Germany, Ireland, Netherlands, Brazil, Finland, Japan, and Sweden.	Strongest evidence was for a positive association between pedestrian infrastructure and aesthetics with physical function. Weaker evidence for land use mix, safety from crime, and traffic. Lack of adequate information for walkability, density, connectivity, and public transport.
Saelens & Handy 2008	(Review of reviews) 29 articles	United States, Australia, Portugal, Belgium, and the Netherlands	Increasingly mixed land use, proximity to destinations, population density, aesthetic qualities, safety, sidewalks, and street connectivity were all correlated with walking. Differences in which qualities influenced walking for exercise and transportation.

Study	Number of articles	Location	Outcomes
Smith et al. 2017	28 studies	United States, Australia, Belgium, England, Scotland, New Zealand	Positive association between street walkability components, parks and playground, and active transportation infrastructure on active transportation, physical activity, and use of community amenities. Some evidence that built environment improvements might benefit wealthier and white residents more than lower income and minority residents.
Van Holle et al. 2012	70 articles from 66 study samples	United Kingdom, Belgium, the Netherlands, Spain, Portugal, Germany, Sweden, Italy, France, Switzerland, Finland, Slovakia, Hungary, Czech Republic, Austria, Lithuania, Greece, Denmark, Croatia, Ukraine, Turkey, Poland, Luxembourg, Ireland, Georgia, Estonia, Bosnia-Herzegovina	Positive relationship between different types of physical activity and walkability, access to shops/services/work, and a composite index of environmental quality
Yang et al. 2021	13 studies	United States, Spain, United Kingdom, Canada, New Zealand, Germany, Malaysia.	Evidence was split, with eight studies finding a positive association between walkability and physical activity and weight, while five did not. Most studies used subjective indices of walkability.

Chapter 3 – Project Content

METHODS

Introduction

This systematic review researched indices of walkability used in studies examining associations between walkability and walking for transportation, among adults in non-developing countries. Methodology of conducting and analyzing the research results follows.

Search strategy

Between January 19th and January 24th, 2021, the databases PubMed, Embase, Web of Science, and Scopus were searched with a list of key words related to walkability and physical activity, developed with the assistance of an advisor and a research librarian. All articles indexed in these databases were eligible for screening provided they had one of the below key words in their title, abstract, or subject descriptions. Articles published at any date were eligible for inclusion.

"Pedestrian infrastructure"
"Smart pedestrian infrastructure"
smart and "pedestrian infrastructure"
"walkable street"
walkable street
"walkable environment"
"walkability assessment"
"walkability metrics"
"pedestrian planning"
"physical activity" and "neighborhoods"
"physical activity barriers"
"walkability indicators"
"neighborhood walkability"
"walkability methods"
"walkability predictors"
"walkability predictor"
walkability and health
"walkability" and "urban planning"
neighborhood and walkability

Study Selection

Title and abstract screening: Studies were downloaded to Covidence and duplicates were automatically removed. Articles eligible for title and abstract screening were read by the author. Exclusion criteria applied during this stage were: 1) The article was not related to measuring walkability of streets. 2) The location was in a developing country, based on the 2014 United Nations classification (United Nations, 2014). 3) The article was not an original single study (exclusions included literature reviews, meta-analyses, discussion articles, and conference proceedings). 4) The article's primary independent variable was not walkability (for example, adjusting for walkability, but not directly examining walkability) 5) A walkability index was not defined. Many studies measured various components of walkability separately, like street connectivity and residential density, but did not develop or use a singular index of walkability. 6) The article was a study plan or protocol. 7) The article was a description of a method or tool development but not a research study. 8) The article was a reliability or validation study. 9) The article was not a study measuring a health outcome or behavior. 10) This was a duplicate article to another already screened and included.

Full text review: The research question and exclusion criteria were further refined to narrow the scope of the literature review and answer a specific and defined research question: how walkability is measured in studies looking at the association between walkability and active transportation in adults in non-developing countries. The additional exclusion criteria were: 1) The outcome was not related to walking for transportation (also known as utilitarian walking). 2) The population was pediatric. 3) The study examined a population with a certain health condition rather than generally representative health profiles. Old age of population was not an exclusion criterium. 4) A subjective (as opposed to objective) walkability index was used, such as the

Neighborhood Environment Walkability Scale (Nichani et al., 2019) or original subjective index (Zuniga-Teran et al., 2017). While generally good concordance may exist between some subjective and objective measures of walkability, the ability to distinguish the influences of the two is beyond the scope of this review. Objective walkability was chosen as the focus of this review.

Population/Participants: Study participants had to be adults (non-pediatric population, generally defined as above age 18). Because children and adult may interact with and be influenced by the built environment very differently, the articles were restricted to adult populations. They could not be classified or selected based on having a health condition (articles focused on older adults were allowed, but not any other specific physical or mental condition - for example, mobility impairment, type 2 diabetes, depression). Additionally, the study had to in a non-developing country based on 2014 United Nations classification (United Nations, 2014). This criterium was added because of differences in road design between countries with road networks designed primarily for automobiles versus pedestrian traffic (developing countries).

Intervention: The intervention had to be measuring objective street walkability and include a specific walkability index, whether pre-existing or created by the authors, not just different types of walkability measurements. Additionally, walkability had to be assessed objectively (for example, street audit and GIS), not subjectively (like a resident survey about perceptions of their neighborhood environment).

Outcome: The outcome had to be walking for transportation (defined variously as purposive or utilitarian walking). Other forms of physical activity (such as overall physical activity, walking for recreation, bicycling, and running) did not meet inclusion criteria. This outcome was narrowed down during the iterative process of abstract screening; the original inclusion outcome was any health outcome, further narrowed down to walking for any purpose, active transportation, and finally, walking for transportation, to answer a specific and defined research question.

Study Design: Included articles were observational studies (most likely, given nature of research, a cross-sectional study, along with some cohort studies) but could not be a systematic review, literature review, or meta-analysis. Research protocols, descriptions of tools, reliability/validation, discussion articles, and conference proceedings were also not accepted.

Data Extraction: Data from the eligible studies was extracted using Covidence extraction software. Information that was extracted included study details (author names, institutions, city and country of study, and sponsorship source); study design methods; description of study population; intervention features (description of walkability index used); and outcome (odds ratio, mean, or beta coefficient of walking for transport).

Quality and Risk of Bias Assessments

Studies were assessed for quality and risk of bias using the NIH Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (National Institutes of Health, 2014). This tool is suitable for evaluating cohort and cross-sectional studies, which is the type of study that all 28 studies included for review were.

The 14 questions evaluated in this quality assessment tool were: 1) Was the research question or objective in this paper clearly stated? 2) Was the study population clearly specified and defined? 3) Was the participation rate of eligible persons at least 50%? 4) Were all the subjects selected or recruited from the same or similar populations (including the same time-period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants? 5) Was a sample size justification, power description, or variance and effect estimates provided? 6) For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured? 7) Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed? 8) For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)? 9) Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants? 10) Was the exposure(s) assessed more than once over time? 11) Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants? 12) Were the outcome assessors blinded to the exposure status of participants? 13) Was loss to follow-up after baseline 20% or less? 14) Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?

If the answer to a question was “yes,” then the risk of bias was labeled as “low.” If the answer to a question was “no,” then the risk of bias was labeled as “high.” Non-applicable questions for any given study were also marked as low risk of bias. If the answer was unclear (typically the issue was not addressed in the article), the risk of bias was labeled as unclear. Table 2, found at the end of Chapter 3, contains results of all quality assessments. Studies with a low risk of bias or unknown answer to any question were assigned a score of zero, while studies with a higher risk of bias were assigned a score of one. Summations of scores for each study yielded a comparative bias across all 28 studies. 12 studies had a score of zero, 13 had a score of one, and three had a score of two, indicating generally low risk of bias across all studies using the NIH tool.

Question 3, “Was the participation rate of eligible persons at least 50%?” was the question most likely to lead to risk of bias, with 10 studies having less than 50% participation of eligible persons. Question 6, “For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?” was the second most likely to lead to risk of bias, with four studies indicating risk of bias for this question; however, there was also a high volume of unknown studies in this area, as most studies (n = 16) did not report the order in which walkability and active transportation were assessed. This question may not be particularly relevant since most studies were cross-sectional. The question with the highest number of studies marked “unclear” was Question 12: “Were the outcome assessors blinded to the exposure status of participants?”: 24 studies were unclear. Question 10, “Was the exposure(s) assessed more than once over time?” had 19 studies that were unclear; the answer for most studies is likely no, but the methods in which exposures were assessed were not described thoroughly enough to create a determination.

RESULTS

Results of Article Screening

The initial search returned 19,337 articles (PubMed (n = 3,892), Embase (n = 3,740), Web of Science (n = 5,850), and Scopus (n = 5,855). 13,363 were removed automatically by Covidence as duplicates. 5,974 articles were eligible for screening. These articles first went through screening by title and abstract by one reviewer. Of 5,974 studies screened for inclusion, 4,920 were excluded for the reasons listed below. Coding of articles during title/abstract screening did not begin until the first 860 articles were screened, so approximately 17.5% of articles in the initial screening do not have reason for exclusion listed.

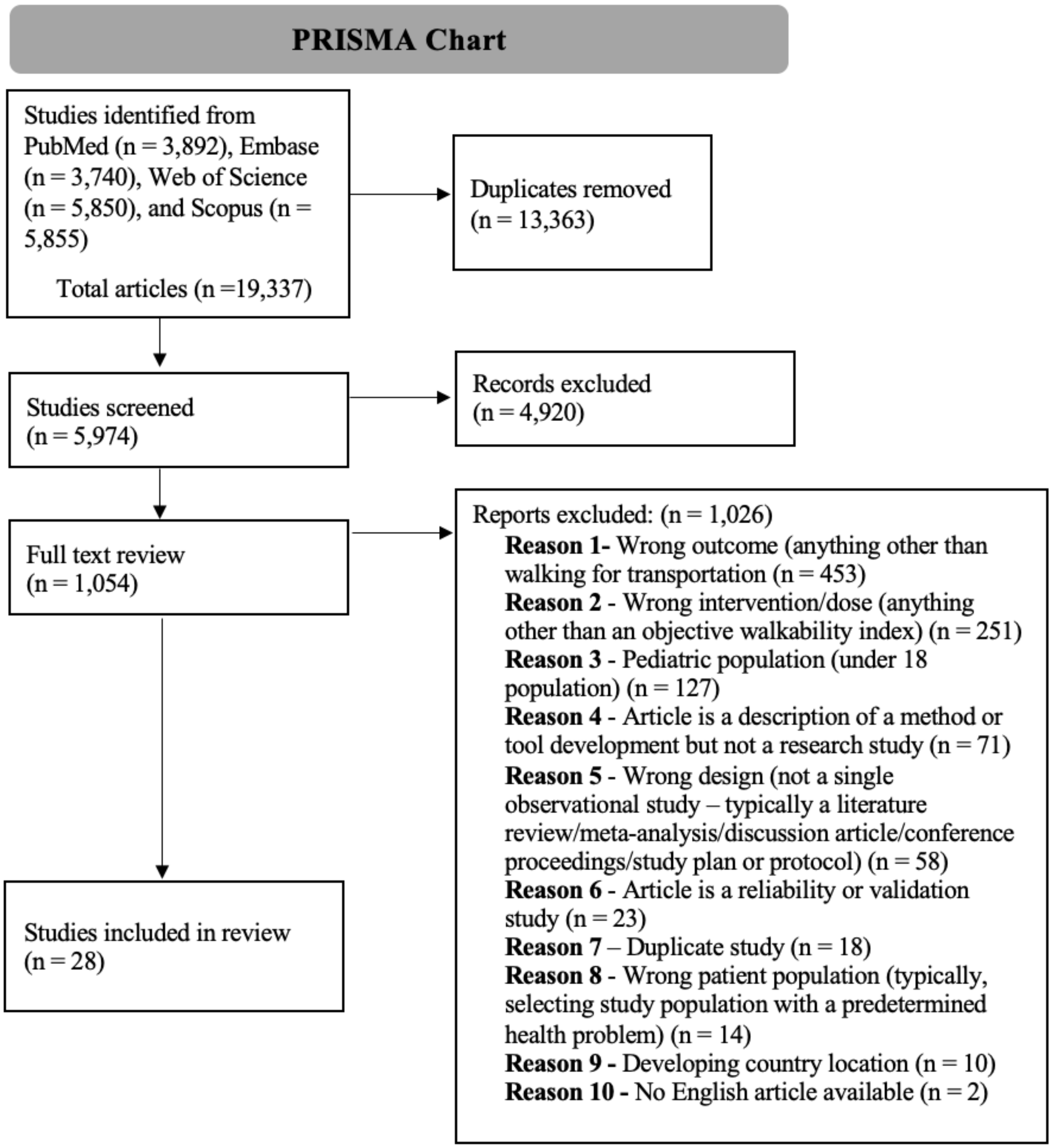
- **2838** - Article not related to measuring walkability of streets
- **566** - Developing country location
- **274** - Article was a literature review, meta-analysis, discussion article, or conference compilation
- **27** - Independent variable did not look directly at walkability
- **15** - Walkability index never clearly defined
- **25** - Article was a study plan or protocol
- **99 -** Article was a description of a method or tool development
- **34** - Article was a reliability or validation study
- **151** - Not a study measuring a health outcome or behavior
- **8** - Duplicate article

Full text review: 1,054 articles were available for full text review. The research question and inclusion/exclusion criteria were further narrowed down to arrive at a defined question to answer. 28 articles were included in the final data extraction phase and systematic review, and 1,026 articles were excluded for the following reasons:

- **453** - Wrong outcome (anything other than walking for transportation)
- **251** - Wrong intervention/dose (anything other than an objectively assessed walkability index)
- **127** - Pediatric population (under 18 population)
- **71** - Article was a description of a method or tool development but not a research study
- **57** - Wrong design (not an observational study – typically a literature review/meta-analysis/discussion article/conference proceedings/study plan or protocol)
- **23** - Article was a reliability or validation study
- **18** – Duplicate study
- **14** - Wrong patient population (typically, selecting study population with a predetermined health problem)
- **10** - Developing country location
- **2** - No English article available

See Figure 1, below, for the PRISMA chart of all articles included and excluded in this study.

Figure 1: PRISMA Chart



Study Characteristics

A total of 28 studies met all eligibility criteria. See Table 3 at the end of Chapter 3 for all relevant extracted data. 11 studies were in Canada, in metropolitan areas across British Columbia (Barnes et al., 2016), urban and suburban Ontario (Chiu et al., 2015), metropolitan Vancouver

(Chudyk et al., 2017), Atlantic Canada, Quebec, Ontario, the Prairies, British Columbia (Hajna et al., 2015), Calgary (Jack & McCormack, 2014; McCormack et al., 2012; McCormack et al., 2017; Salvo et al., 2018), urban areas across Canada (Thielman et al., 2015), and Canada-wide (Wasfi et al., 2016, Wasfi et al., 2017). Seven studies were in the United States, in Miami-Dade County (Brown et al., 2013); Baltimore, Chicago, Forsyth County (North Carolina), Los Angeles, New York City, and St. Paul (Hirsch et al., 2013; Hirsch et al., 2014), the San Francisco Bay Area and Greater Chicago (Kelley et al., 2016), St. Louis County (Kelly et al., 2015), and across the United States (Tuckel & Milczarski, 2015; Watson et al., 2020). Four studies were in Australia, in southeast Queensland (Cole et al., 2015), Adelaide (Owen et al., 2007; Shimura et al., 2012), and Perth (Pikora et al., 2006). Three studies were in Belgium, in Ghent (Van Dyck et al., 2010, Van Holle et al., 2014), and in Sint-Niklaas (Van Dyck et al., 2009). Two studies were in Sweden, both in Stockholm (Arvidsson et al., 2012; Sundquist et al., 2011). One study was in Japan, in Nerima Ward (part of Tokyo Metropolitan Area) and Kanuma City (a rural area 120 km from Tokyo) (Koohsari et al., 2018).

Studies were either cross-sectional (n = 23) or a cohort study (n = 5) in design. Cross-sectional studies were Arvidsson et al. (2012), Barnes et al. (2016), Brown et al. (2013), Chiu et al. (2015), Chudyk et al. (2017), Cole et al. (2015), Hajna et al. (2015), Hirsch et al. (2013), Jack & McCormack (2014), Kelley et al. (2016), Kelly et al. (2015), Koohsari et al. (2018), McCormack et al. (2012), Owen et al. (2007), Pikora et al. (2006), Salvo et al. (2018), Sundquist et al. (2011), Thielman et al. (2015), Tuckel & Milczarski (2015), Van Dyck et al. (2010), Van Dyck et al. (2009), Van Holle et al. (2014), and Watson et al. (2020). Cohort studies were Hirsch et al. (2014), McCormack et al. (2017), Shimura et al. (2012), Wasfi et al. (2016), and Wasfi et al. (2017).

All studies had objectively assessed neighborhood walkability as the independent variable of interest. All studies had transport-related walking as the outcome, which was also defined in terms like "utilitarian walking" and "purposive walking."

Intervention Measures: Walkability Indices

The primary purpose of this systematic review was to determine which walkability indices were used in studies assessing the link between objective neighborhood walkability and transport-related walking. 16 studies used the Walk Score, also known as the "Street Smart Walk Score" (Barnes et al., 2016; Brown et al., 2013; Chiu et al., 2015; Chudyk et al., 2017; Cole et al., 2015; Hajna et al., 2015; Hirsch et al., 2013; Hirsch et al., 2014; Kelley et al., 2016; Koohsari et al., 2018; McCormack et al., 2017; Salvo et al., 2018; Thielman et al., 2015; Tuckel & Milczarski, 2015; Wasfi et al., 2016; Wasfi et al., 2017). Eight studies used variations of the GIS-derived walkability index developed by Lawrence Frank (Arvidsson et al., 2012; Hajna et al., 2015; Kelly et al., 2015; Owen et al., 2008; Shimura et al., 2012; Sundquist et al., 2011; Van Dyck et al., 2010; Van Holle et al., 2014). Two studies used cluster-derived walkability from geocoded postal codes (Jack & McCormack, 2014; McCormack et al., 2012). One study used a Walkability Score derived from the SPACES instrument (Pikora et al., 2006). One study used paper map data on neighborhood connectivity and residential density, further verified through an observational scale based on the Neighborhood Quality of Life Study (NQLS) and Ross Brownson's walkability framework (Van Dyck et al., 2009). One study used the US Environmental Protection Agency's Walkability Index (Watson et al., 2020).

Walk Score: Walk Score is an online tool that measures any address's walkability in the United States, Canada, Australia, New Zealand, and Japan, using a patented system that involves awarding points based on walking distance from a given address to nearby amenities, with a distance-decay function that awards fewer points to amenities further away, with a maximum distance of a 30-minute walk (Walk Score, 2021). Using data sources like Google, Factual, Great Schools, Open Street Map, and the US Census, the Walk Score index also considers measurements like population density, block length, and intersection density. Locations are characterized as Very Car-Dependent if they have a Walk Score between 0-24, Car-Dependent with a Walk Score of 25-49, Somewhat Walkable with a Walk Score of 50-69, Very Walkable with a Walk Score of 70-89, and Walker's Paradise with a Walk Score of 90-100 (Walk Score, 2021). Walk Score is often used in real estate searches but is also a popular measurement in built environment studies and has been validated as an index of neighborhood walkability and access to walkable amenities (Carr et al., 2011; Duncan et al., 2011).

Five studies utilizing Walk Score to measure walkability were in the United States (Brown et al., 2013; Hirsch et al., 2013; Hirsch et al., 2014; Kelley et al., 2016; Tuckel & Milczarski, 2015), nine were in Canada (Barnes et al., 2016; Chiu et al., 2015; Chudyk et al., 2017; Hajna et al., 2015; McCormack et al., 2017; Salvo et al., 2018; Thielman et al., 2015; Wasfi et al., 2016; Wasfi et al., 2017), one was in Australia (Cole et al., 2015), and one was in Japan (Koohsari et al., 2018).

GIS-Derived Walkability – Frank method: Eight studies (Arvidsson et al., 2012; Hajna et al., 2015; Kelly et al., 2015; Owen et al., 2007; Shimura et al., 2012; Sundquist et al., 2011; Van Dyck et al., 2010; Van Holle et al., 2014) used variations of the GIS-derived walkability index developed by Frank and colleagues, with some differences between the studies in which components were included and the relative weights they were assigned. In its original form, the walkability index uses four measurements at the block group level (Frank et al., 2010), with components first proposed in 2003 (Saelens et al., 2003). These measurement are 1) net residential density, indicating the ratio of residential units to the land area zoned for residential use; 2) retail floor area ratio of building floor area divided by land floor area (a proxy for parking space, with a low ratio likely indicating more space for parking, and a high ratio indicating less space for parking); 3) intersection density, which is the ratio of intersections with three or more legs compared to the acreage of the block group, with a higher density indicating shorter walkable routes between destinations; and 4) land use mix, indicating the amount of diversity in land use (uses such as retail, residential, entertainment, workspaces, schools, and community centers). The scores for each of the four components are normalized to z-scores, and the walkability index is the sum of all the z-scores, with double weight given to the intersection density due to its strong influence on travel choices. The original walkability index from Frank et al. (2010) is:

$$\text{Walkability} = [(2 \times \text{z-intersection density}) + (\text{z-net residential density}) + (\text{z-retail floor area ratio}) + (\text{z-land use mix})]$$

The two studies located in Stockholm, Sweden (Arvidsson et al., 2012; Sundquist et al., 2011) used the same walkability index calculation. They included residential density, land use mix, and street connectivity z-score summation to create their index, with street connectivity weighted at 1.5; retail floor area was excluded due to lack of available data. Arvidsson et al. (2012) calculated at the individual level with a 1000-m circular buffer zone around each participants' address, while Sundquist et al. (2011) calculated at the level of Stockholm city administrative unit.

The two Adelaide, Australia studies (Owen et al., 2008; Shimura et al., 2012) used the same walkability index calculation, creating a district level walkability index using residential density, street connectivity, land-use mix, and net retail area. This paper was published before

Frank's 2010 index, though Frank was one of the authors on this paper, and the authors scored each of the four variables from 1-10 based on relative deciles. Each district-level walkability index was the sum of the decile score of each of the four component parts (possible scores ranged from 4 to 40).

The two Ghent, Belgium studies (Van Dyck et al., 2010; Van Holle et al., 2014) used the same walkability index calculation, measuring residential density, intersection density and land use mix at the neighborhood level. Retail floor was excluded due to lack of access and relevance in Belgium. Connectivity was weighted at 2 in the z-score summation. Van Dyck et al. (2010) and Van Holle et al. (2014) both drew data from the Belgian Environmental Physical Activity Study in Ghent, but Van Holle et al. (2014)'s population was adults older than 65 while Van Dyck et al. (2010)'s was adults 20-65 years old.

In St. Louis County, United States, Kelly et al. (2015) calculated the walkability index at the census block group level using net residential density, intersection density, and land-use density, giving double weight to intersection density z-score. An explanation was not given for the exclusion of retail.

In Canada, Hajna et al. (2015)'s approach was slightly different, substituting residential density for population density. The authors calculated the walkability index using 500-m polygonal buffers around the centroid of participants' home postal codes, a good proxy for address in the Canadian context, and variables were land use mix, street connectivity, and population density, with the z-scores summed for index, with no indication of any weighting applied to scores (Hajna et al., 2015).

Cluster-Derived Neighborhood Walkability: Two studies in Calgary, Canada (Jack & McCormack, 2014; McCormack et al., 2012) used a cluster-derived index of neighborhood walkability. Using participant postal code as a proxy for address (typically accurate within 200-500 m in Canada), the studies identified three neighborhood types – low walkable, medium walkable, and high walkable – based on presence of built environment variables including street connectivity (walkshed area), number of businesses, population density, sidewalk density, recreational facilities, green space, transit access, and biking and walking paths. Neighborhoods were placed in three clusters based on the number and density of these built environment attributes contained within. The two-stage cluster analysis had good validity with the three neighborhood walkability designations used in Calgary prior to this index, with high walkability neighborhoods built before World War II and having a grid street pattern with high land use mix, sidewalks, trees, and street connectivity; medium walkability neighborhoods built soon after World War II and having warped-grid street patterns with less pedestrian connectivity, fewer tree-lined main streets, and less land use mix; and low-walkability neighborhoods built in the 1980s-2010s with high-volume connector roads and much less pedestrian walkability due to a "loops and lollipops" street patterns, strips of car-oriented commercial zoning, and few sidewalks.

Walkability Score from SPACES: One study in Perth, Australia used a Walkability Score derived from the SPACES instrument (Pikora et al., 2006), with additional GIS measures added including traffic and destinations like parks and shops. This method involved looking at environment characteristics within a 400-m radius of the participants' home addresses and scoring road segments between 0 and 1 within each radius that contained the characteristics in question. Scores for different features were weighted depending on whether the index was for recreational or transport walking, and the sum of the weighted functional, safety, aesthetic, and destination element scores created the walkability index. Elements for the transit walkability index included the functional elements of walking surface (maintenance, continuity), street width, traffic (volume, speed, control, crossings), and permeability (street pattern, intersection design, intersection distance); safety elements of personal safety (lighting, surveillance) and traffic safety (street crossing safety); aesthetic elements of trees, garden and street maintenance, cleanliness, parks; and destination elements of parks, shops, services, public transport, and parking (Pikora et al., 2006).

Paper Maps, NQLS, and Brownson Framework: One study (Van Dyck et al., 2009) in Sint-Niklaas, Belgium first used paper map data on neighborhood connectivity and residential density to select one high and low walkable neighborhood, and then validated this selection with an observational scale based on the Neighborhood Quality of Life Study (NQLS) and Brownson et al. (2004), calculated within an 800-meter radius around each participant's address. The authors employed field observations of street connectivity, land use mix diversity and access, aesthetics, transportation, and traffic safety; and found good concordance between the original and new measures of walkability, with the high walkability neighborhood having shorter distances from residential addresses to other locations for commerce, reaction, and education; more stores, residences, schools, and facilities, intersections, green spaces, trees, benches, bus stops, bike lanes, sidewalks, crosswalks, traffic lights, and the presence of a train station, compared to the low walkability neighborhood (Van Dyck et al., 2009).

EPA Walkability Index: One study (Watson et al., 2020) used the US Environmental Protection Agency's Walkability Index, calculated at the block group level. The EPA Walkability Index incorporates design, distance, and diversity indicators, with equal weight given to measurements of intersection density, proximity to transit, and land use diversity (employment and residence mix) (Thomas & Zeller, 2017). Each block group was divided into

20 quantiles for each indicator and assigned a corresponding score from 1 to 20 based on low to high values of each indicator, with a score of 20 for the highest relative walkability score. Scores for each indicator were weighted (1/3 weight for intersection density, 1/3 weight for proximity to transit, 1/6 weight for employment mix, 1/6 weight for housing and employment mix) and summed to create a Walkability Index score for each block group ranging from 1 to 20. Block groups with a score from 1-5.75 were "least walkable," 5.76-10.5 were "below average walkable," 10.51-15.25 were "above average walkable," and 15.26-20 were "most walkable" (Watson et al., 2020).

Outcome Measures: Walking for Transportation

All studies assessed the outcome of walking for transportation. Outcome measures included minutes of walking, odds of transportation walking or surpassing a certain time domain of transportation walking, and calories expended in transportation walking. Results are presented by Walkability Index below with further details in Table 3 at the end of Chapter 3.

Walk Score: The five studies in the United States that used a Walk Score index found a positive association between Walk Score 10-point increase and higher odds of walking for transportation (Brown et al., 2013), lower odds of not walking for transportation (Hirsch et al., 2013; Tuckel & Milczarski, 2015), more minutes per week of transportation walking (Brown et al., 2013; Hirsch et al., 2013; Hirsch et al., 2014; Kelley et al., 2016), and higher odds of walking for 150 minutes or more per week for transportation (Hirsch et al., 2014). An association was also seen between living in the most car-dependent neighborhoods and having fewer minutes per week of transportation walking and increased odds of not walking for transportation at all (Hirsch et al., 2013).

The nine studies in Canada that used a Walk Score index found a positive association between Walk Score 10-point or quartile increase and higher odds of walking for transportation (Barnes et al., 2016; Chudyk et al., 2017; Hajna et al., 2015; Wasfi et al., 2016; Wasfi et al., 2017) and increased calories burned via transportation walking (Thielman et al., 2015). An association was also seen between living in more car-dependent neighborhoods and increased odds of not walking for transportation for at least an hour per week (Chiu et al., 2014) and less overall transportation walking (McCormack et al., 2017; Salvo et al., 2018).

The one study using Walk Score in Australia (Cole et al., 2015) found that residents of every Walk Score category higher than "Very Car Dependent" had increased odds of walking for transport to or from home for 30 minutes or more on the day of the survey, while the study in Japan found a 10-point Walk Score increase to be associated with higher odds of any commute and errands walking in the past week, and of walking for 150 minutes or more for commuting and errands (Koohsari et al., 2018).

GIS-Derived Walkability – Frank method: The two Swedish studies found that high neighborhood walkability was associated with more minutes per week of walking for transportation (Arvidsson et al., 2012; Sundquist et al., 2011) and higher odds of transportation walking (Sundquist et al., 2011). The two Australian studies found that high walkability was associated with higher frequency of walking for transportation (Owen et al., 2007) and that minutes per day of transportation walking declined less over a 4-year period among residents of a high walkability neighborhood compared to a low walkability neighborhood (Shimura et al., 2012). The two Belgian studies found that high neighborhood walkability was associated with more minutes per week of walking for transportation (Van Dyck et al., 2010; Van Holle et al., 2014) compared to low neighborhood walkability. The study in the United States found an association between a higher walkability quartile and increased odds of walking to work (Kelly et al., 2015), and the study in Canada found an association between higher walkability quartiles and increased odds of an hour or more a week of utilitarian walking (Hajna et al., 2015).

Cluster-Derived Neighborhood Walkability: Two studies in Calgary, Canada (Jack & McCormack 2014; McCormack et al., 2012) found that residents in medium and high walkable neighborhoods had increased odds of 10 minutes or more of neighborhood-based transport walking per week (both studies), and 150 minutes or more of transport walking per week (McCormack et al., 2012), compared to residents of low walkable neighborhoods.

Walkability Score from SPACES: The Australian study using the SPACES walkability score found that residents of medium and high walkability neighborhoods had increased odds of walking for transportation in the last two weeks (Pikora et al., 2006).

Paper Maps, NQLS, and Brownson Framework: The Belgian study found that high neighborhood walkability was associated with more minutes per week of neighborhood-based transportation walking (Van Dyck et al., 2009).

EPA Walkability Index: The United States study found that a higher EPA National Walkability Index was associated with higher odds of walking for transportation. There was also a positive relationship between Walkability Index category and minutes per week of transportation walking among walkers (Watson et al., 2020).

Table 2: Quality Assessment

Study	1. Was the research question or objective in this paper clearly stated?	2. Was the study population clearly specified and defined?	3. Was the participation rate of eligible persons at least 50%?	4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?	5. Was a sample size justification, power description, or variance and effect estimates provided?
Arvidsson 2012	low	low	high	low	low
Barnes 2016	low	low	low	low	low
Brown 2013	low	low	high	low	low
Chiu 2015	low	low	low	low	low
Chudyk 2017	low	low	high	low	unclear
Cole 2015	low	low	unclear	low	unclear
Hajna 2015	low	low	low	low	low
Hirsch 2013	low	low	low	low	low
Hirsch 2014	low	low	low	low	low
Jack 2014	low	low	high	low	low
Kelley 2016	low	low	unclear	low	low
Kelly 2015	low	low	low	low	low
Koohsari 2018	low	low	high	low	low
McCormack 2012	low	low	high	low	low
McCormack 2017	low	low	high	low	low
Owen 2007	low	low	high	low	low
Pikora 2006	low	low	unclear	low	low
Salvo 2018	low	low	low	low	low
Shimura 2012	low	low	high	low	low
Sundquist 2011	low	low	low	low	low
Thielman 2015	low	low	low	low	low
Tuckel 2015	low	low	unclear	low	low
Van Dyck 2010	low	low	unclear	low	low
Van Dyck 2009	low	low	high	low	low
Van Holle 2014	low	low	low	low	low
Wasfi 2016	low	low	low	low	low
Wasfi 2017	low	low	unclear	low	low
Watson 2020	low	low	low	low	low

Study	6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?	7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?	8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?	9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
Arvidsson 2012	unclear	low	low	low
Barnes 2016	unclear	low	low	low
Brown 2013	unclear	low	low	low
Chiu 2015	unclear	low	low	low
Chudyk 2017	unclear	low	low	low
Cole 2015	unclear	low	low	low
Hajna 2015	unclear	low	low	low
Hirsch 2013	unclear	low	low	low
Hirsch 2014	unclear	low	low	low
Jack 2014	unclear	low	low	low
Kelley 2016	unclear	low	low	low
Kelly 2015	low	low	low	low
Koohsari 2018	unclear	low	low	low
McCormack 2012	unclear	low	low	low
McCormack 2017	low	low	low	low
Owen 2007	unclear	low	low	low
Pikora 2006	high	low	low	low
Salvo 2018	low	low	low	low
Shimura 2012	low	low	low	unclear
Sundquist 2011	low	low	low	low
Thielman 2015	unclear	unclear	low	low
Tuckel 2015	unclear	low	low	low
Van Dyck 2010	low	low	low	unclear
Van Dyck 2009	low	low	low	low
Van Holle 2014	low	low	low	unclear
Wasfi 2016	high	low	low	low
Wasfi 2017	high	low	low	low
Watson 2020	high	low	low	unclear

Study	10. Was the exposure(s) assessed more than once over time?	11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	12. Were the outcome assessors blinded to the exposure status of participants?	13. Was loss to follow-up after baseline 20% or less?	14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?
Arvidsson 2012	low	low	low	low	low
Barnes 2016	high	unclear	unclear	low	low
Brown 2013	low	low	unclear	low	low
Chiu 2015	unclear	unclear	unclear	low	low
Chudyk 2017	unclear	low	unclear	low	low
Cole 2015	unclear	unclear	unclear	low	low
Hajna 2015	unclear	low	unclear	low	low
Hirsch 2013	unclear	low	unclear	low	low
Hirsch 2014	unclear	unclear	unclear	low	low
Jack 2014	unclear	low	unclear	low	low
Kelley 2016	unclear	unclear	unclear	low	low
Kelly 2015	unclear	low	low	low	low
Koohsari 2018	low	low	unclear	low	low
McCormack 2012	unclear	low	unclear	low	low
McCormack 2017	unclear	low	unclear	low	low
Owen 2007	unclear	low	unclear	low	low
Pikora 2006	unclear	unclear	unclear	low	low
Salvo 2018	low	low	low	low	high
Shimura 2012	unclear	low	unclear	high	low
Sundquist 2011	unclear	low	unclear	low	low
Thielman 2015	low	unclear	unclear	low	low
Tuckel 2015	low	unclear	unclear	low	low
Van Dyck 2010	unclear	low	unclear	low	low
Van Dyck 2009	high	low	unclear	low	low
Van Holle 2014	unclear	low	unclear	low	low
Wasfi 2016	unclear	unclear	low	low	low
Wasfi 2017	low	unclear	unclear	high	low
Watson 2020	unclear	unclear	unclear	unclear	low

Study	Cumulative Bias Score
Arvidsson 2012	1
Barnes 2016	1
Brown 2013	1
Chiu 2015	0
Chudyk 2017	1
Cole 2015	0
Hajna 2015	0
Hirsch 2013	0
Hirsch 2014	0
Jack 2014	1
Kelley 2016	0
Kelly 2015	0
Koohsari 2018	1
McCormack 2012	1
McCormack 2017	1
Owen 2007	1
Pikora 2006	1
Salvo 2018	1
Shimura 2012	2
Sundquist 2011	0
Thielman 2015	0
Tuckel 2015	0
Van Dyck 2010	0
Van Dyck 2009	2
Van Holle 2014	0
Wasfi 2016	1
Wasfi 2017	2
Watson 2020	1

Table 3: Overview of Studies

Study	Location	Demographics	Number	Study Design	Walkability Index	Results
Arvidsson et al. 2012	Sweden - Stockholm	20-66 years old	1925	Cross-Sectional	GIS Frank	High neighborhood walkability was associated with 35 more minutes per week (95% CI = 14.6, 64.6) of walking for transportation than low neighborhood walkability.
Barnes et al. 2016	Canada - metropolitan British Columbia	45 years and older	3860	Cross-Sectional	Walk Score	A 10- point Walk Score increase was associated with 34% higher odds (OR 1.34, 95% CI = 1.23, 1.47) of walking for transport in the last month.
Brown et al. 2013	United States - Miami-Dade County	30-45 years old, Recent Cuban immigrants (within last 4 months)	391	Cross-Sectional	Walk Score	A 10-point Walk Score increase was associated with 18.5% higher odds (OR 1.185, 95% CI = 1.043, 1.347) of engaging in purposive walking in the last week, and a 27% increase in the minutes of purposive walking in the past week (0.103 log10-minutes, SE 0.033).
Chiu et al. 2015	Canada - urban/suburban Ontario	20 and older	106,337	Cross-Sectional	Walk Score	Compared to residents living in the highest Walk Score category of "Walker's Paradise," the odds of utilitarian walking for at least an hour per week were lower in every other Walk Score category (ORs 0.68 in "Very Walkable," 0.62 in "Somewhat Walkable," 0.54 in "Car Dependent," 0.53 in "Very Car Dependent").
Chudyk et al. 2017	Canada - metro Vancouver	65 and older	161	Cross-Sectional	Walk Score	A 10-point Walk Score increase was associated with 45% higher odds (OR 1.45, 95% CI 1.18, 1.78) of walking for transportation in a typical week in the last four weeks.
Cole et al. 2015	Australia - southeast Queensland	18 to 64 years old	16,944	Cross-Sectional	Walk Score	Compared to residents of the least walkable Walk Score category, "Very Car Dependent," residents of all other categories had increased odds of walking for transport to or from home for 30 minutes or more on the day of the survey. (ORs 1.07 in "Car Dependent," 1.4 in "Somewhat Walkable," and 2.04 in "Highly Walkable (combination of Walker's Paradise and Very Walkable))

Study	Location	Demographics	Number	Study Design	Walkability Index	Results
Hajna et al. 2015	Canada - Atlantic Canada, Quebec, Ontario, the Prairies, British Columbia	18 years and older	5605	Cross-Sectional	Walk Score, GIS Frank	Comparing each walkability quartile (both GIS-derived walkability and Walk Score) to the others, living in higher quartiles was consistently associated with higher odds of more than or equal to one hour a week of utilitarian walking. For the GIS-derived walkability index, living in Quartile 4 compared to Quartile 1 was associated with 66% increased odds of utilitarian walking (OR 1.66, 95% CI 1.31, 2.11), while the same comparison for walk score was associated with 100% higher odds (OR 2.0, 95% CI 1.57, 2.54). Similar although less pronounced relationships were seen when comparing Quartiles 3 and 2 to Quartile 1 for both indices, although neither Quartile 2 to 1 comparison was statistically significant.
Hirsch et al. 2013	United States - Baltimore MD; Chicago IL; Forsyth County NC; Los Angeles CA; New York NY; and St. Paul MN	45 to 84 years old (baseline)	4552	Cross-Sectional	Walk Score	A 10-point Walk Score increase was associated with 9.01 more minutes per week of transportation walking (95% CI 1.45, 16.62) among those who already walked, and 12% lower odds of not walking for transport (OR 0.88, 95% CI 0.85, 0.92). Living in a "Very Car-Dependent" Walk Score neighborhood, compared to residents of "Walker's Paradise," was associated with 99.77 fewer minutes per week of transportation walking (95% CI -167.06, -32.47) among those who already walked, and an over five-fold increased odds of not walking for transport at all (OR 5.31, 95% CI 3.58, 7.87).
Hirsch et al. 2014	United States - Baltimore MD; Chicago IL; Forsyth County NC; Los Angeles CA; New York NY; and St. Paul MN	45 to 84 years old (baseline)	701	Cohort	Walk Score	Moving to a neighborhood with a 10-point higher Walk Score was associated with 16.04 more minutes per week of walking for transportation (95% CI 5.13, 29.96) and 11% higher odds of walking for 150 minutes or more per week (meeting the Every Body Walk! Goals) (95% CI 1.02, 1.21). When participants were categorized into tertiles of change in Walk Score due to residential relocation, those in Tertile 1 had 9.3 fewer minutes of transportation walking per week (SD 460.9), Tertile 2 had 128.5 more minutes of transportation walking per week (SD 533.3), and Tertile 3 had 91.2 more minutes of transportation walking per week (SD 462.2), with a significant difference seen between these categories.

Study	Location	Demographics	Number	Study Design	Walkability Index	Results
Jack & McCormack 2014	Canada - Calgary	18 years and older	1967	Cross-Sectional	Cluster-derived	Compared to residents of low walkable neighborhoods, those in medium walkable neighborhoods had 1.4 times the odds of engaging in more than or equal to 10 minutes of neighborhood-based transport walking per week (OR 1.4, 95% CI 1.12, 1.75) and those in high walkable neighborhoods had 2.08 times the odds (OR 2.08, 95% CI 1.35, 3.19).
Kelley et al. 2016	United States - San Francisco Bay Area, Greater Chicago	South Asian Americans, 40 to 84 years old	906	Cross-Sectional	Walk Score	A 10-point increase in Walk Score was associated with 13.17 more Met-minutes per week (SE 4.92) of walking for transportation among male participants, while no significant change was seen in females (3.64 more Met-minutes per week, SE 6.79).
Kelly et al. 2015	United States - St. Louis County	Adults	1124 block groups	Cross-Sectional	GIS Frank	Compared to living in Quartile 1, the lowest walkability index, residents in higher walkability quartiles had increased odds of walking to work in an unadjusted model and when adjusting for different socioeconomic indicators. In an unadjusted model, living in the highest walkability quartile compared to the lowest walkability quartile was associated with 4.9 times higher odds of walking to work (95% CI 2.8, 8.59).
Koohsari et al. 2018	Japan - Nerima Ward, Kanuma City	40 to 69 years old	1072	Cross-Sectional	Walk Score	A 10-point Walk Score increase was associated with 34% higher odds of walking for commuting in the past week (OR 1.34, 95% CI 1.25, 1.42), 36% higher odds of walking 150 minutes or more per week for commuting purposes (OR 1.36, 95% CI 1.23, 1.5), 6% higher odds of walking for errands (OR 1.06, 95% CI 1.01, 1.11), and 8% higher odds of walking 150 minutes or more per week for errands (OR 1.08, 95% CI 0.98, 1.19).

Study	Location	Demographics	Number	Study Design	Walkability Index	Results
McCormack et al. 2012	Canada - Calgary	18 years and older	4034	Cross-Sectional	Cluster-derived	Compared to living in a low walkable neighborhood, residents of a medium walkable neighborhood had 42% higher odds of neighborhood-based walking for transportation in a week (OR 1.42, 95% CI 1.21, 1.67), and residents of a high walkable neighborhood had 38% higher odds (OR 1.38, 95% CI 0.89, 2.14). Compared to living in a low walkable neighborhood, residents of a medium walkable neighborhood had 14% higher odds of walking for 150 minutes or more per week for transportation (OR 1.14, 95% CI 0.91, 1.42), and residents of a high walkable neighborhood had 60% higher odds (OR 1.6, 95% CI 1.08, 2.37).
McCormack et al. 2017	Canada - Calgary	20 years and older	915	Cohort	Walk Score	This study examined residential relocation. Compared to walkability "maintainers," the odds of self-perceived increased transportation walking among walkability improvers was 4.14 (95% CI 2.0, 8.43), and among walkability decliners was 4.37 (95% CI 1.98, 9.44). This study examined residential relocation. Compared to walkability "maintainers," the odds of self-perceived decreased transportation walking among walkability improvers was 1.17 (95% CI 0.39, 2.97), and among walkability decliners was 3.17 (95% CI 1.43, 6.81). Result indicate that moving to a less walkable neighborhood may increase the odds of decreasing transportation waking.
Owen et al. 2007	Australia - Adelaide	20 to 65 years old	2650	Cross-Sectional	GIS Frank	District-level high walkability was associated with a non-significant beta coefficient of 1.2 (SE 0.8) for increased weekly minutes of walking for transportation, and a significant though small beta coefficient of 0.02 (SE 0.01) for weekly frequency of walking for transportation.
Pikora et al. 2006	Australia - Perth	18 to 59 years old	1678	Cross-Sectional	SPACES	Compared to residents in low walkability neighborhoods, the odds of walking for transport in the last two weeks were 44% higher (95% CI 1.1, 1.87) among residents of medium walkability neighborhoods and 95% higher (95% CI 1.49, 2.55) among residents of high walkability neighborhoods.

Study	Location	Demographics	Number	Study Design	Walkability Index	Results
Salvo et al. 2018	Canada - Calgary	Adults	97	Cross-Sectional	Walk Score	Relocating to a less walkable neighborhood was associated with a transportation walking score of 2.96 (SD 1.12), while relocating to a more walkable neighborhood was associated with a transportation walking score of 3.29 (SD 0.87) (Responses were on a 5-point scale of (1) a lot less now, (2) a little less now, (3) about the same, (4) a little more now, and (5) a lot more now.) The p-value of the difference between the two categories was 0.053 (close to significance).
Shimura et al. 2012	Australia - Adelaide	50 to 65 years old	504	Cohort	GIS Frank	Over a 4-year period, living in the lowest quintile of neighborhood walkability was associated with 6.7 fewer minutes (95% CI -10.1, -3.4) of transportation walking per day, while living in the highest walkability quintile was associated with only 1.1 fewer minutes (95% CI -5.1, 2.9) of transportation walking per day.
Sundquist et al. 2011	Sweden - Stockholm	20 to 66 years old	2,269	Cross-Sectional	GIS Frank	Individuals living in the highest compared to the lowest quintile of neighborhood walking had 77% higher odds of engaging in transportation walking in a week (OR 1.77, 95% CI 1.3, 2.41) and had 50 more minutes per week of transportation walking (95% CI 20, 81).
Thielman et al. 2015	Canada - urban areas	12 and older	151,318	Cross-Sectional	Walk Score	Comparing Walk Score quintiles, living in Quintiles 2-5 compared to Quintile 1 was associated with increased daily energy expenditure (in kcals/day) from transport walking. This relationship was seen in all Quintiles comparing Quintiles 2-5 with Quintile 1 with a positive dose-response relationship; Quintile 5 was associated with 0.17 higher kcal/day from transport walking (95% CI 0.15, 0.18) than Quintile 1.
Tuckel & Milczarski 2015	United States (general)	18 and older	1224	Cross-Sectional	Walk Score	A 10-point Walk Score increase was associated with 7% lower odds (OR 0.93, 95% CI 0.88, 0.99) of not walking for transportation for at least 10 minutes in the past 7 days.

Study	Location	Demographics	Number	Study Design	Walkability Index	Results
Van Dyck et al. 2009	Belgium - Sint-Niklaas	20 to 65 years old	120	Cross-Sectional	Paper/NQLS/Brownson	High neighborhood walkability was associated with 104.33 minutes per week of walking for transportation in one's neighborhood (SD 95.10) and low neighborhood walkability was associated with 22.83 minutes per week (SD 61.0), with a significant difference (p<0.001) between the two.
Van Dyck et al. 2010	Belgium - Ghent (urban)	20 to 65 years old	1166	Cross-Sectional	GIS Frank	A high neighborhood walkability index was associated with more minutes per week of walking for transportation, with a beta coefficient of 0.746 (SE 0.157, p<0.001)
Van Holle et al. 2014	Belgium - Ghent (urban and suburban)	65 and older	438	Cross-Sectional	GIS Frank	A 1-unit increase in the Neighborhood Walkability index score was associated with 21.39 more minutes per week of transportation walking (95% CI 6.61, 44.61, p < 0.001). Living in a low-walkable neighborhood was associated with 42.3 minutes per week of transportation walking (SD 88.6) and living in a high-walkable neighborhood was associated with 128.2 minutes per week of transportation walking (SD 166.9).
Wasfi et al. 2016	Canada, urban areas	18 to 55 years old	2976	Cohort	Walk Score	Spending more time in higher Walk Score quartiles relative to the first quartile increased the probability of high utilitarian walking. A one-unit increase in the probability spending more time in the third Walk Score quartile relative to the first quartile was associated with 2.7% more (95% CI 0.7, 4.7) high utilitarian walking. A one-unit increase in the probability of spending more time in the fourth Walk Score quartile relative to the first quartile was associated with 7.7% more (95% CI 5.8, 9.7) high utilitarian walking. Moving neighborhood with higher walkability than the one a person left, increased the odds of engaging in moderate and high utilitarian walking by 59% (95% CI 3, 140).

Study	Location	Demographics	Number	Study Design	Walkability Index	Results
Wasfi et al. 2017	Canada (general)	18 to 90 years old (baseline)	11,200	Cohort	Walk Score	Increased cumulative exposure to high walkability environments was associated with higher odds of engaging in utilitarian walking for one hour of more a week, with 66% higher odds (OR 1.66, 95% CI 1.31, 2.1) in small population centers, 25% higher odds in medium population centers (OR 1.25, 95% CI 1.06, 1.47), and 61% higher odds in large population centers (OR 1.61, 95% CI 1.47, 1.76).
Watson et al. 2020	United States (general)	18 and older	28,857	Cross-Sectional	EPA Walkability Index	An increased score for the EPA's National Walkability Index was associated with higher odds of walking for transportation. Residents of the most walkable neighborhoods had 2.88 times higher odds of transportation walking (OR 2.88, 95% CI 2.43, 3.41) as residents of the least walkable neighborhoods, with a positive dose response seen in each of the four categories of walkability. There was also a positive relationship between Walkability Index category and minutes per week of transportation walking among walkers, with a beta coefficient of 1.26 (95% CI 1.13, 1.4) in the most walkable neighborhoods and a significant ($p<0.05$) difference between categories.

Chapter 4: Discussion, Conclusions, and Recommendations

In each of the 28 studies assessed in this systematic review, walkability – by any index – was associated with transportation walking, with higher walkability scores associated with more transportation walking and lower walkability scores associated with less transportation walking. Almost all results were statistically significant, although some had very wide confidence intervals. Even if effect sizes remain uncertain, enough evidence exists from this body of cross-sectional and cohort studies to infer a plausible causal pathway between neighborhood walkability and walking for transportation. More high-quality longitudinal studies are undoubtedly needed to further define this pathway and control for issues like physical activity self-reporting and residential self-selection. Given the large body of evidence in this review specifically about walkability indices and walking for transportation – and a wider field of evidence around built environment and health behavior – a solid basis for further investigations is established.

In this systematic review, Walk Score was the most used index of walkability, with 16 out of 28 studies using Walk Score as one of, or as the singular, definition of neighborhood walkability. Many authors of the studies reviewed, as well as the existing systematic reviews discussed in Chapter 2, called for a coalescing of the built environment and health field around common measurements of street characteristics, and Walk Score is ideally poised to play this role given its ease of use, good availability (depending on country), and revised "Street Smart" characteristics that, starting in 2011, improved the index beyond straight line distances and now incorporate real street layouts into walkability scores (Walk Score, 2021). Walk Score is a free service that eliminates the need for GIS expertise, advanced statistical knowledge, and human error in measurement bias. It is already fully integrated with address information in the United

States, Canada, and Australia. Users can easily find local bike, walk, and transit times within a given time domain (10 to 60 minutes), and maps of any address show neighborhood amenities like restaurants, coffee, groceries, parks, schools, and more (Walk Score, 2021). Its user-friendly interface, broad applicability, and lack of technical expertise needed to use the index, underscore why it may have been used frequently by studies in this systematic review.

Walk Score has one major drawback, in that it is limited by geography. Scores are only published online for areas in the United States, Canada, and Australia, though validation has also occurred in Japan and New Zealand (Walk Score, 2021). Five studies in this systematic review occurred in Sweden (Arvidsson et al., 2012; Sundquist et al., 2011) and Belgium (Van Dyck et al., 2009; Van Dyck et al., 2010; Van Holle et al., 2014), and all except one used a version of the GIS/Frank method of walkability index calculation. Of the remaining 22 studies, Walk Score was used in 16 of them.

Two of the Canadian (Calgary) studies that did not use Walk Score, but instead used cluster-derived measurements of neighborhood walkability (Jack & McCormack 2014; McCormack et al., 2012), may have chosen this measurement because they were interested in the association between an individual's residence in neighborhoods of different walkability levels, and specifically neighborhood-based walking for transportation. Neither article indicated why cluster-derived walkability was chosen as the measurement index, but this is one potential reason based on the outcome the studies were examining.

The studies using the Frank GIS method of walkability calculation (sums of z-scores of metrics including intersection density, residential density, retail floor area ratio, and land use mix; with retail sometimes not included and intersection density receiving 1.5 or 2x weighting) may have chosen it for similar reasons. Additionally, many (but not all) of the studies using this methodology were written and published in or before 2012 (Arvidsson et al., 2012; Owen et al., 2007; Shimura et al., 2012; Sundquist et al., 2011; Van Dyck et al., 2010), as well as located outside of the United States, Canada, and Australia (Arvidsson et al., 2012; Sundquist et al., 2011; Van Dyck et al., 2010; Van Holle et al., 2014). Prior to 2011, the Walk Score index was not as accurate, with straight line rather than path-following distance to amenity calculations, so studies with research conducted prior to the "Street Smart" Walk Score index development may not have viewed it as a reliable measurement tool to assess walkability. One study located both in the United States (St. Louis County) and published after the advent of "Street Smart" Walk Score (Kelly et al., 2015) used the Frank GIS index. This study, however, was also the only one where individual-level data was not available: outcomes were assessed at the block group level (n = 1,124), with data gathered from the 2005-2009 American Community Survey.

Watson et al. (2020) may have chosen their index, the EPA Walkability Index, for similar reasons. Their representative countrywide dataset for the United States came from the National Health Interview Survey, and the restricted geocodes in the dataset placed participants in block groups and urban/rural dichotomized identity. The indicators that the EPA index assesses (intersection density, proximity to transit stops, and mixed use/diversity of buildings) are available at the block group level, which enabled the index to match with the available participant dataset. The index was only developed in 2017 (Thomas & Zeller, 2017), which may explain its lack of appearance in any other studies, and as it was developed by the United States Environmental Protection Agency, it is only available for studies in the United States. Watson et al. (2020) was the only study in this systematic review located in the United States and published after 2016, and thus it is the only study that could have chosen to use this index, based on its availability.

Pikora et al. (2006) was another study that did not use Walk Score. Located in Perth, Australia, data collectors trained in the Systematic Pedestrian and Cycling Environmental Scan (SPACES) audited the segments of roadway within 400 meters of participants' addresses. The study was published in 2006 and the street audits were conducted in 2000, before the development of the Frank GIS method, which was officially published in 2010 (Frank et al., 2010). (Similar versions of the index, however, were in use by the author and colleagues earlier (Frank et al., 2005; Owen et al., 2007).)

In describing how and why different walkability indices were used in studies examining the association between walkability and walking for transportation, themes emerge which may explain why authors chose to use certain indices. The Walk Score is validated, reliable, easy to use, and widely available for individual addresses in the United States, Canada, and Australia. It was a less accurate index before 2011, when scores were calculated based on "straight line" distance to amenities rather than actual roadway/sidewalk distances. The GIS walkability index developed by Frank and colleagues has been in literature since the mid-2000s and is good for assessing neighborhood characteristics, as its component are based on density of amenities in any given unit (like a block group). Its use may signify the lack of availability of Walk Score in a country (Sweden and Belgium), that the Walk Score was not in its newer form (prior to 2011) and thus a less reliable index at the time of the study, or that researchers wanted to assess walkability at a neighborhood level rather than centered around an address. Cluster-derived neighborhood indices may also have been used due to a combination of lack of updated Walk Score methodology and a desire to analyze data at the neighborhood level. Methods used over a decade ago, like SPACES methodology (Pikora et al., 2006) and paper map data validated by the

NQLS and Brownson framework (Van Dyck et al., 2009) have not been repeated within the field of this systematic review.

Based on the studies in this systematic review, researchers studying similar environment and physical activity variables may find themselves choosing between the Frank GIS method and Walk Score for measuring walkability. While the EPA's National Walkability Index is a thorough and accurate index, it can only be used in the United States, and would not be suitable if the goal is to improve comparability of metrics across countries. The Walk Score is an easier to use index that requires no additional datasets to calculate a score, but it is geographically limited. The Frank GIS method can be used and adapted in any setting with data on all or some variables related to intersection density, residential density, retail floor area ratio, and land use mix, which makes it broadly applicable in any setting where these four factors are likely to influence walking behavior. Two potential solutions to unify the field of walkability research in future studies are to expand and validate Walk Score in additional countries, or to universally adopt the more labor-intensive Frank GIS method. In using the Frank GIS method, it is also important to provide adequate justification for, and standardized use of, z-score weighting schemes; in the current literature, some authors use three out of four metrics, or apply different weights to the z-scores than seen in the original index, where intersection density received a 2x weight compared to residential density, retail floor area ratio, and land use mix (Frank et al., 2010).

Another possibility is to establish correlation between the Frank method and Walk Score, as seen in Hajna et al. (2015), where the authors found that the Frank-style GIS-derived walkability and Walk Score exhibited strong correlation (R = 0.82, 95% CI 0.80-0.83). Further studies on the two indices in a variety of settings and countries could allow for better comparability between the two options.

The results of the studies in this systematic review substantially add to the body of evidence in favor of promoting walking for transportation across the world. While most studies were cross-sectional and thus of limited individual utility in establishing a direct causal link between walkability and walking for transportation, the preponderance of evidence showing positive associations between the two is compelling evidence of a causal link. Furthermore, several longitudinal studies were included in this review, including Hirsch et al. (2014), McCormack et al. (2017), Shimura et al. (2012), Wasfi et al. (2016), and Wasfi et al. (2017). Longitudinal study results showed the influence of moving to neighborhoods with higher walkability on increased transportation walking (Hirsch et al. 2014; McCormack et al. 2017; Wasfi et al., 2016), cumulative exposure to neighborhoods with lower walkability on decreased walking for transportation (Shimura et al., 2012), and cumulative exposure to higher walkability neighborhoods on increased walking for transportation (Wasfi et al., 2016; Wasfi et al., 2017). This field of study would benefit from more longitudinal studies, as they are considered higher quality than cross-sectional studies, but rely on the occurrence of natural experiments in the population such as moving neighborhoods or having a shift in neighborhood walkability due to additions of walkability infrastructure.

The process of interpreting and contextualizing the results of the studies in this review must account for the Modifiable Areal Unit Problem, a potential source of bias stemming from the different spatial scales at which the walkability indices are created. Walk Score is based on all amenities within a 30-minute walk of the participants' home address. The geographic extent of a 30-minute walk varies considerably between neighborhood design patterns, with grid-like street patterns having longer 30-minute walk distances than loops-and-lollipops designs (Walk Score, 2021). The Frank and colleagues index was original designed to be measured at the census block group level (within the United States, this is typically 600 to 3,000 people). Within the studies in this systematic review, Frank-style walkability indices were developed at the following scales: a 1000-meter circular buffer around individual home address (Arvidsson et al., 2012); within each Stockholm city administrative unit (Sundquist et al., 2011); at the Adelaide Census Collection Division level (approximately 250 households each) (Owen et al., 2008; Shimura et al., 2012); at the Belgian statistical sector level (approximately 1,000 residents each) (Van Dyck et al., 2010; Van Holle et al., 2014); at the U.S. block group level (Kelly et al., 2015); and via 500-meter polygonal buffers around Canadian home postal code addresses (Hajna et al., 2015). While the index was originally designed to be used at the U.S. block group level, only one study in this review that used it was conducted in the United States.

The studies using cluster-derived neighborhood walkability (Jack & McCormack, 2014; McCormack et al., 2012) primarily considered built environment characteristics within 1.6 km (an approximately 15-minute walk) of participants' home addresses (via street walking route, not a straight-distance buffer), with some measurements (green space and path/cycleway) at the level of neighborhood administrative boundary. The study using the SPACES instrument measured built environment within a 400-meter radius of participants' home addresses (Pikora et al., 2006). In their paper map and subsequent Brownson framework walkability validation, Van Dyck et al. (2009) considered characteristics within an 800-meter radius of participants' addresses. And Watson et al. (2020)'s use of the U.S. EPA Walkability index considered walkability indicators at the block group level. Due to the variety of spatial scales at which walkability indices were created in the studies in this review, comparing results between studies must account for the Modifiable Areal Unit Problem.

Methodologically, Walk Score is superior to other indices because of its distance-decay function whereby amenities closer to a given address receive higher scores than those further away. Unlike other indices in this study that used pre-defined neighborhood or census blocks, or uniform radius buffers around an address, and then calculate density or number of amenities within that area, Walk Score incorporates distance to amenities as a key aspect of defining neighborhood walkability. This methodology may provide higher-quality evidence when studying individual health outcomes that are correlated with walkability, because Walk Score's methodology closely tailors its score to both individual addresses and natural human behavior patterns that value convenience of amenities in daily life. Other walkability indices that make walkability calculations at a block group or neighborhood level may miss individual differences in distance to amenities and thus give weaker evidence for correlations between walkability and individual health behaviors.

It is also important to consider whether methodology that rates walkability based on distance to, or density of, amenities, accurately assesses true walkability. There is likely a certain amount of over- and under-estimation of walkability in different scenarios. For example, a neighborhood with high street connectivity, intersection density, and green canopy may be a relatively pleasant and safe place for individuals to walk, even in the absence of nearby amenities – characteristics of walkability that might be better captured with the cluster-derived index used by Jack & McCormack (2014) and McCormack et al. (2012), than by Walk Score. Walkability islands may overestimate neighborhood walkability in small mixed-use developments in which residential and commercial space is heavily intermingled, but this is contained to a small geographic area surrounded by less walkable areas. Even in areas with many safe intersections and amenities, issues like noise and air pollution, weather, and crime may inhibit walkability. While objective indices of walkability like those evaluated in this review have an important place in research, accounting for more variables – or relying on mixed-methods subjective and objective walkability measurements – may give a more accurate assessment of true walkability and thus have greater utility for studies on the link between walkability and behavior. Smartphone data offers a new frontier to validate existing walkability indices and create new ones, as seen in Assemi et al. (2020), when two weeks of smartphone data for young adults in Australia was used to understand time and spatial patterns of walking. It is important to gain a greater understanding of the differences and similarities between objective and subjective walkability (further discussed below).

Several additional limitations exist in the applicability of the results of this systematic review to all research around walkability and health. First, as mentioned above, it is difficult to draw definitive conclusions about cause and effect with an evidence base primarily composed of cross-sectional studies. Second, to answer a well-defined research question, many populations, countries, and indices of walkability were not assessed. All studies came from developed countries, as defined in the 2014 United Nations index. While this distinction was made to separate countries with road systems primarily developed for automobile versus pedestrian traffic, level of economic development is not the only way to make this distinction, and many countries classified as developing by the United Nations may have urban areas suitable for inclusion in this review.

Third, only objective indices of walkability were reviewed in this study. Some of the articles used both objective and subjective indices, but the results compiled and discussed were only for objective indices. The perception and objective reality of built environment may have some concordance, as seen in Arvidsson et al. (2012), where the measures agreed for 67% of participants. An expansion upon the results of this current systematic review could look at the indices used to assess subjective walkability in studies looking at the association of subjective walkability and walking for transportation. Fourth, the studies in this review were not in pediatric populations; a substantial body of research exists around walkability and active transportation for children. Adults and children may interact with and be influenced by their neighborhood walkability in very different ways. Like the possibility of expanding this study to cover subjective walkability, a parallel and subsequent review could focus on indices of walkability used in studies of pediatric populations.

Conclusion: Results from cross-sectional and longitudinal studies show strong evidence of associations between objectively measured walkability indices and walking for transportation among adults. These results add to the literature base showing associations between various aspects of built environment and different modalities of physical activity. These results are applicable to public health programs and practice with goals to increase population physical activity and improve health outcomes related to physical inactivity (including obesity and metabolic syndrome). Results are also useful for climate change and greenhouse gas emission mitigation because forms of active transportation like walking can reduce reliance on and output of fossil fuels. Articles included in this review overwhelmingly used one of two walkability indices: Walk Score and a GIS-based method developed by Frank and colleagues, with benefits and drawbacks of both methods when considering which to use in future studies. Future research could also focus on the concordance between these two measures or the expansion of Walk Score's locations.

References

Armstrong, M. E., Green, J., Reeves, G. K., Beral, V., Cairns, B. J., & Million Women Study Collaborators (2015). Frequent physical activity may not reduce vascular disease risk as much as moderate activity: large prospective study of women in the United Kingdom. *Circulation*, *131*(8), 721–729. https://doi.org/10.1161/CIRCULATIONAHA.114.010296

Arvidsson, D., Kawakami, N., Ohlsson, H., & Sundquist, K. (2012). Physical activity and concordance between objective and perceived walkability. *Medicine and science in sports and exercise*, *44*(2), 280–287. https://doi.org/10.1249/MSS.0b013e31822a9289

Assemi, B., Zahnow, R., Zapata-Diomedi, B., Hickman, M., & Corcoran, J. (2020). Transport-related walking among young adults: when and why?. *BMC public health*, *20*(1), 244. https://doi.org/10.1186/s12889-020-8338-0

Barnes, R., Winters, M., Ste-Marie, N., Mckay, H., & Ashe, M. C. (2016). Age and retirement status differences in associations between the built environment and active travel behaviour. *Journal of Transport & Health*, *3*(4), 513–522. https://doi.org/10.1016/j.jth.2016.03.003

Barnett, D. W., Barnett, A., Nathan, A., Van Cauwenberg, J., Cerin, E., & Council on Environment and Physical Activity (CEPA) – Older Adults working group. (2017). Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis. *The international journal of behavioral nutrition and physical activity*, *14*(1), 103. https://doi.org/10.1186/s12966-017-0558-z

Brown, S. C., Pantin, H., Lombard, J., Toro, M., Huang, S., Plater-Zyberk, E., Perrino, T., Perez-Gomez, G., Barrera-Allen, L., & Szapocznik, J. (2013). Walk Score®: associations with purposive walking in recent Cuban immigrants. *American journal of preventive medicine*, *45*(2), 202–206. https://doi.org/10.1016/j.amepre.2013.03.021

Brownson, R.C., Hoehner, C.M., Brennan, L.K., Cook, R.A., Elliott, M.B., McMullen, K. (2004). Reliability of two instruments for auditing the environment for physical activity. *Journal of Physical Activity & Health* 1, 191–208

Caballero B. (2019). Humans against Obesity: Who Will Win?.*Advances in nutrition (Bethesda, Md.)*, *10*(suppl_1), S4–S9. https://doi.org/10.1093/advances/nmy055

Carr, L. J., Dunsiger, S. I., & Marcus, B. H. (2011). Validation of Walk Score for estimating access to walkable amenities. *British journal of sports medicine*, *45*(14), 1144–1148. https://doi.org/10.1136/bjsm.2009.069609

Cerin, E., Nathan, A., van Cauwenberg, J., Barnett, D. W., Barnett, A., & Council on Environment and Physical Activity (CEPA) – Older Adults working group (2017). The neighbourhood physical environment and active travel in older adults: a systematic review and meta-analysis. *The international journal of behavioral nutrition and physical activity*, *14*(1), 15. https://doi.org/10.1186/s12966-017-0471-5

Chiu, M., Shah, B. R., Maclagan, L. C., Rezai, M. R., Austin, P. C., & Tu, J. V. (2015). Walk Score® and the prevalence of utilitarian walking and obesity among Ontario adults: A cross-sectional study. *Health reports*, *26*(7), 3–10.

Chudyk, A. M., McKay, H. A., Winters, M., Sims-Gould, J., & Ashe, M. C. (2017). Neighborhood walkability, physical activity, and walking for transportation: A cross-sectional study of older adults living on low income. *BMC geriatrics*, *17*(1), 82. https://doi.org/10.1186/s12877-017-0469-5

Cole, R., Dunn, P., Hunter, I., Owen, N., & Sugiyama, T. (2015). Walk Score and Australian adults' home-based walking for transport. *Health & place*, *35*, 60–65. https://doi.org/10.1016/j.healthplace.2015.06.011

de Nazelle, A., Nieuwenhuijsen, M. J., Antó, J. M., Brauer, M., Briggs, D., Braun-Fahrlander, C., Cavill, N., Cooper, A. R., Desqueyroux, H., Fruin, S., Hoek, G., Panis, L. I., Janssen, N., Jerrett, M., Joffe, M., Andersen, Z. J., van Kempen, E., Kingham, S., Kubesch, N., Leyden, K. M., … Lebret, E. (2011). Improving health through policies that promote active travel: a review of evidence to support integrated health impact assessment. *Environment international*, *37*(4), 766–777. https://doi.org/10.1016/j.envint.2011.02.003

Dixon, B. N., Ugwoaba, U. A., Brockmann, A. N., Ross, K. M. (2021). Associations between the built environment and dietary intake, physical activity, and obesity: A scoping review of reviews. *Obesity Reviews*. 22:e13171. https://doi-org.proxy.library.emory.edu/10.1111/obr.13171

Duncan, D. T., Aldstadt, J., Whalen, J., Melly, S. J., & Gortmaker, S. L. (2011). Validation of walk score for estimating neighborhood walkability: an analysis of four US metropolitan areas. *International journal of environmental research and public health*, *8*(11), 4160–4179. https://doi.org/10.3390/ijerph8114160

Farkas, B., Wagner, D. J., Nettel-Aguirre, A., Friedenreich, C., & McCormack, G. R. (2019). Evidence synthesis - A systematized literature review on the associations between neighbourhood built characteristics and walking among Canadian adults. *Health promotion and chronic disease prevention in Canada : research, policy and practice*, *39*(1), 1–14. https://doi.org/10.24095/hpcdp.39.1.01

Frank, L. D., Schmid, T. L., Sallis, J. F., Chapman, J., & Saelens, B. E. (2005). Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. *American journal of preventive medicine*, *28*(2 Suppl 2), 117–125. https://doi.org/10.1016/j.amepre.2004.11.001

Frank, L. D., Sallis, J. F., Saelens, B. E., Leary, L., Cain, K., Conway, T. L., & Hess, P. M. (2010). The development of a walkability index: application to the Neighborhood Quality of Life

Study. *British journal of sports medicine*, *44*(13), 924–933. https://doi.org/10.1136/bjsm.2009.058701

Grasser G., Van Dyck D., Titze S., Stronegger W. (2013). Objectively measured walkability and active transport and weight-related outcomes in adults: a systematic review. *Int J Public Health*. 2013;58:615–25.

Hajna, S., Ross, N. A., Joseph, L., Harper, S., & Dasgupta, K. (2015). Neighbourhood walkability, daily steps and utilitarian walking in Canadian adults. *BMJ open*, *5*(11), e008964. https://doi.org/10.1136/bmjopen-2015-008964

Handy S. L., Boarnet M. G., Ewing R, Killingsworth R. E. (2002). How the built environment affects physical activity: views from urban planning. American Journal of Preventive Medicine 2002;23:64–73.

Henriksen, E.J. (2002). Effects of acute exercise and exercise training on insulin resistance. *J. Appl. Physiol.* 93,788–796

Hilland, T. A., Bourke, M., Wiesner, G., Garcia Bengoechea, E., Parker, A. G., Pascoe, M., & Craike, M. (2020). Correlates of walking among disadvantaged groups: A systematic review. *Health & place*, *63*, 102337. https://doi.org/10.1016/j.healthplace.2020.102337

Hirsch, J. A., Moore, K. A., Evenson, K. R., Rodriguez, D. A., & Diez Roux, A. V. (2013). Walk Score® and Transit Score® and walking in the multi-ethnic study of atherosclerosis. *American journal of preventive medicine*, *45*(2), 158–166. https://doi.org/10.1016/j.amepre.2013.03.018

Hirsch, J. A., Diez Roux, A. V., Moore, K. A., Evenson, K. R., & Rodriguez, D. A. (2014). Change in walking and body mass index following residential relocation: the multi-ethnic study of atherosclerosis. *American journal of public health*, *104*(3), e49–e56. https://doi.org/10.2105/AJPH.2013.301773

Jack, E., & McCormack, G. R. (2014). The associations between objectively-determined and self-reported urban form characteristics and neighborhood-based walking in adults. *The international journal of behavioral nutrition and physical activity*, *11*, 71. https://doi.org/10.1186/1479-5868-11-71

Kelley, E. A., Kandula, N. R., Kanaya, A. M., & Yen, I. H. (2016). Neighborhood Walkability and Walkinnbm g for Transport Among South Asians in the MASALA Study. *Journal of physical activity & health*, *13*(5), 514–519. https://doi.org/10.1123/jpah.2015-0266

Kelly, C. M., Lian, M., Struthers, J., & Kammrath, A. (2015). Walking to Work: The Roles of Neighborhood Walkability and Socioeconomic Deprivation. *Journal of physical activity & health*, *12 Suppl 1*, S70–S75. https://doi.org/10.1123/jpah.2012-0359

Koohsari J. M., Sugiyama, T., Shibata, A., Ishii, K., Hanibuchi, T., Liao, Y., Owen, N., Oka, K. (2018). Walk Score® and Japanese adults' physically-active and sedentary behaviors, Cities, Volume 74, 2018, Pages 151-155, ISSN 0264-2751, https://doi.org/10.1016/j.cities.2017.11.016.

Koolhaas, C. M., Dhana, K., Schoufour, J. D., Ikram, M. A., Kavousi, M., & Franco, O. H. (2017). Impact of physical activity on the association of overweight and obesity with cardiovascular disease: The Rotterdam Study. *European journal of preventive cardiology*, *24*(9), 934–941. https://doi.org/10.1177/2047487317693952

Manson, J. E., Greenland, P., LaCroix, A. Z., Stefanick, M. L., Mouton, C. P., Oberman, A., Perri, M. G., Sheps, D. S., Pettinger, M. B., & Siscovick, D. S. (2002). Walking compared with vigorous exercise for the prevention of cardiovascular events in women. *The New England journal of medicine*, *347*(10), 716–725. https://doi.org/10.1056/NEJMoa021067

Mayne, S. L., Auchincloss, A. H., & Michael, Y. L. (2015). Impact of policy and built environment changes on obesity-related outcomes: a systematic review of naturally occurring experiments. *Obesity reviews : an official journal of the International Association for the Study of Obesity*, *16*(5), 362–375. https://doi.org/10.1111/obr.12269

McCormack G. R., Shiell A. (2011). Search of causality: a systematic review of the relationship between the built environment and physical activity among adults. *Int J Behav Nutr Phys Act.* 2011;8:125.

McCormack, G. R., Friedenreich, C., Sandalack, B. A., Giles-Corti, B., Doyle-Baker, P. K., & Shiell, A. (2012). The relationship between cluster-analysis derived walkability and local recreational and transportation walking among Canadian adults. *Health & place*, *18*(5), 1079–1087. https://doi.org/10.1016/j.healthplace.2012.04.014

McCormack, G. R., McLaren, L., Salvo, G., & Blackstaffe, A. (2017). Changes in Objectively-Determined Walkability and Physical Activity in Adults: A Quasi-Longitudinal Residential Relocation Study. *International journal of environmental research and public health*, *14*(5), 551. https://doi.org/10.3390/ijerph14050551

Myers, J., Kokkinos, P., & Nyelin, E. (2019). Physical Activity, Cardiorespiratory Fitness, and the Metabolic Syndrome. *Nutrients*, *11*(7), 1652. https://doi.org/10.3390/nu11071652

National Highway Traffic Safety Administration (NHTSA). (2018). Summary. *US Department of Transportation.* https://www-fars.nhtsa.dot.gov/Main/index.aspx

National Institutes of Health. (2014). Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies. https://www.nhlbi.nih.gov/health-pro/guidelines/in-develop/cardiovascular-risk-reduction/tools/cohort

Nichani, V., Vena, J. E., Friedenreich, C. M., Christie, C., & McCormack, G. R. (2019). A population-based study of the associations between neighbourhood walkability and different types of physical activity in Canadian men and women. *Preventive medicine*, *129*, 105864. https://doi.org/10.1016/j.ypmed.2019.105864

Orru, H., Ebi, K. L., & Forsberg, B. (2017). The Interplay of Climate Change and Air Pollution on Health. *Current environmental health reports*, *4*(4), 504–513. https://doi.org/10.1007/s40572-017-0168-6

Owen, N., Cerin, E., Leslie, E., duToit, L., Coffee, N., Frank, L. D., Bauman, A. E., Hugo, G., Saelens, B. E., & Sallis, J. F. (2007). Neighborhood walkability and the walking behavior of Australian adults. *American journal of preventive medicine*, *33*(5), 387–395. https://doi.org/10.1016/j.amepre.2007.07.025

Pikora, T. J., Giles-Corti, B., Knuiman, M. W., Bull, F. C., Jamrozik, K., & Donovan, R. J. (2006). Neighborhood environmental factors correlated with walking near home: Using SPACES. *Medicine and science in sports and exercise*, *38*(4), 708–714. https://doi.org/10.1249/01.mss.0000210189.64458.f3

Prior, J. H., Connon, I. L., McIntyre, E., Adams, J., Capon, A., Kent, J., Rissel, C., Thomas, L. E., Thompson, S. M., & Westcott, H. (2018). Built environment interventions for human and planetary health: integrating health in climate change adaptation and mitigation. *Public health research & practice*, *28*(4), 2841831. https://doi.org/10.17061/phrp2841831

Rachele, J. N., Sugiyama, T., Davies, S., Loh, V., Turrell, G., Carver, A., & Cerin, E. (2019). Neighbourhood built environment and physical function among mid-to-older aged adults: A systematic review. *Health & place*, *58*, 102137. https://doi.org/10.1016/j.healthplace.2019.05.015

Roberts, C.K.; Hevener, A.L.; Barnard, R.J. (2013). Metabolic syndrome and insulin resistance: Underlying causesand modification by exercise training. *Compr. Physiol* 3, 1–58.24.

Rojas-Rueda, D., de Nazelle, A., Andersen, Z. J., Braun-Fahrländer, C., Bruha, J., Bruhova-Foltynova, H., Desqueyroux, H., Praznoczy, C., Ragettli, M. S., Tainio, M., & Nieuwenhuijsen, M. J. (2016). Health Impacts of Active Transportation in Europe. *PloS one*, *11*(3), e0149990. https://doi.org/10.1371/journal.pone.0149990

Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Annals of behavioral medicine : a publication of the Society of Behavioral Medicine*, *25*(2), 80–91. https://doi.org/10.1207/S15324796ABM2502_03

Saelens B. E,, Handy S. L. (2008). Built environment correlates of walking: a review. *Med Sci Sports Exerc*. 40:S550–S66.

Frank, L. D., Sallis, J. F., Conway, T., Chapman, J., Saelens, B., Bachman, W. (2006). Multiple pathways from land use to health: walkability associations with active transportation, body mass index, and air quality. *J Am Planning Assoc* 72:75– 87.

Salvo, G., Lashewicz, B. M., Doyle-Baker, P. K., & McCormack, G. R. (2018). A Mixed Methods Study on the Barriers and Facilitators of Physical Activity Associated with Residential Relocation. *Journal of environmental and public health*, 1094812. https://doi.org/10.1155/2018/1094812

Shimura, H., Sugiyama, T., Winkler, E., & Owen, N. (2012). High neighborhood walkability mitigates declines in middle-to-older aged adults' walking for transport. *Journal of physical activity & health*, *9*(7), 1004–1008. https://doi.org/10.1123/jpah.9.7.1004

Smith, M., Hosking, J., Woodward, A., Witten, K., MacMillan, A., Field, A., Baas, P., & Mackie, H. (2017). Systematic literature review of built environment effects on physical activity and active transport - an update and new findings on health equity. *The international journal of behavioral nutrition and physical activity*, *14*(1), 158. https://doi.org/10.1186/s12966-017-0613-9

Sundquist, K., Eriksson, U., Kawakami, N., Skog, L., Ohlsson, H., & Arvidsson, D. (2011). Neighborhood walkability, physical activity, and walking behavior: the Swedish Neighborhood and Physical Activity (SNAP) study. *Social science & medicine (1982)*, *72*(8), 1266–1273. https://doi.org/10.1016/j.socscimed.2011.03.004

Thielman, J., Rosella, L., Copes, R., Lebenbaum, M., & Manson, H. (2015). Neighborhood walkability: Differential associations with self-reported transport walking and leisure-time physical activity in Canadian towns and cities of all sizes. *Preventive medicine*, *77*, 174–180. https://doi.org/10.1016/j.ypmed.2015.05.011

Thomas, J., Zeller, L. (2017). National Walkability Index User Guide and Methodology. *US Environmental Protection Agency.*

Tuckel, P., & Milczarski, W. (2015). Walk Score (TM), Perceived Neighborhood Walkability, and walking in the US. *American journal of health behavior*, *39*(2), 242–256. https://doi.org/10.5993/AJHB.39.2.11

United Nations. (2014). *Country Classification.* World Economic Situation and Prospects 2014. https://www.un.org/en/development/desa/policy/wesp/wesp_current/2014wesp_country_classification.pdf

US Environmental Protection Agency (US EPA). (2013). Stormwater to Street Trees: Engineering Urban Forests for Stormwater Management. *Office of Wetlands, Oceans and Watersheds, Nonpoint Source Control Branch.* https://www.epa.gov/sites/production/files/2015-11/documents/stormwater2streettrees.pdf

Van Dyck, D., Cardon, G., Deforche, B., Sallis, J. F., Owen, N., & De Bourdeaudhuij, I. (2010). Neighborhood SES and walkability are related to physical activity behavior in Belgian adults. *Preventive medicine*, *50 Suppl 1*, S74–S79. https://doi.org/10.1016/j.ypmed.2009.07.027

Van Dyck, D., Cerin, E., Conway, T. L., De Bourdeaudhuij, I., Owen, N., Kerr, J., Cardon, G., Frank, L. D., Saelens, B. E., & Sallis, J. F. (2012). Perceived neighborhood environmental attributes associated with adults' transport-related walking and cycling: Findings from the USA, Australia and Belgium. *The international journal of behavioral nutrition and physical activity*, *9*, 70. https://doi.org/10.1186/1479-5868-9-70

Van Dyck, D., Deforche, B., Cardon, G., & De Bourdeaudhuij, I. (2009). Neighbourhood walkability and its particular importance for adults with a preference for passive transport. *Health & place*, *15*(2), 496–504. https://doi.org/10.1016/j.healthplace.2008.08.010

Van Holle, V., Deforche, B., Van Cauwenberg, J., Goubert, L., Maes, L., Van de Weghe, N., & De Bourdeaudhuij, I. (2012). Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. *BMC public health*, *12*, 807. https://doi.org/10.1186/1471-2458-12-807

Van Holle, V., Van Cauwenberg, J., Van Dyck, D., Deforche, B., Van de Weghe, N., & De Bourdeaudhuij, I. (2014). Relationship between neighborhood walkability and older adults' physical activity: results from the Belgian Environmental Physical Activity Study in Seniors (BEPAS Seniors). *The international journal of behavioral nutrition and physical activity*, *11*, 110. https://doi.org/10.1186/s12966-014-0110-3

Walk Score. (2021). Walk Score ®: Live Where You Love. https://www.walkscore.com/

Wasfi, R., Dasgupta, K., Eluru, N., Ross, N.A. (2016). Exposure to walkable neighbourhoods in urban areas increases utilitarian walking: Longitudinal study of Canadians, Journal of Transport & Health, Volume 3, Issue 4, 2016, Pages 440-447, ISSN 2214-1405, https://doi.org/10.1016/j.jth.2015.08.001.

Wasfi, R., Steinmetz-Wood, M., & Kestens, Y. (2017). Place matters: A longitudinal analysis measuring the association between neighbourhood walkability and walking by age group and population center size in Canada. *PloS one*, *12*(12), e0189472. https://doi.org/10.1371/journal.pone.0189472

Watson, K. B., Whitfield, G. P., Thomas, J. V., Berrigan, D., Fulton, J. E., & Carlson, S. A. (2020). Associations between the National Walkability Index and walking among US Adults - National Health Interview Survey, 2015. *Preventive medicine*, *137*, 106122. https://doi.org/10.1016/j.ypmed.2020.106122

Wildman, R. P., Muntner, P., Reynolds, K., McGinn, A. P., Rajpathak, S., Wylie-Rosett, J., & Sowers, M. R. (2008). The obese without cardiometabolic risk factor clustering and the normal weight with cardiometabolic risk factor clustering: prevalence and correlates of 2 phenotypes among the US population (NHANES 1999-2004). *Archives of internal medicine*, *168*(15), 1617–1624. https://doi.org/10.1001/archinte.168.15.1617

Williams P. T. (2013). Dose-response relationship of physical activity to premature and total all-cause and cardiovascular disease mortality in walkers. *PloS one*, *8*(11), e78777. https://doi.org/10.1371/journal.pone.0078777

World Health Organization. (2020). Obesity and overweight. *Newsroom – Fact Sheets.* https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight

Yang, S., Chen, X., Wang, L., Wu, T; Fei, T., Xiao, Q., Zhang, G., Ning, Y., Jia, P. (2021). Walkability indices and childhood obesity: A review of epidemiologic evidence. *Obesity Reviews*. 22(S1):e13096. https://doi-org.proxy.library.emory.edu/10.1111/obr.13096

Zuniga-Teran A. A., Orr B.J., Gimblett R. H., Chalfoun N.V., Marsh S.E., Guertin D.P., Going S.B. (2017). Designing healthy communities: Testing the walkability model, Frontiers of Architectural Research, Volume 6, Issue 1, 2017, Pages 63-73, ISSN 2095-2635, https://doi.org/10.1016/j.foar.2016.11.005.