A novel walkability index for London predicts walking time in adults

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Abstract

Objective: To develop a novel walkability index for London and test it through measurement of associations between neighbourhood walkability and walking among adults using data from the Whitehall II Study.

Background: Physical activity is essential for health; walking is the easiest way to incorporate it into everyday life. Many studies have reported positive associations between neighbourhood walkability and walking but the majority have focused on cities in North America and Australasia. Urban form with respect to street connectivity, residential density and land use mix – common components of walkability indices – is likely to differ in European cities.

Methods: A walkability index for the 633 spatially contiguous census area statistics wards of London was constructed, comprising three core dimensions associated with walking behaviours: residential dwelling density, street connectivity and land use mix. Walkability was expressed as quartile scores, with wards scoring 1 being in the bottom 25% in terms of walkability, and those scoring 4 in the top 25%. A neighbourhood walkability score was assigned to each London-dwelling Whitehall II Study participant (2003-04, N=3020, mean +/- SD age=61.0y +/-6.0) as the walkability score of the ward in which their residential postcode fell. Associations between neighbourhood walkability and weekly walking time were measured using multiple logistic regression.

Results: After adjustment for individual level factors and area deprivation, people in the most walkable neighbourhoods were significantly more likely to spend ≥6hr/wk (Odds Ratio 1.4; 95%Confidence Interval 1.1-1.9), than those in the least walkable.

Conclusions: The walkability index constructed can predict walking time in adults: living in a more walkable neighbourhood is associated with longer weekly walking time. The index may help urban planners identify and design neighbourhoods in London with characteristics that are potentially more supportive of walking and, thereby, promote public health.

1. Background

Walking is a form of transport, with physical activity a healthy “side-effect”. An understanding of the physical environmental barriers and facilitators of this personal mobility is thus a prerequisite of creating neighbourhoods that improve public health. The relationships between urban form and physical activity have been examined in many cities of high income countries but most studies have focussed on cities in North America and Australia (Adams et al., 2013). The urban form of London in the United Kingdom is likely to differ in many ways from that of non-European cities: London is significantly older and its growth has been constrained by a greenbelt, a land use policy to restrict urban growth. Public health concerns and industrialisation during the nineteenth and twentieth centuries in London led to dispersal of the population and a shift from a pedestrian-oriented transport network to one prioritizing motorised vehicles. Whilst this shift helped eradicate overcrowding-associated endemic infectious diseases and to transport people and goods faster, London’s rapid spatial evolution may have inadvertently driven the emergence of the non-infectious public health crises we see today. High blood pressure, obesity and overweight, and physical inactivity are the top three causes of death (Ezzati et al., 2006) and are major contributors to disability-adjusted life-years (DALYs) in England (Newton et al., 2015). The enablement of excessive mobility, which permits travel over greater distances than on foot or by bicycle, probably reduced physical activity in individuals' daily routines and increased obesity (Adams, 1999): for example, countries with the highest levels of active transportation have the lowest obesity rates (Bassett et al., 2008).

Walking is associated with physical environmental attributes such as greater diversity in land use (land use mix) (Duncan et al., 2009) (Ewing et al., 2004) (Badland and Schofield, 2005), greater street connectivity (Sallis et al., 2004) (Lee and Moudon, 2006) (Saelens et al., 2003), and higher residential density (Glazier et al., 2014) (Forsyth et al., 2007). Greater land use mix is posited to enable better access to services and employment, and to induce shorter within-neighbourhood travel by foot when a range of destinations is located near residences (Cervero and Kockelman, 1997). In areas where different destinations such as restaurants and workplaces are co-located, walking is also likely to be more time-efficient than using public or private motorised transport to access them. Street connectivity relates to the feasibility of walking from one point to another: the more connected the streets, the more direct the route through the network and the greater the walkability (Handy et al., 2002). Higher residential density is proposed to create a more walkable environment by providing a critical mass of walkers seen by other people who are, in turn, encouraged by safety in numbers to walk as well (Frank et al., 2005). Also, traffic congestion associated with higher residential density may promote active above non-active travel (Forsyth et al., 2007). Attributes of the physical environment that are associated with walking often co-exist; historically many researchers quantified a single attribute as a proxy for walkability, defined as the extent to which a place supports walking and cycling as physically active forms of transport and recreation. However, a consensus is growing that physical environmental attributes should not be measured in isolation because they do not always reflect one another, and may be insufficient individually to promote physical activity (Krizek, 2003). For example, greater street connectivity may be relevant only if people have a range of places with complementary uses to visit - greater land use mix (Frank and Engelke, 2001).

Walkability indices are designed to reflect these various elements by capturing the multiple attributes of a place for which there is evidence for a positive association with walking or cycling. The last decade has seen the construction and testing of walkability indices, at various spatial scales and in different settings, for a wide range of populations. Researchers have tailored components and their quantification, and units of analysis to fit their hypotheses because walkability indices must be designed specifically with the research population and setting in mind (Maghelal and Capp, 2011). However, three core components – net residential density, street connectivity and land use mix – are salient across populations and form the basis of a majority of indices. There is much evidence for positive associations between composite measures of walkability and walking (Owen et al., 2004) (Wendel-Vos et al., 2004) (Saelens and Handy, 2008) but most is from studies of cities in North America and Australia, with less research conducted in European settings. Given differences in urban form, extrapolation of findings to European cities such as London is not appropriate. A review of European studies investigating the relationship between the physical environment and physical activity found results generally concordant with those of non-European studies (Van Holle et al., 2012). However, it noted that measurements of environmental attributes were more often perceived than objective, and that walkability was understudied in European cities. Also, more studies measured total physical activity than walking specifically. This study aimed to fill the research gap through examination of associations between a novel walkability index and walking in London using data from the Whitehall II Study. A positive association between walkability and time spent walking per week was expected.

2. Method

The study sample was drawn from Phase 7 of the Whitehall II study conducted in 2003/04. This is an ongoing longitudinal study of civil servants to examine the social determinants of health (Marmot and Brunner, 2005). In 1985, all people between the ages of 35 and 55 years employed in the London offices of the British Civil Service were invited to participate in the study. 73% agreed to participate, giving a sample size of 10,308 at Phase 1. At 5-yearly intervals, the cohort is invited to a research clinic at which physical examinations are conducted and biological specimens taken. Between these clinic phases, a questionnaire is mailed to participants to collect self-reported data. Geographic residential data including postcodes is collected to maintain contact with participants. These data are useful for examining relationships between health-related behaviors and environmental factors which have an inherent spatial dimension. Phase 7 comprised 6,967 individuals (68% of Phase 1 participants), from whom the 3,020 with a valid London postcode and data on physical activity were selected. 38% of this sample (LWIIP7) was female; the mean age (standard deviation) was 61.0 years (±6.0). The walking volume outcome was derived from the physical activity section of the questionnaire, a modified version of the Minnesota leisure-time physical activity questionnaire (Taylor et al., 1978). The reliability of the Minnesota questionnaire has been shown to be high (Folsom et al., 1986). Questionnaire items elicited information on frequency and duration of walking over the past 4 weeks. Walking volume was calculated as the product of duration and frequency of walking. A variable was then constructed, constituting the outcome of being in the top tertile of LWIIP7 for time spent walking per week (TTW) i.e. >6 to 63hrs/wk.

Neighbourhoods were operationalised as census area statistics wards because in London the size of these administrative units was relatively uniform and approximated the extent of the walkable area from home (Moudon et al., 2006). Also, previous work suggested that wards constituted a better spatial unit of enumeration of walkability for investigation of association with walking than other administrative units, and circular and network buffers (Stockton, 2014). The construction of the walkability index was based on a method detailed elsewhere (Christian et al., 2011), with measurements of street connectivity, residential density and land use mix. However, a major revision of this method was made with regard to the spatial units of enumeration. The index for the present study was derived from the walkability component scores of all constituent administrative areas – wards – for the spatially contiguous area (London) that contained the residential locations of participants. Neighbourhood walkability was evaluated objectively using Geographical Information Systems (GIS) software, ArcGIS for Desktop Advanced version 10.1 ("Esri Products | A Complete GIS Mapping Software System," 2012). For each ward three environmental measurements representing the core dimensions of walkability of residential density, street connectivity and land use mix were taken. Residential density was the number of occupied households in the ward as indicated by census data ("Casweb Homepage CP1," 2012) divided by the area of land classified as residential in the ward in a land use mapping database, UKMap ("UKMap – The GeoInformation Group," 2012). Residential dwelling densities were recoded into deciles with wards scoring 1 having the lowest residential dwelling density and those scoring 10 the highest. Street connectivity was the number of three or more way junctions in the ward as indicated by a combined road and urban paths network (Ordnance Survey, 2013) divided by the total ward area. As for residential densities, street connectivities were recoded into deciles. In the measurement of land use mix, an entropy score for each neighbourhood was calculated according to the following equation (where H = land use mix score, i = the land use, p_i = the proportion of the area covered by the land use against the sum of the area of the land uses of interest, n = the number of land use categories), adapted from previous research (Frank et al., 2005) (Frank et al., 2007):

$$H = -1 \sum_{i=1}^{n} p_i * \ln(p_i) / \ln(n)$$

Land uses included in the derivation of the land use mix measure were those falling into the four categories of “Residential”, “Health, welfare and community”, “Retail” and “Offices”. These categories were considered to encompass land uses supportive of physical activity as personal business destinations potentially reached by foot. Land use mix scores were recoded into deciles. The overall walkability score was calculated as the sum of the three core walkability component decile scores and the final walkability scores were then recoded into quartiles. Thus, each ward was assigned a score of 1, 2, 3 or 4, with a score of 1 indicative of the lowest walkability relative to other wards and a score of 4 indicative of the highest. Each participant was then attributed the walkability score of the ward in which his or her residential postcode fell. Multivariate logistic regression was performed to examine the associations between walkability and walking. Model 1 was unadjusted for any confounders; Model 2 was adjusted for individual level sociodemographic factors; and Model 3 was also adjusted for area deprivation, in addition to the individual level factors. The individual level factors were sex, age, economic activity, car availability, marital status and ethnicity, and the area deprivation variable was constructed as England-based quintiles of the 2004 Index of Multiple Deprivation (IMD2004) at lower super output area (LSOA) level (Government, 2005). Results were computed as odds ratios alongside their 95% confidence intervals. The reference category in each model was the lowest walkability quartile score, Quartile score 1, representing the lowest neighbourhood walkability. Therefore, an odds ratio indicated the odds of being in the top tertile for time spent walking per week for those exposed to – or living in – a neighbourhood of higher walkability relative to the odds of this outcome for those in a neighbourhood of the lowest walkability. Statistical tests for trend were performed to evaluate overall patterns in the relationships between walkability and walking with respect to the trend for a dose effect of the quartile score.

3. Results

Spatial variation in walkability decile scores for wards across London is presented in the Map 1, illustrating a radial decay in the walkability of London from the centre to the periphery. Of the 3020 LWIIP7 participants the highest proportion (38%) resided in ward-defined neighbourhoods of the lowest walkability as indicated by a quartile score of 1, whilst the lowest proportion (16%) resided in the highest walkability neighbourhoods as indicated by a quartile score of 4. Characteristics of the participants as a function of being in the top tertile of the sample for time spent walking (TTW) are presented in Table 1. All factors were included as potential confounders in subsequent analyses of associations between walking and walkability. The associations between walkability and TTW are presented in Table 2. Those in more walkable neighbourhoods were significantly more likely to have this outcome before accounting for sociodemographic factors. Even after adjustment for sociodemographic factors and further adjustment for area deprivation, a positive association remained between walkability and TTW: relative to those in the least walkable neighbourhoods, those in the most were more likely to spend a total of 6 or more hours walking per week (OR = 1.42.; 95% CI:1.07-1.89). There was a dose-response association between walkability and TTW, as indicated by a positive trend test z statistic.

Map 1 Spatial variation in walkability decile scores for wards across London.

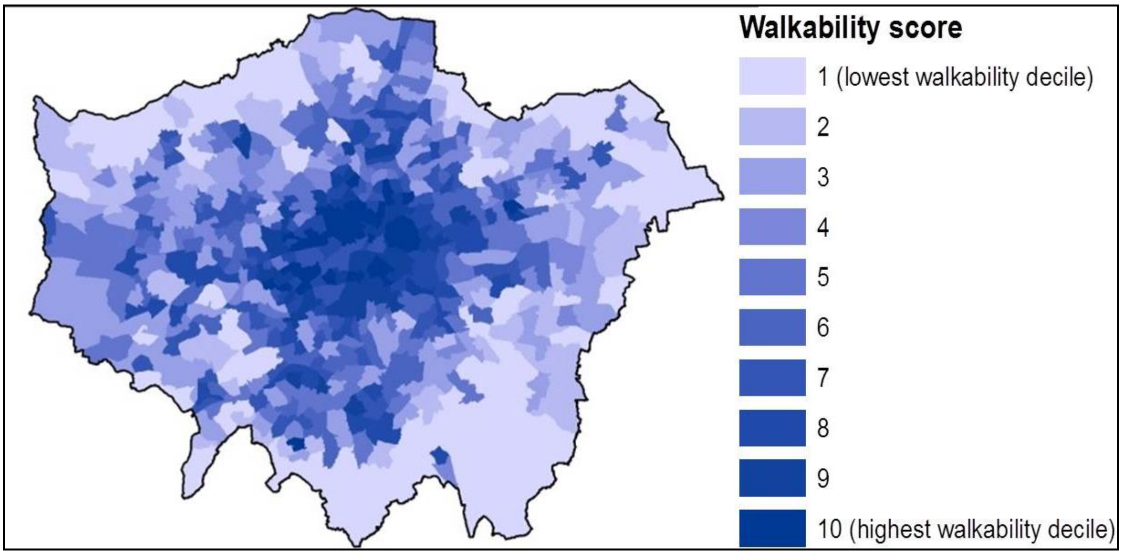

Table 1 Univariate associations of being in the top tertile of the study sample for time spent walking per week with sociodemographic factors and area deprivation.

Covariate	N	%	OR	CI	p
Male (ref)	1,769	64.19	1.00		
Female	987	35.81	1.08	0.92-1.28	0.354
50y to <56y (ref)	767	27.83	1.00		
>=56y to <60y	623	22.61	1.05	0.84-1.32	0.647
>=60y to <66y	682	24.75	1.03	0.82-1.29	0.807
>=66y to 75y	684	24.82	1.26	1.01-1.57	0.036
Remaining in Civil Service (ref)	941	34.14	1.00		
Not working-lt sick	46	1.67	0.51	0.24-1.07	0.077
Car available (ref)	2,156	78.57	1.00		
No car available	588	21.43	1.68	1.39-2.02	<0.001
Married (ref)	1,793	65.25	1.00		
Single	565	20.56	1.43	1.18-1.74	<0.001
Widowed	40	1.46	1.10	0.56-2.14	0.787
White (ref)	2,372	86.07	1.00		
Non-white	384	13.93	0.59	0.46-0.76	<0.001
IMD1 (ref)	695	25.22	1.00		
IMD5	293	10.63	1.25	0.93-1.66	0.133

Table 2 Association of being in the top tertile of the study sample for time spent walking per week (TTW) with walkability in the LWIIP7 study sample, before and after adjustment for individual factors and area level deprivation.

	No adjustment			Adjustment for individual-level factors			Adjustment for individual-level factors & area deprivation		
N	2756			2736			2736		
Quartile score	OR	CI	p	OR	CI	p	OR	CI	p
1	1	REF		1	REF		1	REF	
2	1.04	0.84-1.28	0.729	1.02	0.82-1.27	0.863	1.04	0.82-1.30	0.762
3	1.29	1.04-1.60	0.018	1.24	0.99-1.55	0.058	1.26	0.99-1.60	0.056
4	1.51	1.19-1.91	0.001	1.39	1.08-1.79	0.010	1.42	1.07-1.89	0.015
	Test for trend p <0.001			Test for trend p <0.01			Test for trend p <0.01		

4. Discussion

This study examined associations between neighbourhood walkability and time spent walking per week (TTW). Findings here support the large body of work which has shown that more walkable neighbourhoods may encourage walking, independently of potential confounders (Sundquist et al., 2011) (Arvidsson et al., 2012) (Madsen et al., 2013) (Van Dyck et al., 2010) (Freeman et al., 2012) and specifically among older adults (King et al., 2011). This suggests that a walkability index developed for use in non-European contexts as an indicator of walking also serves as an indicator of this behaviour, in terms of volume, in the context of a city in the United Kingdom.

The population density of London is high relative to other cities in which walkability indices have been used to assess associations between walkability and PA outcomes (*Demographia World Urban Areas: 9th Annual Edition*, 2013). This may limit variation in the components of walkability between areas because there is less “room” for variation within London; deviation from the high mean land use mix, residential density and street connectivity in different areas of London is likely to be lower than for less dense cities. Low inter-neighbourhood variation in absolute levels of walkability may, in part, account for the weak strength of association between walkability and walking time found here relative to that of associations identified by others. Christian et al (2011), for example, found those living in more walkable neighbourhoods in the Perth metropolitan area, Australia, to be more than twice as likely to spend 60 minutes or more per week on transport-related walking (OR = 2.24; 95% CI:1.58-3.18) as those in less walkable neighbourhoods (Christian et al., 2011). The Whitehall II study was not designed with walking as an outcome of particular interest so there was no differentiation in the purpose, such as for recreation or as transport. However, given geographical differences it is improbable that comparable specifications of outcomes would yield the same relationships between walking time and walkability for a compact city in the United Kingdom as those for a sprawling city in Australia.

Limitations and strengths

The core components of the walkability index and the land uses included in the land use mix part were not weighted to reflect their hypothesized relative importance, a procedure that is advocated by others (Frank et al., 2009). However, in the novel UK city context in which this study was set, there was scant evidence on which to base such weightings. Whilst significant relationships between walkability and walking were found, causality could not be inferred due to the cross-sectional study design. Even if this study had had a longitudinal design and showed that moving to a more walkable area resulted in greater walking, this could be due to self-selection, with the reason for the move or the choice of location when moving being influenced by a desire to walk more (Van Dyck et al., 2011). Also, participants did not report the location of their self-reported walking so it may have been independent of the neighbourhood exposure. Another weakness of this study was that it drew a sample from an occupation-specific cohort of older adults, limiting the generalizability of findings.

Innovatively, the spatial units of enumeration in construction of the walkability index in this study were all constituent administrative areas for the spatially contiguous area that contained the residential locations of participants, rather than only the administratively-defined residential neighbourhoods represented by the study participants. This revised approach ensured the index was independent of the participants’ characteristics, such as wealth, an important consideration in a sample that is not regionally representative. The Whitehall II Study had a very high response rate, enabling the use of a large study sample. This limited the influence of outliers as extreme observations and allowed detection of statistically significant associations that may not have been detectable with smaller samples. The high quality and large quantity of data collected in the Whitehall II Study also allowed adjustment for a multitude of sociodemographic factors for which there is evidence for association with walking. Identification of participants to postcode-level enabled examination of the effects on associations of neighbourhood operationalisation at a wide range of scales (Stockton, 2014), a privilege enjoyed by few researchers using large study samples in this field of study, and selection of an appropriate spatial unit of enumeration of walkability. The administrative boundary and Census data used in the calculation of walkability was of high quality and freely available, reducing the financial cost of producing the index. Also, the use of high quality road and path network data, sourced from a well-established organisation which is one of the world's largest producers of maps, provided confidence that the measures of walkability were accurate.

Conclusions

To the authors' knowledge, this study is the first to construct and test a walkability index for the European city of London employing a construction methodology akin to that of indices developed in non-European contexts. The significant association between walkability and walking that remained even after adjustment for individual-level sociodemographic factors and for area deprivation represents a novel finding, and one that confirms the validity of the walkability tool constructed in the context of London, UK. The study provides the first examination of the relationships between walkability and walking in this geographical context that is internationally comparable.

Walkability is only a measure of the potential of the neighbourhood to encourage walking and the physical environment can only offer support. It may be people's interaction with the neighbourhood physical environment, shaped in part by social norms, that is the primary driver of others' use of it. Nevertheless, in the context of the most populous city in Europe, the findings of this study highlight the potential importance of the physical environment of the neighbourhood in eliciting physical activity in individuals and thereby promoting public health at a population level. The walkability index constructed here may offer urban planners and public health professionals a simple tool in building and maintaining healthy neighbourhoods.

Longitudinal studies are needed to determine whether the relationship between walkability and walking is causal. The walkability index could be used to assess relationships between walkability and walking in regionally or nationally representative samples, and for different age groups.

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