The relationship between walk score® and perceived walkability in ultrahigh density areas

Mohammad Javad Koohsari [a,b,c,*], Gavin R. McCormack [d,e,f,a], Ai Shibata [g], Kaori Ishii [a], Akitomo Yasunaga [h], Tomoki Nakaya [i], Koichiro Oka [a]

[a] Faculty of Sport Sciences, Waseda University, Japan
[b] Behavioural Epidemiology Laboratory, Baker Heart and Diabetes Institute, Australia
[c] Melbourne School of Population and Global Health, The University of Melbourne, Australia
[d] Department of Community Health Sciences, Cumming School of Medicine, University of Calgary, Canada
[e] Faculty of Kinesiology, University of Calgary, Canada
[f] School of Architecture, Planning and Landscape, University of Calgary, Canada
[g] Faculty of Health and Sport Sciences, University of Tsukuba, Japan
[h] Faculty of Liberal Arts and Sciences, Bunka Gakuen University, Japan
[i] Graduate School of Environmental Studies, Tohoku University, Japan

ARTICLE INFO

ABSTRACT

Walk Score® is a free web-based tool that provides a walkability score for any given location. A limited number of North American studies have found associations between Walk Score® and perceived built environment attributes, yet it remains unknown whether similar associations exist in Asian countries. The study's objective is to examine the covariate-adjusted correlations between the Walk Score® metric and measures of the perceived built environment in ultrahigh density areas of Japan. Cross-sectional data were obtained from a randomly selected sample of adult residents living in two Japanese urban localities. There was a large correlation between Walk Score® and access to shops (0.58; p < 0.001). There were medium correlations between Walk Score® and population density (0.38; p < 0.001), access to public transport (0.34; p < 0.001), presence of sidewalks (0.41; p < 0.001), and access to recreational facilities (0.37; p < 0.001), and there was a small correlation between Walk Score® and presence of bike lanes (0.16; p < 0.001). There was a small negative correlation between Walk Score® and traffic safety (-0.13; p < 0.001). There was a medium correlation between Walk Score® and overall perceived walkability (0.48; p < 0.001). This study's findings highlight that Walk Score® was correlated with several perceived walkable environment attributes in the context of ultrahigh density areas in Asia.

1. Introduction

Evidence suggests that the built environment influences levels of physical activity, which is important for public health. Physical inactivity is known as one of the leading risk factors for global mortality, causing approximately 9% of deaths globally (Lee et al., 2012). It has been established as an important modifiable risk factor for a range of chronic diseases, such as cardiovascular diseases, type 2 diabetes, and cancer (Al Tunaiji et al., 2014; Dietz et al., 2016; Wahid et al., 2016). Nevertheless, the prevalence of physical inactivity is high worldwide: data from 168 countries showed that approximately 27.5% of the world's adult population was physically inactive in 2016 (Guthold et al.,

2018). Physical inactivity also represents a high economic cost for health organisations costing health-care systems at least 53.8 billion international dollars worldwide in 2013 (Ding et al., 2016; Pratt et al., 2014). Therefore, developing strategies to improve physical activity is closely matched with several sustainable development goals (SDGs) (Nugent et al., 2018; United Nations, 2015).

Socioecological models in health behaviours have highlighted the built environment's role in promoting physical activity (Sallis and Owen, 2015). The built environment refers to "the part of the physical environment that is constructed by human activity", such as houses, shops, workplaces, and public open spaces (Saelens and Handy, 2008). Mounting evidence suggests links between several built environment

attributes and people's physical activity (Durand et al., 2011; Kärmeniemi et al., 2018; McCormack and Shiell, 2011). For example, a systematic review of 33 studies found that higher population density, well-connected streets, and various destinations nearby were supportive of physical activity (McCormack and Shiell, 2011). Another systematic review found that better access to destinations and infrastructure for active travel was associated with higher total and transport-related physical activity (Kärmeniemi et al., 2018).

Measuring built environment attributes is a crucial step in conceptualising the built environment in relation to physical activity (Brownson et al., 2009). Two types of measures, perceived and objective, have been commonly used in studies examining the built environment and physical activity (Lin and Moudon, 2010). Perceived measures of the built environment are obtained by asking residents about their surrounding built environment attributes conducive to physical activity. Several questionnaires, such as the Neighbourhood Environment Walkability Scale (Saelens et al., 2003), the St. Louis instrument (Brownson et al., 2001), the Environmental Supports for Physical Activity Questionnaire (Group, 2007), and the Physical Activity Neighbourhood Environment Scale (Sallis et al., 2010) have been used to capture residents' perceptions of the built environment. Objective measures of built environment attributes are collected by audit tools or geographic information systems (GIS). Nevertheless, both perceived and objective measures of the built environment have limitations. While perceived measures of the built environment are relatively easy to collect, these measures are subject to reporting bias (Brownson et al., 2009; Weiss et al., 2010), which may require translation and validation within specific populations, and a low response rate is a challenge for both interview and self-administered questionnaires (Brownson et al., 2009; Lee et al., 2011). Objective measures of the built environment require detailed spatial data, which are often not readily available or are costly to collect (Adams et al., 2014; Salvo et al., 2014; Wilson et al., 2012). For example, GIS measures of the built environment, such as land use mix, net residential density, and retail area, are highly dependent on access to fine-grained geographical data, which makes sourcing them difficult even in high-income countries (Kerr et al., 2013). These issues underscore the necessity of comparing objective and perceived measures of the built environment, characterising the activity-friendly built environment in different contexts.

A growing body of research has investigated the association between Walk Score® and physical activity (Chudyk et al., 2017; Cole et al., 2015; Koohsari et al., 2019, 2018b; Towne et al., 2016; Twardzik et al., 2019). For instance, a Canadian study found that Walk Score® was associated with a greater probability of older adults walking for transport (Chudyk et al., 2017). Another study conducted in Japan found that a higher Walk Score® was associated with walking for commuting and walking for errands (Koohsari et al., 2018b). Walk Score® has also been examined in relation to other health biomarkers that are associated with physical activity, such as body mass index, blood lipid levels, and blood pressure (Braun et al., 2016; Chiu et al., 2016; McCormack et al., 2018; Méline et al., 2017).

Despite being publicly available, Walk Score® is a commercial product, and its detailed algorithm is not accessible to the public. Additionally, Walk Score® uses data sources obtained from Google, Factual, Great Schools, Open Street Map, and other open-source data (Walk Score, 2020). Different rules and methods were likely used to construct these base maps in each area. For instance, different raster-based and vector-based methods can be used in generating street maps. Defining and geocoding commercial destination points are also not the same across the areas. This causes a comparability issue for the Walk Score® output derived from these maps, especially for regions outside of North America (Koohsari et al., 2018a). Thus, it is necessary to examine whether Walk Score® is correlated with other built environment attributes supportive of walking in different contexts.

Several studies have examined the concurrent validity of Walk Score® for estimating objective built environment measures in the U.S.

(Carr et al., 2010; Duncan et al., 2013, 2011), Canada (Nykiforuk et al., 2016), and more recently in Japan (Koohsari et al., 2018a). For instance, a study conducted in the U.S. found that Walk Score® was positively associated with several objective neighbourhood walkability measures calculated within an 800-metre buffer around residential addresses (Duncan et al., 2013). Another study conducted in Japan found significant positive correlations between Walk Score® and objective built environment attributes relevant to walking (Koohsari et al., 2018a). A limited number of studies have also found significant correlations between Walk Score® and perceived built environment attributes (Bereitschaft, 2018; Carr et al., 2010; Consoli et al., 2020; Frehlich et al., 2020; Lo et al., 2019; Silveira and Motl, 2020; Tuckel and Milczarski, 2015). All these studies were conducted in the U.S. and Canada; no study, to the best of our knowledge, has examined the correlations between Walk Score® and perceived built environment attributes in regions or countries outside of North America. Walk Score® does have similarity across regions, but perceptions of built environment attributes are likely to differ to a greater extent across populations. The perceived built environment is a slightly different construct from the objective built environment. While perceptions of one's surrounding neighbourhood are determined mainly by the objective built environment, they are also influenced by people's awareness of their environment, attitudes, beliefs, etc. This means that perceptions of the built environment can be modified by more than making physical changes to the environment by improving awareness of existing facilities and changing attitudes. Examining correlations between perceived and objective measures of the built environment is important from this perspective, as this can inform the types of changes that should be made to perceptions that may ultimately result in more physical activity within the built environment and better health.

Therefore, this study examined the relationships between Walk Score® and perceived walkable environmental attributes in ultrahigh density areas in Japan.

2. Methods

2.1. Data source and participants

Cross-sectional data were collected from an epidemiological study to identify social and urban design correlations of sedentary behaviour and physical activity among middle-aged adults in Japan. The study design and recruitment procedure details have been described elsewhere (Ishii et al., 2018; Koohsari et al., 2020). Briefly, data were obtained between July and December 2013 and April 2014 to February 2015 from a randomly selected sample of residents living in two Japanese urban localities, Koto Ward and Matsuyama City. An invitation letter was sent to 6,000 adult residents (aged 40–64 years), randomly selected from the government registry of residential addresses (balanced by gender and age group). A total of 866 individuals agreed to participate in the study (response letter = 14.4%), of which 779 completed a self-administrative questionnaire. A book voucher (¥1000 equivalent to approximately USD 10) was offered to these participants. The Institutional Ethics Committee of Waseda University approved this study (2010–238).

2.2. Measures

2.2.1. Walk Score®

Walk Score® is a free, openly available web-based tool that provides an objective walkability score for any given location. Walk Score® uses a decay function to assign a raw score to each location based on its network distance to nearby amenities such as stores, cafes, bookshops, parks, and restaurants within a mile from that location (Walk Score, 2020). Population density and road metrics such as block length and intersection density were taken into account to calculate the final scores ranging from 0 to 100. Higher scores indicate areas that are conducive and supportive of walking. Each participant's residential address was

entered into the Walk Score® publicly available interface (www.walk-score.com) by two independent project members in 2016. Disagreements between the two researchers were checked and rectified by the first author. Continuous Walk Score® values were examined in this study.

2.2.2. Perceived walkable environment attributes

The perceived walkable built attributes were evaluated using the Japanese version of the International Physical Activity Questionnaire Environmental Module (IPAQ-E) with a 4-point Likert scale (strongly agree, somewhat agree, somewhat disagree and strongly disagree). The IPAQ-E has demonstrated good test–retest reliability in Japanese adults (Inoue et al., 2009). Nine items of the IPAQ-E were included (Inoue et al., 2009): (1) population density ('What is the main type of housing in your neighbourhood?' For this question, the five answers were detached single-family housing; apartments with 2–3 storeys; a mix of single-family housing and apartments with 2–3 storeys; condos with 4–12 storeys; and condos with > 13 storeys); (2) access to shops ('Many shops, stores, markets or other places to buy things I need are within easy walking distance of my home'); (3) access to public transport ('It is within a 10–15 min walk to a transit stop from my home); (4) presence of sidewalks ('There are sidewalks on most of the streets in my neighbourhood'); (5) presence of bike lanes ('There are facilities to bicycle in or near my neighbourhood, such as special lanes, separate paths or trails, shared use paths for cycles and pedestrians'); (6) access to recreational facilities ('My neighbourhood has several free or low-cost recreation facilities, such as parks, walking trails, bike paths, recreation centres, playgrounds, public swimming pools, etc.'); (7) aesthetics ('There are many interesting things to look at while walking in my neighbourhood'; (8) traffic safety ('There is so much traffic on the streets that it makes it difficult or unpleasant to walk in my neighbourhood'; (9) safety from crime ('The crime rate in my neighbourhood makes it unsafe to go on walks at night'). Two negative items, including traffic safety and safety from crime, were reverse coded, with higher scores representing a safer environment. In line with several previous studies (Arvidsson et al., 2012; Orstad et al., 2018), perceived overall walkability was measured by summing the nine perceived built environment attributes, resulting in a possible range from 11 to 37 (Cronbach's alpha = 0.70).

2.2.3. Covariates

Participants reported several sociodemographic factors including age, gender (female or male), working status (employed or unemployed), highest education (tertiary or below tertiary), marital status (single or couple), living status (alone or with others), and gross annual household income (<¥5,000,000 or ≥ ¥5,000,000).

2.3. Statistical analysis

Descriptive statistics of participants' sociodemographic and perceived walkable environmental attributes were reported. Partial correlation coefficients were used to estimate the correlations between Walk Score® and perceived walkable environmental attributes including overall walkability, adjusted for covariates. The magnitude of the observed significant correlation coefficients was interpreted using Cohen's guidelines for small ($r > 0.10$), medium ($r > 0.30$), and large ($r > 0.50$) (Cohen, 2013). Analyses were conducted using Stata 15.0 (Stata Corp, College Station, Texas), and the level of significance was set at $p < 0.05$.

3. Results

After excluding missing data on Walk Score® and perceived walkable environmental attributes, data from 756 participants (97%) were analysed. Participants' sociodemographic characteristics are presented in Table 1. The mean age of the participants was 52.2 ± 7.0 years and approximately 60% were female. The majority of participants were

Table 1
Characteristics of study participants (N = 756).

Variable	Mean (SD) or N (%)
Age (years)	52.2 (7.0)
Gender	
Female	455 (60.2)
Male	301 (39.8)
Working status	
Employed	620 (82.0)
Unemployed	131 (17.3)
Missing	5 (0.7)
Highest education	
Tertiary	483 (63.9)
Below tertiary	269 (35.6)
Missing	4 (0.5)
Marital status	
Single	155 (20.5)
Couple	596 (78.8)
Missing	5 (0.7)
Living status	
Alone	85 (11.2)
With others	671 (88.8)
Gross annual household income	
<¥5,000,000	402 (53.2)
≥ ¥5,000,000	337 (44.6)
Missing	17 (2.2)

employed (82%), had a high tertiary educational attainment (64%), were couples (79%), lived with others (89%), and had an annual gross household income lower than ¥5,000,000 per year (53%).

Mean scores for perceived walkable environmental attributes are shown in Table 2. The mean Walk Score® was 73.0 (SD = 25.0), ranging from 0 to 100. Adjusted for covariates, positive correlations were observed between Walk Score® and several perceived walkable environmental attributes. There was a large correlation between Walk Score® and access to shops (0.58; $p < 0.001$). There were medium correlations between Walk Score® and population density (0.38; $p < 0.001$), access to public transport (0.34; $p < 0.001$), presence of sidewalks (0.41; $p < 0.001$), and access to recreational facilities (0.37; $p < 0.001$), and there was a small correlation between Walk Score® and the

Table 2
Partial correlation coefficients between Walk Score® and perceived walkable environmental attributes (N = 756).

Variable	M ± SD	Unadjusted r	P	Adjusted r [a]	P
Population density	2.60 ± 1.65	0.44	< 0.001	0.38	< 0.001
Access to shops	3.02 ± 1.02	0.58	< 0.001	0.58	< 0.001
Access to public transport	3.62 ± 0.78	0.37	< 0.001	0.34	< 0.001
Presence of sidewalks	3.17 ± 0.97	0.44	< 0.001	0.41	< 0.001
Presence of bike lanes	2.04 ± 1.08	0.18	< 0.001	0.16	< 0.001
Access to recreational facilities	2.84 ± 1.04	0.39	< 0.001	0.37	< 0.001
Aesthetics	2.70 ± 0.85	−0.02	0.61	−0.06	0.08
Traffic safety	3.11 ± 0.81	−0.10	< 0.05	−0.13	< 0.001
Safety from crime	3.20 ± 0.76	0.06	0.08	0.06	0.13
Overall perceived walkability	26.30 ± 5.00	0.52	< 0.001	0.48	< 0.001

The maximum value for perceived population density and for other perceived built environment attributes was 5 and 4, accordingly. The maximum value for overall perceived walkability was 37.

[a] Adjusted for age, gender, working status, highest education, marital status, living status, and gross annual household income.

presence of bike lanes (0.16; p < 0.001). There was a small negative correlation between Walk Score® and traffic safety (-0.13; p < 0.001). No significant correlations were found between Walk Score® and aesthetics or between Walk Score® and safety from crime. There was a medium correlation between Walk Score® and overall perceived walkability (0.48; p < 0.001).

4. Discussion

In this study, as the first study conducted in Asia, we aimed to examine the correlations between Walk Score® and perceived walkable environment. We found that Walk Score® was significantly positively correlated with several perceived walkable environmental attributes, including population density, access to shops, public transport, recreational facilities, and the presence of sidewalks and bike lanes. Notably, a large and a medium correlation was observed between Walk Score® and perceived access to shops and between Walk Score® and overall perceived walkability, respectively. Commercial destinations tend to exist in areas with high population densities (i.e., cost-benefit). Therefore, a positive correlation between Walk Score® and perceived population density was expected. These findings are consistent with previous studies conducted in the U.S. reporting small to large associations between Walk Score® and perceived built environment (Carr et al., 2010; Lo et al., 2019; Silveira and Motl, 2020). For example, Silveira and Motl (2020) found significant positive correlations between several perceived built environment measures such as street connectivity, land use mix and residential density (measured using the NEWS-A questionnaire), and Walk Score®. Lo et al. (2019) also found that a higher Walk Score® was significantly correlated with perceived proximity to destinations and having street shoulders. Our results add to these findings and extend them into the Japanese context as an example of Asian ultrahigh density areas.

Several previous studies found that Walk Score® was significantly correlated with objective measures of the built environment in relation to walking (Carr et al., 2011; Koohsari et al., 2018a). However, the magnitudes of the correlation coefficients were mostly larger than those of the perceived built environment measures. People's perceptions of built environment attributes do not always match objective environmental measures, and they do have a distinct influence on people's engagement in active behaviours (Gebel et al., 2009, 2011; Koohsari et al., 2015). Therefore, it is suggested that strategies to promote physical activity should target both the objective environment and people's perceptions of the environment (Koohsari et al., 2015). Our findings together with the results from the studies examining Walk Score® and objective built environment measures suggest that Walk Score® can be useful as an evaluative intervention tool, as it can represent (to some degree) both objective and perceived measures of the built environment related to walking.

We also identified that Walk Score® was related to the presence of bike lanes. It is likely that a walkable area with high density and a variety of destinations nearby attract cyclists and benefit from bike infrastructure. However, built environment features conducive to walking are not necessarily the same as those beneficial for biking (Forsyth and Krizek, 2011). Further research is needed to explore whether Walk Score® is correlated with other built environment features beneficial for biking. No significant correlations were observed between Walk Score® and aesthetics and safety from crime. This does not necessarily mean that aesthetics and safety from crime have limited importance for walking behaviour. While the influence of these factors on walking has only received limited interest, some have pointed to their significance (Mehta, 2008). Aesthetics and safety from crime are microscale urban design qualities that Walk Score® does not attempt to measure. Future studies can match a street segment with excellent micro-scale urban design qualities and another with poor qualities for a survey of residents' perceptions in the surrounding area.

A small negative correlation was observed between Walk Score® and traffic safety. This is consistent with a previous study, which found a small positive correlation between Walk Score® and perceived traffic hazards (Silveira and Motl, 2020). Since Walk Score® algorithm does not include any traffic-related items (at this stage), it is unknown whether the observed correlation between Walk Score® and traffic safety is spurious or whether there is a plausible link. While highly walkable areas characterised by various destinations and well-connected streets are attractive for pedestrians, such areas may also inevitably draw motor vehicles. A study conducted in the U.S. found that higher street connectivity was associated with more accidents between cars and people and among cars (Marshall and Garrick, 2011). Another study conducted in Canada found that residents in walkable neighbourhoods, those with good street connectivity and destinations, had significantly lower perceived traffic safety (Jack and McCormack, 2014). Thus, traffic safety may be a concern for residents in areas with higher Walk Score® values, where large numbers of pedestrians and cars interact.

This study has some limitations. The majority of the participants in our sample were involved in a couple's relationship and lived with others and we had a low response rate. These may limit the generalisability of our findings. There was a temporal mismatch between our perceived built environment measures (based on the survey in 2013–2015) and Walk Score® (extracted in 2016). However, changes in the built environment (macrolevel) are relatively stable in the short term (Clary et al., 2020; Hirsch et al., 2014). Additionally, Walk Score® company did not release the detailed procedure on how they account for road metrics in their final Walk Score®. Other factors, such as physical activity behaviour and exposure to or interaction with their neighbourhood built environment, which may influence perceptions, were not considered in this study.

5. Conclusions

Walk Score® is a freely-available objective tool that provides an objective neighbourhood walkability score with no need for any spatial data or GIS expertise. This study's findings highlight that Walk Score® was correlated with several perceived walkable environment attributes in the context of ultrahigh density areas in Asia. Further research is needed to confirm these findings in other countries and areas.

CRediT authorship contribution statement

Mohammad Javad Koohsari: Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Gavin R. McCormack:** Methodology, Writing - review & editing. **Ai Shibata:** Project administration, Writing - review & editing. **Kaori Ishii:** Project administration, Writing - review & editing. **Akitomo Yasunaga:** Methodology, Writing - review & editing. **Tomoki Nakaya:** Methodology, Writing - review & editing. **Koichiro Oka:** Conceptualization, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. In particular, none of the authors has a financial interest in https://www.walkscore.com/.

References

Adams, M.A., Frank, L.D., Schipperijn, J., Smith, G., Chapman, J., Christiansen, L.B., Coffee, N., Salvo, D., du Toit, L., Dygrýn, J., Hino, A.A., Lai, P.-C., Mavoa, S., Pinzón, J., Van de Weghe, N., Cerin, E., Davey, R., Macfarlane, D., Owen, N., Sallis, J.F., 2014. International variation in neighborhood walkability, transit, and recreation environments using geographic information systems: the IPEN adult study. Int. J. Health Geogr. 13 (1), 43.

Al Tunaiji, H., Davis, J.C., Mackey, D.C., Khan, K.M., 2014. Population attributable fraction of type 2 diabetes due to physical inactivity in adults: a systematic review. BMC Public Health 14 (1), 1–9.

Arvidsson, D., Kawakami, N., Ohlsson, H., Sundquist, K., 2012. Physical activity and concordance between objective and perceived walkability. Med. Sci. Sports Exerc. 44 (2), 280–287.

Bereitschaft, B., 2018. Walk Score® versus residents' perceptions of walkability in Omaha, NE. J. Urbanism: Int. Res. Placemaking Urban Sustainability 11 (4), 412–435.

Braun, L.M., Rodríguez, D.A., Evenson, K.R., Hirsch, J.A., Moore, K.A., Diez Roux, A.V., 2016. Walkability and cardiometabolic risk factors: cross-sectional and longitudinal associations from the multi-ethnic study of atherosclerosis. Health Place 39, 9–17.

Brownson, R.C., Baker, E.A., Housemann, R.A., Brennan, L.K., Bacak, S.J., 2001. Environmental and policy determinants of physical activity in the United States. Am. J. Public Health 91 (12), 1995–2003.

Brownson, R.C., Hoehner, C.M., Day, K., Forsyth, A., Sallis, J.F., 2009. Measuring the built environment for physical activity: state of the science. Am. J. Prev. Med. 36 (4), S99–S123.e12.

Carr, L.J., Dunsiger, S.I., Marcus, B.H., 2010. Walk score™ as a global estimate of neighborhood walkability. Am. J. Prev. Med. 39 (5), 460–463.

Carr, L.J., Dunsiger, S.I., Marcus, B.H., 2011. Validation of Walk Score for estimating access to walkable amenities. Br. J. Sports Med. 45 (14), 1144–1148.

Chiu, M., Rezai, M.-R., Maclagan, L.C., Austin, P.C., Shah, B.R., Redelmeier, D.A., Tu, J. V., 2016. Moving to a highly walkable neighborhood and incidence of hypertension: a propensity-score matched cohort study. Environ. Health Perspect. 124 (6), 754–760.

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 Geriatr 17 (1), 82.

Clary, C., Lewis, D., Limb, E., Nightingale, C.M., Ram, B., Page, A.S., Cooper, A.R., Ellaway, A., Giles-Corti, B., Whincup, P.H., Rudnicka, A.R., Cook, D.G., Owen, C.G., Cummins, S., 2020. Longitudinal impact of changes in the residential built environment on physical activity: findings from the ENABLE London cohort study. Int. J. Behavioral Nutrition Phys. Activity 17 (1). https://doi.org/10.1186/s12966-020-01003-9.

Cohen, J., 2013. Statistical power analysis for the behavioral sciences. Academic press.

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.

Consoli, A., Nettel-Aguirre, A., Spence, J.C., McHugh, T.-L., Mummery, K., McCormack, G.R., Vuillemin, A., 2020. Associations between objectively-measured and self-reported neighbourhood walkability on adherence and steps during an internet-delivered pedometer intervention. PLoS ONE 15 (12), e0242999.

Dietz, W.H., Douglas, C.E., Brownson, R.C., 2016. Chronic disease prevention: tobacco avoidance, physical activity, and nutrition for a healthy start. JAMA 316 (16), 1645–1646.

Ding, D., Lawson, K.D., Kolbe-Alexander, T.L., Finkelstein, E.A., Katzmarzyk, P.T., Van Mechelen, W., Pratt, M., Committee, L.P.A.S.E., 2016. The economic burden of physical inactivity: a global analysis of major non-communicable diseases. Lancet 388 (10051), 1311–1324.

Duncan, D.T., Aldstadt, J., Whalen, J., Melly, S.J., 2013. Validation of Walk Scores and Transit Scores for estimating neighborhood walkability and transit availability: a small-area analysis. GeoJournal 78 (2), 407–416.

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. Int. J. Environ. Res. Public Health 8 (11), 4160–4179.

Durand, C.P., Andalib, M., Dunton, G.F., Wolch, J., Pentz, M.A., 2011. A systematic review of built environment factors related to physical activity and obesity risk: implications for smart growth urban planning. Obes. Rev. 12 (5), e173–e182.

Forsyth, A., Krizek, K., 2011. Urban design: is there a distinctive view from the bicycle? J Urban Des 16 (4), 531–549.

Frehlich, L., Blackstaffe, A., McCormack, G.R., 2020. Test–retest Reliability and Construct Validity of an Online and Paper Administered Physical Activity Neighborhood Environment Scale (PANES). Meas. Phys. Educ. Exerc. Sci. 24 (1), 1–10.

Gebel, K., Bauman, A., Owen, N., 2009. Correlates of non-concordance between perceived and objective measures of walkability. Ann. Behav. Med. 37 (2), 228–238.

Gebel, K., Bauman, A.E., Sugiyama, T., Owen, N., 2011. Mismatch between perceived and objectively assessed neighbourhood walkability attributes: prospective relationships with walking and weight gain. Health Place 17 (2), 519–524.

Group, S.-R., 2007, Environmental Supports for Physical Activity Questionnaire. Prevention Research Center, Norman J. Arnold School of Public Health, University of South Carolina; 2002.

Guthold, R., Stevens, G.A., Riley, L.M., Bull, F.C., 2018. Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1· 9 million participants. Lancet Glob Health 6 (10), e1077–e1086.

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. Am. J. Public Health 104 (3), e49–e56.

Inoue, S., Murase, N., Shimomitsu, T., Ohya, Y., Odagiri, Y., Takamiya, T., Ishii, K., Katsumura, T., Sallis, J.F., 2009. Association of physical activity and neighborhood environment among Japanese adults. Prev. Med. 48 (4), 321–325.

Ishii, K., Shibata, A.i., Kurita, S., Yano, S., Inoue, S., Sugiyama, T., Owen, N., Oka, K., 2018. Validity and reliability of Japanese-language self-reported measures for assessing adults domain-specific sedentary time. J. Epidemiology 28 (3), 149–155.

Jack, E., McCormack, G.R., 2014. The associations between objectively-determined and self-reported urban form characteristics and neighborhood-based walking in adults. Int. J. Behavioral Nutrition Physical Activity 11 (1), 71. https://doi.org/10.1186/1479-5868-11-71.

Kärmeniemi, M., Lankila, T., Ikäheimo, T., Koivumaa-Honkanen, H., Korpelainen, R., 2018. The built environment as a determinant of physical activity: a systematic review of longitudinal studies and natural experiments. Ann. Behav. Med. 52 (3), 239–251.

Kerr, J., Sallis, J.F., Owen, N., De Bourdeaudhuij, I., Cerin, E., Sugiyama, T., Reis, R., Sarmiento, O., Fromel, K., Mitas, J., 2013. Advancing science and policy through a coordinated international study of physical activity and built environments: IPEN adult methods. J. Phys. Act Health 10 (4), 581–601.

Koohsari, M.J., Badland, H., Sugiyama, T., Mavoa, S., Christian, H., Giles-Corti, B., 2015. Mismatch between perceived and objectively measured land use mix and street connectivity: associations with neighborhood walking. J. Urban Health 92 (2), 242–252.

Koohsari, M.J., Kaczynski, A.T., Nakaya, T., Shibata, A.i., Ishii, K., Yasunaga, A., Stowe, E.W., Hanibuchi, T., Oka, K., 2019. Walkable urban design attributes and Japanese older adults' body mass index: mediation effects of physical activity and sedentary behavior. Am. J. Health Promotion 33 (5), 764–767.

Koohsari, M.J., Shibata, A., Ishii, K., Kurosawa, S., Yasunaga, A., Hanibuchi, T., Nakaya, T., McCormack, G.R., Oka, K., 2020. Dog ownership and adults' objectively-assessed sedentary behaviour and physical activity. Sci. Rep. 10 (1), 1–7.

Koohsari, M.J., Sugiyama, T., Hanibuchi, T., Shibata, A.i., Ishii, K., Liao, Y., Oka, K., 2018a. Validity of Walk Score® as a measure of neighborhood walkability in Japan. Prev. Med. Rep. 9, 114–117.

Koohsari, M.J., Sugiyama, T., Shibata, A.i., Ishii, K., Hanibuchi, T., Liao, Y., Owen, N., Oka, K., 2018b. Walk Score® and Japanese adults' physically-active and sedentary behaviors. Cities 74, 151–155.

Lee, I.-M., Shiroma, E.J., Lobelo, F., Puska, P., Blair, S.N., Katzmarzyk, P.T., 2012. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. Lancet 380 (9838), 219–229.

Lee, R.E., McAlexander, K., Banda, J., 2011. Reversing the obesogenic environment. Human Kinetics.

Lin, L., Moudon, A.V., 2010. Objective versus subjective measures of the built environment, which are most effective in capturing associations with walking? Health Place 16 (2), 339–348.

Lo, B., Graham, M., Folta, S., Paul, L., Strogatz, D., Nelson, M., Parry, S., Carfagno, M., Wing, D., Higgins, M., Seguin, R., 2019. Examining the associations between walk score, perceived built environment, and physical activity behaviors among women participating in a community-randomized lifestyle change intervention trial: strong hearts, healthy communities. Int. J. Environ. Res. Public Health 16 (5), 849. https://doi.org/10.3390/ijerph16050849.

Marshall, W.E., Garrick, N.W., 2011. Does street network design affect traffic safety? Accid. Anal. Prev. 43 (3), 769–781.

McCormack, G.R., Blackstaffe, A., Nettel-Aguirre, A., Csizmadi, I., Sandalack, B., Uribe, F.A., Rayes, A., Friedenreich, C., Potestio, M.L., 2018. The independent associations between Walk Score® and neighborhood socioeconomic status, waist circumference, waist-to-hip ratio and body mass index among urban adults. Int. J. Environ. Res. Public Health 15 (6), 1226.

McCormack, G.R., Shiell, A., 2011. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. Int. J. Behav. Nutr. Phys. Act 8 (1), 125. https://doi.org/10.1186/1479-5868-8-125.

Mehta, V., 2008. Walkable streets: pedestrian behavior, perceptions and attitudes. J. Urbanism 1 (3), 217–245.

Méline, J., Chaix, B., Pannier, B., Ogedegbe, G., Trasande, L., Athens, J., Duncan, D.T., 2017. Neighborhood walk score and selected Cardiometabolic factors in the French RECORD cohort study. BMC Public Health 17 (1), 960.

Nugent, R., Bertram, M.Y., Jan, S., Niessen, L.W., Sassi, F., Jamison, D.T., Pier, E.G., Beaglehole, R., 2018. Investing in non-communicable disease prevention and management to advance the Sustainable Development Goals. Lancet 391 (10134), 2029–2035.

Nykiforuk, C.I.J., McGetrick, J.A., Crick, K., Johnson, J.A., 2016. Check the score: Field validation of Street Smart Walk Score in Alberta, Canada. Prev. Med. Rep. 4, 532–539.

Orstad, S.L., McDonough, M.H., James, P., Klenosky, D.B., Laden, F., Mattson, M., Troped, P.J., 2018. Neighborhood walkability and physical activity among older women: Tests of mediation by environmental perceptions and moderation by depressive symptoms. Prev. Med. 116, 60–67.

Pratt, M., Norris, J., Lobelo, F., Roux, L., Wang, G., 2014. The cost of physical inactivity: moving into the 21st century. Br. J. Sports Med. 48 (3), 171–173.

Saelens, B.E., Handy, S.L., 2008. Built environment correlates of walking: a review. Med. Sci. Sports Exerc. 40 (7 Suppl), S550.

Saelens, B.E., Sallis, J.F., Black, J.B., Chen, D., 2003. Neighborhood-based differences in physical activity: an environment scale evaluation. Am. J. Public Health 93 (9), 1552–1558.

Sallis, J.F., Kerr, J., Carlson, J.A., Norman, G.J., Saelens, B.E., Durant, N., Ainsworth, B. E., 2010. Evaluating a brief self-report measure of neighborhood environments for physical activity research and surveillance: Physical Activity Neighborhood Environment Scale (PANES). Journal of physical activity and health 7 (4), 533–540.

Sallis, J. F., Owen, N., 2015, Ecological models of health behavior, in: Health Behavior Theory (K. Glanz, B. K. Rimer, k. Viswanath, eds.), San Francisco, Jossey-Bass., San Francisco, Jossey-Bass., pp. 43-64.

Salvo, D., Reis, R.S., Sarmiento, O.L., Pratt, M., 2014. Overcoming the challenges of conducting physical activity and built environment research in Latin America: IPEN Latin America. Prev. Med. 69, S86–S92.

Silveira, S.L., Motl, R.W., 2020. Abbreviated Neighborhood Environment Walkability scale in persons with multiple sclerosis: Initial validation of score inferences. J. Transp Health 19, 100952. https://doi.org/10.1016/j.jth.2020.100952.

Towne, S.D., Won, J., Lee, S., Ory, M.G., Forjuoh, S.N., Wang, S., Lee, C., 2016. Using Walk Score™ and neighborhood perceptions to assess walking among middle-aged and older adults. J. Community Health 41 (5), 977–988.

Tuckel, P., Milczarski, W., 2015. Walk Score^TM, perceived neighborhood walkability, and walking in the US. Am. J. Health Behav. 39 (2), 242–256.

Twardzik, E., Judd, S., Bennett, A., Hooker, S., Howard, V., Hutto, B., Clarke, P., Colabianchi, N., 2019. Walk Score and objectively measured physical activity within a national cohort. J. Epidemiol. Community Health 73 (6), 549–556.

United Nations, 2015. Transforming our world: The 2030 agenda for sustainable development. United Nations, Department of Economic and Social Affairs, New York.

Wahid, A., Manek, N., Nichols, M., Kelly, P., Foster, C., Webster, P., Kaur, A., Friedemann Smith, C., Wilkins, E., Rayner, M., Roberts, N., Scarborough, P., 2016. Quantifying the association between physical activity and cardiovascular disease and diabetes: a systematic review and meta-analysis. J Am Heart Assoc 5 (9). https://doi.org/10.1161/JAHA.115.002495.

Walk Score, 2020, Walk Score Methodology. https://www.walkscore.com/methodology.shtml.

Weiss, R.L., Maantay, J.A., Fahs, M., 2010. Promoting active urban aging: A measurement approach to neighborhood walkability for older adults. Cities and the Environment 3 (1), 1–17.

Wilson, J.S., Kelly, C.M., Schootman, M., Baker, E.A., Banerjee, A., Clennin, M., Miller, D. K., 2012. Assessing the built environment using omnidirectional imagery. Am. J. Prev. Med. 42 (2), 193–199.