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Can walking habits be encouraged through area-based regeneration and relocation? A longitudinal study of deprived communities in Glasgow, UK

Angela Curl[a,*], Ade Kearns[b], Laura Macdonald[c], Phil Mason[d], Anne Ellaway[c]

[a] Department of Geography, University of Canterbury, Christchurch, New Zealand
[b] Urban Studies, University of Glasgow, Glasgow, UK
[c] Medical Research Council/Chief Scientist Office Social and Public Health Sciences Unit (MRC/CSO-SPHSU), University of Glasgow, Glasgow, UK
[d] Urban Big Data Centre, University of Glasgow, Glasgow, UK

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ABSTRACT

This paper examines changes to the walkability of the built environment and associated changes in walking behaviour following area regeneration or relocation in Glasgow, UK. The aim is to contribute to longitudinal evidence of links between the built environment and walking behaviour. Most studies to date have been cross-sectional and the evidence they provide that changing the built environment will lead to changes in walking behaviour is weak. Our study examines how changes in neighbourhood walkability influence levels of walking in the local area.

We use household survey data from deprived neighbourhoods in Glasgow undergoing housing-led and area regeneration at two time points, 2011 and 2015. Measures of walkability were calculated for each year as a product of intersection density (connectivity) and dwelling density and attached to survey data. Relationships between changes in walkability and repeated measures of walking frequency are examined. We compare changes in walking between those who move house compared with those who experience changes to the built environment in their existing home location.

Those who relocate ('movers') are more likely to increase their frequency of walking in the neighbourhood, but this is not necessarily as a result of changes in the built environment as measured using walkability metrics. Prior walking habits are a strong influence, with those who walk at baseline being more likely to increase their walking later. Environmental improvements through renewal programmes are often of insufficient quality or extent to stimulate increased walking. It is likely that area regeneration needs to be combined with people-based and social interventions to produce 'behavioural spillovers' that encourage walking habits.

1. Introduction

Low levels of physical activity are associated with a range of poor health outcomes across the life course and include cardiovascular disease, diabetes, musculoskeletal health, cancer, and low levels of mental health and wellbeing (Allender et al., 2007; WHO, 2010; Lee et al., 2012). There is increasing recognition of the potential of active modes of transport, such as walking and cycling, to address many of the health issues associated with inactivity. Increasingly sedentary lifestyles and low levels of physical activity are partly due to the dominance of private car travel and reductions in rates of active travel over recent decades. Such car reliance has

* Corresponding author.
E-mail address: angela.curl@canterbury.ac.nz (A. Curl).

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been perpetuated by changes to the built environment to facilitate car use. As a result, urban sprawl and fewer local destinations have reduced the walkability of neighbourhoods, further entrenching reliance on the car as a mode of transport.

It has been suggested that the public health sector could take a lead in advocating for cross-sector urban planning to make active modes of travel more desirable (Grant et al., 2017; Giles-Corti et al., 2016). However, in order to achieve this, health, planning and transport bodies need stronger evidence of causal relationships between built environment interventions and health outcomes. A systematic review of causal evidence of the links between active travel and health concluded that a more robust evidence base is needed (Saunders et al., 2013). Only five out of 24 studies evaluated a specific active travel intervention and none of these studied a built environment intervention. Saunders et al. (2013) argue that investments in the built environment need to be supported by causal evidence of their likely health benefits.

Our study adds to this evidence in the context of neighbourhoods in Glasgow, UK undergoing significant physical and residential change as part of a housing and neighbourhood regeneration programme, an aim of which is to improve health and reduce health inequalities among those living in the most deprived neighbourhoods of the city. It is therefore important to understand how the urban environment has changed, particularly in terms of walkability, and the impact these changes might have had on active travel behaviours, such as walking.

2. Background

2.1. Encouraging walking habits

Changing habits, such as travel behaviours, involves people learning new routines and losing some behavioural control, at least initially (Bamberg et al., 2003; van Acker et al., 2010). Walking has been described as *"a year-round, readily repeatable, self-reinforcing, habit-forming activity and the main option for increasing physical activity in sedentary populations"* (Morris and Hardman, 1997). Gaps remain, however, in our understanding of how to encourage this habitual behaviour in order to realise health benefits. The psychology of habit formation as used in public health aims to encourage healthy behaviours in response to contextual cues, which are likely to continue beyond any conscious attempt at behaviour change (Gardner et al., 2012) – such as walking in response to walkable environments.

For many people, walking is not recognised or valued as a form of exercise, but rather is seen as a functional activity undertaken on pragmatic grounds, i.e. if it is efficient and there is enough time to do it (Darker et al., 2007). Personal support and goal setting, as used for other behaviours, may have a role to play, with simple messages such as '10,000 steps a day' likely to have some effect upon walking (Bravata et al., 2007). However, behavioural interventions on physical activity with low-income groups have been found to have only small positive effects, which are not sustained over time (Bull et al., 2014).

On this basis, major areas for intervention on the habit of walking as a travel or health behaviour may be those that act through cultural and social norms, and the built environment, especially in more deprived areas. Indeed, the social and environmental elements of walking are intertwined in that the more people there are walking in an area, the safer people feel in public, and the more likely they are to walk, particularly in more deprived areas (Mason et al., 2013). Environmental improvements, such as making places more walkable, can therefore serve as a habit-shaper through place-making. On the other hand, relocation, which involves changes of context and physical environment, offers the opportunity for behaviour change, such as increased intention to walk more, as has been observed with regard to smoking behaviour (Bond et al., 2013).

2.2. The built environment influence on travel behaviours

There is a considerable body of research into associations between aspects of the built environment and physical activity, active travel and health outcomes. The key factors found to encourage active forms of travel such as walking and cycling, and to discourage use of the car include: high dwelling density, high street connectivity or intersection density, diversity in the types of destinations or services available, land-use mix, and distance to key destinations (Boulange et al., 2017; Cervero and Kockelman, 1997; King et al., 2015; Pikora et al., 2005). Some studies have found associations between high densities of dwellings and intersections and higher levels of walking among residents (e.g. Sallis et al., 2016; Christiansen et al. 2016; Thielman et al., 2015; Kerr et al., 2014) whilst others have not (e.g. Oakes et al., 2007; Ferdinand et al., 2012; Tuckel and Milczarski, 2015). However, while there is strong associational evidence between urban form and active travel, the causal evidence base is much weaker.

One of the main problems with cross-sectional analyses is the issue of residential self-selection (RSS), which can inflate associations between neighbourhood walkability, and walking behaviour because people who prefer to walk may choose to live in neighbourhoods more conducive to walking (Cao et al., 2009, Morris et al., 2016). Although the strength of RSS has recently been challenged (Ettema and Nieuwenhuis, 2017), on the basis that travel preferences are not the only factor influencing decisions on residential location, a longitudinal design can help address the issue and be applied to both residential moves and changes 'in place'. There is a need for *'stronger longitudinal evidence…to better inform planning'* (Giles-Corti et al., 2013, p.21) concerning such issues as the effects of the local environment and relocation upon walking behaviours.

A small number of studies have looked at the influence of *changes* in the built environment on active travel and health and have reported increased physical activity following infrastructural interventions (Brown et al. 2016; Heesch et al., 2016; Goodman et al., 2014). Overall, however, the evidence base on physical and health impacts following built environment interventions remains small, particularly for studies involving residents of deprived areas. Goodman et al. (2014) noted the need to evaluate larger city-wide programmes of changes to the built environment and active travel as well as specific interventions, which is what we do here in examining the impact of neighbourhood change across the city.

2.3. Urban regeneration, relocation and walking

A review of research on neighbourhood walkability concluded that aspects of the built environment commonly associated with walking may not be consistent in all socio-economic contexts and cannot necessarily be translated to all areas (Talen and Koschinsky, 2013), meaning that attention needs to be paid to factors associated with walking behaviours in more deprived communities. Shortt et al. (2014) and Christiansen et al. (2016) found that walking for transport was more common in deprived areas and less dependent on the environment, potentially because it is more of a necessary than an optional mode of transport. Similarly, Ogilvie et al. (2008) found limited relationships between the perceived environment and walking behaviour in a deprived urban context. However, it has previously been found that active travel accounts for a substantial proportion of overall physical activity for residents in deprived communities (Mason et al., 2016) so it is important to ensure that the built environment can support this in order to maintain or increase active travel.

Urban regeneration in disadvantaged communities usually involves changing people's local environments through in situ improvements, or through relocation to other neighbourhoods, although the impacts of these two actions upon physical activity, walking or other travel behaviours are rarely examined. What little evidence there is for impacts from area improvement is mixed, with the evaluation of the New Deal for Communities Programme in England reporting relative gains for intervention areas in terms of neighbourhood quality and satisfaction, but relative losses on measures of exercising by residents (Batty et al., 2010).

Longitudinal evidence on the effects of relocation (not necessarily from areas undergoing regeneration) is contradictory. Australian evidence has shown that transport-related walking declined among movers in Perth, probably due to a reduction in local destinations, but that recreational walking increased alongside more positive perceptions of the local environment in terms of aesthetics, accessibility of destinations, and safety (Giles-Corti et al., 2013). North American studies show contrasting results. Transportation walking has been shown to increase among people who moved home in Calgary, Canada, but irrespective of whether they moved to a more walkable or a less walkable neighbourhood (McCormack et al., 2017). In the southern USA, low-income women are reported to have walked more after moving to neighbourhoods with fewer cul-de-sacs, and to have walked less in areas with more non-residential land uses (Wells and Yang, 2008).

Some studies have examined changes in health following residential relocation to areas with different infrastructural conditions, finding mixed results. Braun et al. (2016) found increased walkability affected some health outcomes positively, e.g. lower blood pressure, but others negatively, e.g. levels of inflammatory markers such as c-reactive protein.

However, very few studies have examined the effects that moves that occur specifically due to area regeneration programmes might have upon health or travel behaviours such as walking. It has previously been shown that people who moved out of a regeneration area were more likely to do little or no walking than those who remained in the areas undergoing renewal, and that similar proportions of both groups walked on most days of the week, one to three years after moving (Mason and Kearns, 2011), but this study did not look at changes to the built environment.

2.4. Aims

Our aim is to examine how neighbourhood environments and walking behaviours change for residents in deprived communities that are experiencing area-based urban regeneration. We address the following questions:

- How does the frequency of neighbourhood walking among residents change over time?
- How does the walkability of residents' neighbourhoods change over time?
- Are changes in walking associated with changes in neighbourhood walkability?
- How do patterns of change in walkability and walking differ between those people who remain in the same house and those who move home?

3. Methods

3.1. Study context

The study was undertaken in Glasgow, a city with relatively poor health and extensive areas of multiple deprivation where levels of physical activity are low, with 35% of adults meeting the recommended levels of physical activity in the most deprived areas which make up four-fifths of the city (www.understandingglasgow.com; Scottish Government, 2012). From 2003 onwards the city has undergone housing-led regeneration in most of its deprived areas, with £1.2 billion spent on stock improvements over ten years to 2013 together with an extensive demolition programme that has seen nearly 20,000 units, mostly in high-rise blocks, removed (Glasgow Housing Association, 2010). Alongside the housing works, and sometimes facilitated by demolition, there has been a range of environmental improvements, which vary from area to area and comprise a mixture of green space enhancements, provision of new and improved play-parks, environmental maintenance programmes, and improved building and street lighting. In eight large 'Transformational Regeneration Areas' across the city (Glasgow Housing Association, 2006), the demolition of high-rise blocks and redevelopment of the neighbourhood is resulting in the conversion of neighbourhood layouts featuring clustered blocks separated by large open areas (some green, others tarmac) to more traditional, regular street patterns with roads and pavements and low- and medium-rise buildings.

3.2. Survey

Our analysis draws on two waves of household survey data from the GoWell study. GoWell is a long-term project exploring the impacts of a ten year programme of investment in housing, regeneration and neighbourhood renewal on the health and wellbeing of individuals, families and communities across 15 deprived areas in Glasgow, UK (Egan et al., 2010). Surveys were undertaken in 2006, 2008, 2011 and 2015. In this paper we use the two latest survey waves from 2011 and 2015 because we have corresponding geospatial datasets to calculate walkability scores for these years.

The survey design is a repeated cross-section with a nested longitudinal sample. In the cross-sectional study, there were 4270 responses in 2011 and 3614 in 2015, with response rates of 45.4% and 47.0% respectively. Retrospective matching of names and addresses was used to identify the longitudinal cases embedded in the surveys, where we had interviewed the same householder on more than one occasion. Here we use only the longitudinal cases so that we can analyse changes in walking frequency for the same individuals over time, giving a useable sample size of 1063.

The study design is a natural experiment of changes in walking behaviour as a result of changes to the built environment caused by regeneration. Changes in the walkability of the built environment can occur because of neighbourhood renewal and redesign (for 'stayers') or because a participant has moved house, voluntarily or due to relocation resulting from the regeneration ('movers'). Between 2011 and 2015, 149 (14%) of the participants moved house. We use an objective measure of walkability of the built environment. Levels of walkability of neighbourhoods of participants who moved home are compared with those of participants who remained in the same property. We examine the relationship between walkability and measures of walking frequency at two time points.

3.3. Walking measure

Given our focus in this paper on walking behaviour related to changes in the neighbourhood around the home, we use a measure of neighbourhood walking to correspond with this. Respondents were asked on how many days in the past week they had walked in their local neighbourhood for at least 20 minutes at a time.

3.4. Neighbourhood walkability

Measures of walkability were calculated at the level of the data zone (a Scottish small area statistical geography containing an average of 750 household residents) for 2011 and 2015 as a product of intersection density (connectivity) and dwelling density (see Table 1 for more details). Intersection and dwelling density were included in the walkability score because they have previously been linked to walking behaviour (Saelens et al., 2003; Witten et al., 2012; Boulange et al., 2017). Land use has previously been incorporated within composite walkability scores, but reliable data on this were not available for the study area and time periods covered in our study. Christian et al. (2011) maintain that variations in methods to define land use and calculate land-use mix may influence associations with walking outcomes. Our paper made use of an existing Scottish-based walkability score; future work could include developing a walkability score with additional land-use measures and destination information included.

Street network and path network datasets for Scotland for 2011 and 2015 were obtained from Ordnance Survey. A count of the number of dwellings and the land area in hectares for each data zone (for 2012 and 2015) were acquired from Scottish Neighbourhood Statistics (2013). ArcMap version 10.3 was used to combine the street network dataset with the path network via respective nodes. For each data zone, a measure of street connectivity was calculated using intersection density, i.e. the ratio of the number of true intersections (three or more legs) to the data zone area (Frank, et al. 2009). Z-scores were computed using IBM SPSS Statistics V.21 for both variables to standardise scores, and the following formula was used: WS = (2 × intersection z-scores) + (dwelling density z-scores) (a similar formula to that used by Frank et al., 2009). Street connectivity was weighted more heavily as previous work highlights the strong influence of this measure on active travel choices (Saelens et al., 2003).

Respondent home postcodes were linked to population-weighted centroids and an 800-m network buffer along the street/path network was drawn around each postcode centroid. A population-weighted centroid provides the grid reference of the property closest to the average grid reference for all the properties within the unit postcode (around 15 properties). Given the dense urban environment, this represents a relatively small geographic area. Using address-weighted centroids is seen as superior to using geometric centroids, because it is more accurate, especially within urban areas (Berke and Shi, 2009). The 800-m buffer extent is typically used in such studies (Boone-Heinonen et al., 2010; Troped et al., 2010; Hino et al. (2011); Moore et al., 2013). At an average walking speed of 5 km/hour (Ogilvie et al., 2011) it would take around 10 minutes to walk 800 m. Therefore, a return walk from

Table 1
Calculating the walkability score.

Built environment feature	Implied relationship with walking
Dwelling density (i.e. the ratio of residential units to the land area)	With high dwelling densities, areas tend to become less car dependent (e.g. it is more difficult to drive and park) and more convenient for walking.
Street/path connectivity (i.e. the ratio of true intersections to the land area)	When intersection densities are high, the route between origin and destination is more direct and quicker.

home of 20 min, which corresponds with our walking frequency survey question, would be contained within the 800-m radius. Mean walkability scores were calculated for each respondent's neighbourhood buffer based on the data zone centroids falling within the 800-m buffer. This was repeated for 2011 and 2015 so that each respondent had a walkability score for their neighbourhood for each survey. Scores were standardised across the whole dataset including both time points so that any changes in walkability score represent a real, rather than a relative change in walkability.

3.5. Analysis

After matching the measures of neighbourhood walkability to survey data based on respondent postcode, we undertook analyses in three stages. First, we describe changes in walking in the sample over time. Second, we describe changes in walkability in the respondents' neighbourhoods between the two time points. Lastly, we analyse the changes in walking frequency related to changes in walkability using logistic regression modelling to examine factors associated with increased and decreased frequencies of walking over time. In the logistic regression models we predict the likelihood of an increase or a decrease in walking, relative to no change, controlling for baseline walking frequency, baseline walkability score, and socio-demographic variables associated with walking: sex, age, disability status, vehicle ownership, education level and built form of the home (i.e. low-rise flat or house vs. multi-storey flat). We include changes in walkability and moving house as explanatory variables. Statistical and geospatial analyses were undertaken using IBM SPSS Statistics v.21 and Arcmap v.10.3, respectively.

3.6. Ethics

The NHS Scotland Multi-centre Research Ethics Committee approved the study in January 2006.

4. Results

This section presents the results in three stages, according to the order of analyses outlined above. Table 2 shows the sample characteristics.

4.1. Changes in walking frequency

In 2011, around a third of respondents did not walk for 20 min on any day, around a third walked for at least 20 min every day and the remaining third walked for at least 20 min on 1–6 days (Fig. 1). Between 2011 and 2015 there was a slight increase in the number of participants who reported not walking at all for 20 minutes in the local neighbourhood.

However, these aggregate-level changes mask change in individuals. While a third of respondents did not change their behaviour, a third increased and a third decreased the frequency of their walking (Table 3). Moreover, those who moved house were more likely

Table 2
Proportion of sample in each socio-demographic group (overall and by walking frequency) and mean walkability score by socio-demographic group.

	2011(%)	Walked 0 days (2011,%)	Walked 1–4 days (2011,%)	Walked 5+ days (2011,%)	Mean Walk Score 2011
Walking frequency		–		–	
0 days	32.8	–		–	-0.45
1–4 days	29.7	–		–	-0.02
5+ days	37.5	–		–	-0.21
Moved status					
Remained	86.0	88.4	85.0	84.3	-0.15
Moved	14.0	11.6	15.0	15.7	-0.58
Gender					
Male	35.8	32.9	27.4	39.7	-0.07
Female	64.2	32.7	31.1	36.3	-0.29
Age group					
16–24	2.7	1.4	2.9	3.5	-0.49
25–39	18.5	14.5	18.8	21.3	0.24
40–54	29.1	32.2	26.5	28.6	-0.14
55–64	20.1	21.2	21.4	18.7	-0.37
65+	29.5	30.7	30.4	27.8	-0.42
Long term sick	43.0	55.4	38.7	35.3	-0.40
Access to vehicle	26.6	24.5	27.2	19.4	
Secondary school education or higher (ref: no qualifications)	28.7	24.3	25.9	34.7	
Built form					
Multi-storey flat	31.2	25.2	32.9	34.7	0.73
Other flat	31.5	32.2	31.3	31.1	-0.05
House	37.3	42.6	35.8	34.2	-1.13

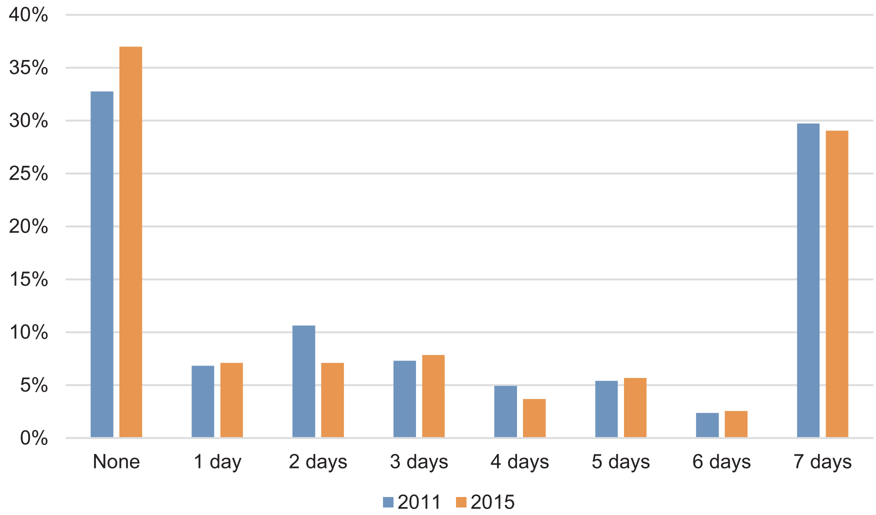

Fig. 1. Percentage of respondents walking on each number of days in 2011 and 2015.

to increase their frequency of walking than those who did not move house (β = 2.10, p = 0.01) but also more likely to decrease walking (β = 1.67, p = 0.03), indicating that moving house is related to a greater likelihood of change in walking frequency in either direction.

Of those who reported never walking in their local neighbourhood at first interview, almost half (48.8%) reported some walking at second interview. Furthermore, 77.5% of those who reported no walking in the neighbourhood in 2011 and later moved house reported an increase in walking compared with 45% of non-walkers who did not move house.

4.2. Changes in neighbourhood walkability

The mean walkability score of respondents' neighbourhoods improved over time. On average, intersection density increased but dwelling density declined, probably reflecting regeneration activity such as demolition and replacement of high-rise with lower-density housing (Table 4). The walkability score of most respondents' neighbourhoods changed over time: only 1.3% did not have any change in walkability between the two times, 38.5% had a decrease in walkability and 60.2% had an increase.

Those that moved house had a mean change in neighbourhood walkability of 1.17 compared with 0.29 (t = -5.83, p < 0.01) for those who did not move.

In order not to focus on small changes in walkability we looked at a change in the quartile of walkability. Although the quartile approach will still include some small changes at the boundaries and ignore larger changes within quartiles, overall those who change quartile did have a greater change in walkability score than those who do not change quartile. 57.9% of respondents did not move into a different quartile of walkability. 23.0% of respondents showed a decrease in walkability quartile and 19.2% of respondents had an increase in walkability quartile.

Table 3
Reported changes in walking 2011 to 2015 by resident group.

	All respondents	Movers	Stayers
No change	32.51%	22.19%	35.77%
Increase	32.5%	40.9%	30.10%
Decrease	34.99%	36.91%	34.13%

Table 4
Mean "Walkability" of residents' neighbourhoods.

	2011	2015	Mean Change
Dwelling density	33.54 (13.29) Range: 7.39– 82.06	33.32 (12.87) Range: 7.39–82.38	-0.21 (6.86) Range: -56.98 to 52.25
Intersection density	1.82 (0.65) Range: 0.45–3.82	1.95 (0.61) Range: 0.5–3.82	0.14 (0.55) Range: -1.44 to 2.67
Walkability score	-0.21 (2.64) Range: -6.40 to 14.17	0.21 (2.53) Range: -5.88 to 7.81	0.42 (1.74) Range: -5.67 to 7.85

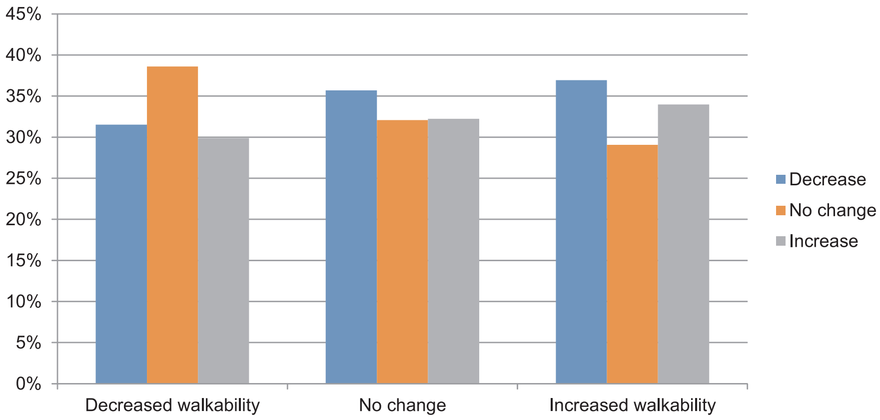

Fig. 2. % of respondents who show decrease, no change or increase in walking frequency by change in quartile of walkability score.

Those who moved house were more likely to change walkability quartile compared with those who did not move (64.4% vs. 38.5%). 15.5% of stayers had an increase in walkability quartile compared with 40.9% of those who moved house. Those who moved house were only slightly more likely to show a decrease in quartile (23.5%) compared with those who did not move house (22.8%). Thus, those who move house are more likely to exhibit a change in walking behaviour and to experience a greater change in neighbourhood walkability.

We have described the changes in walking and walkability between 2011 and 2015 for our longitudinal sample. In the next section we examine whether these changes in walkability are associated with changes in walking behaviour.

4.3. Walkability and walking

Figs. 2–4 show the percentage of respondents who increased, decreased or showed no change in frequency of walking compared with changes in their neighbourhood quartile of walkability for the whole sample (Fig. 2), stayers (Fig. 3) and movers (Fig. 4).

Fig. 2 shows that among those who were in a lower quartile of walkability in 2015 compared with 2011 the percentages of respondents who reported increased or decreased frequency of walking are very similar, but that more respondents did not change their frequency of walking. For those who experienced no change in walkability, the percentages of respondents who reported increased, decreased or no change in walking are very similar, although a slightly higher number reported decreased walking. For those who were in a higher walkability quartile in 2015 compared with 2011, respondents most frequently reported a *decrease* in walking, followed by an increase and then no change in walking frequency.

Similarly, those who stayed in the same house are more likely to have reported a decrease in walking when their neighbourhood transitioned into a higher walkability quartile (Fig. 3). However, the results show a different pattern for those who moved house (Fig. 4). Across the categories of walkability change, respondents are less likely to report no change in walking frequency than either

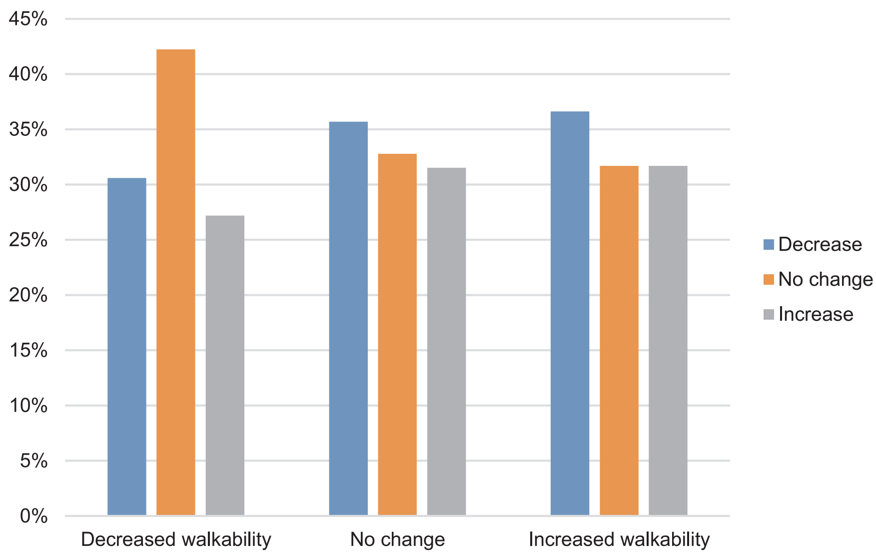

Fig. 3. % of respondents who show decrease, no change or increase in walking frequency by change in quartile of walkabillity score (stayers).

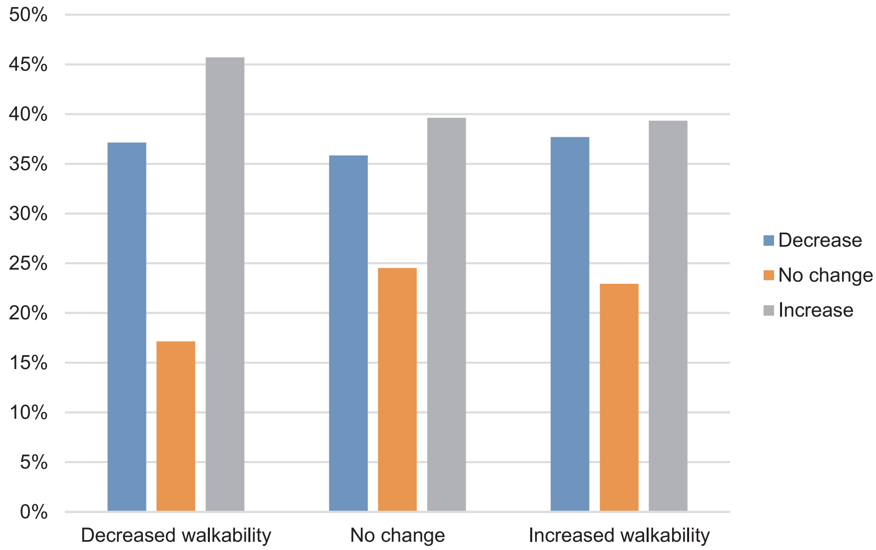

Fig. 4. % of respondents who show decrease, no change or increase in walking frequency by change in quartile of walkabillity score (movers).

Table 5
Logistic regression: odd ratios for increase and decrease in walking at T2.

	Increase in frequency of walking	Decrease in frequency of walking
Baseline walking (ref: 0 days per week - increase; 1–3 day for decrease)		
1–3 days per week	5.11 (2.98–8.78)*	
4–7 days per week (4–6 for increase)	5.59 (2.40–13.06)*	3.24 (1.89–5.53)*
Baseline walkability score	1.05 (0.96–1.15)	1.15 (1.05–1.26)*
Change in walkability score quartile: (ref: decrease)		
No change	1.01 (0.61–1.67)	2.15 (1.31–3.53)*
Increase	1.64 (0.81–3.34)	2.42 (1.24–4.76)*
Moved house	2.62 (1.25–5.48)*	1.45 (0.77–2.73)

Controlling for: sex, age, long term sick/disabled, vehicle ownership, education and built form of house. (*)indicates $p < 0.05$.

an increase or decrease, but there does not appear to be a pattern of change in walking behaviour in relation to walkability. In fact, among movers, those who move into a lower walkability quartile are most likely to report an increase in walking.

The results of the logistic regression are shown in Table 5. Only one of the socio-demographic control variables was associated with changes in walking: those who had a long-standing illness at baseline were less likely to report increased walking at T2, and more likely to report a decrease. Of the key independent variables, baseline walking is a significant predictor of changes in walking behaviour, with those doing any walking at baseline being over five times more likely to report a later increase in walking frequency, and those walking 4–7 days at baseline being more likely to report a decrease in frequency over time ($\beta = 3.24$, $p < 0.01$). Those who moved house are more likely to report increased ($\beta = 2.62$, $p = 0.01$) walking frequency. Changes in neighbourhood walkability scores were not associated with increased walking frequency in the multivariate model. Decreased walking was associated with neighbourhoods that did not change or showed an increase in walkability.

5. Discussion and conclusion

In aggregate, we found that among residents living in deprived areas undergoing housing-led and area regeneration, there was little change in aggregate neighbourhood walking frequency over a four-year period, although the sample divided into approximate thirds comprising those whose walking frequency decreased, was unchanged, or increased. The walkability of neighbourhoods improved over time. For stayers, those who experienced an increase in neighbourhood walkability were more likely to report a reduction in walking frequency. Among movers, those whose neighbourhood walkability decreased through relocation were most likely to report an increase in walking frequency. In the multivariate analysis, moving home was associated with an increased frequency of walking, but the strongest positive association with increased walking was the frequency of walking at baseline: the more often people walked at baseline, the more likely they were to report increased walking frequency at follow-up. Those whose neighbourhood became more walkable or did not change were more likely to show a decrease in frequency walking. In summary, there are no associations between changes in walkability, and increased walking behaviour. The associations with decreased walking are confusing, but potentially suggest that in an already dense urban environment, further increases may not be beneficial.

The results suggest that there may be value in looking at neighbourhood walking as a habit that needs to be nurtured, with the strongest influence upon increased walking frequency being the residents' prior walking behaviour. Looking at the two main components of environmental change within regeneration programmes (in situ changes and house moves), there is evidence to indicate that moving home may be the more important, acting as a habit-creator and habit-enhancer in respect of local walking. The notion of 'habit discontinuity' contends that habits are unconscious choices cued by stability, and that habits —in our case, the choice to walk frequently or not— can be changed when the context for them changes, such as due to moving home (Verplanken et al., 2008). In the case of Glasgow, people who move into newly built homes through regeneration report being better able to cope with ongoing health issues (Lawson and Kearns, 2017), which may make them more capable of walking, whilst other relocators see moving as an opportunity for transitioning to a new lifestyle (Lawson et al., 2015), which may include being more active. However, our findings also suggest that changes to a person's local environment as a result of relocation may be insufficient on their own to bring about positive alterations in walking habits, and that other social supports for behaviour change may be required alongside relocation. Indeed there is also an issue of habit-preservation to be addressed, given the significant numbers of movers whose walking decreased over time.

As regards the second element of regeneration, although walkability improved slightly on aggregate there is no evidence that in situ neighbourhood improvements are strong enough to override the influence of prior habits and personal characteristics on walking behaviour. This suggests that the improvements in neighbourhood walkability were insufficient to result in increased walking frequency, although surprisingly they are associated with reductions in walking frequency. One of the weaknesses of area-based regeneration programmes is that whilst they aim to deliver environmental improvements, the scale or quality of those improvements is rarely defined; in policy terms, *'the objectives [fail to] define the status to be attained by the adopted solution that would be considered as satisfactory'* (Knoepfel et al., 2007, p.154). Moreover, although area renewal plans often include new street layouts, environmental improvements and new amenities, the last of these —provision of additional retail, leisure and social destinations to use and walk to— is often found to be lacking in so-called 'holistic regeneration' (Dodds, 2011; Taylor, 2008). This highlights the need for more research to understand what level and type of environmental change is required in order to promote changes in health outcomes.

Given that walking is a multi-dimensional activity it would appear well suited to the combination of people and place policies intrinsic to holistic regeneration (Tallon, 2010; Taylor, 2008). Nevertheless, in this case it appears that neighbourhood changes have not been substantial enough to lead to expected changes in walking behaviour, meaning that there has potentially been a missed opportunity in terms of increasing walking as a health behaviour, through physical neighbourhood regeneration. This demonstrates the importance of gathering evidence about what kinds of environments support walking with which to inform future regeneration interventions. Although environmental improvements are often of insufficient magnitude to be effective, and enhancements to services and local economic activity are often absent, physical regeneration is nonetheless what policy and practice in the UK has focused on the most.

Social regeneration, involving the stimulation of community empowerment and development activities, lags behind physical regeneration (Dodds, 2011) but may be a further means of facilitating walking. This involves an extension of the notion of 'behavioural spillover', whereby one pro-environmental, or in this case pro-social, activity leads to another (Poortinga et al., 2012; Thogersen, 1999). Such a spillover is consistent with findings of the positive effect of community belonging on physical activity (Hystad and Carpiano, 2012) and of sense of community on walking (Wood et al., 2010). The development of walking as part of community belonging, which has been found to be positively associated with health behaviour change, including physical activity (Hystad and Carpiano, 2010), might also serve as a habit-enhancer. There may also be ways of enacting habit-discontinuity (Verplanken et al., 2008), through the use of either public information campaigns or housing and neighbourhood change as a transition within people's lives. For example, a public information campaign could make sedentarism less socially acceptable, as has happened with smoking and passive smoking.

Although behavioural interventions have been found to have limited effects in lower income areas, it may be that combined environmental and behavioural interventions would be most effective in encouraging walking. Combining social and physical regeneration could help to improve perceptions and encourage associated changes in behaviour. Further research should address this possibility.

5.1. Limitations and future work

There are several limitations to our analysis. Although there is strength in the longitudinal nature of the data, we have not been able to include measures of length of residence or reasons for moving as further counters to self-selection issues. Recent work (Ettema and Nieuwenhuis, 2017) supports the notion of controlling for reasons for residential choice in future work. Whilst people may self-select into neighbourhoods that are supportive of walking behaviours, households on low income (which is the case for the majority of our study respondents) make locational choices within a restricted choice set (Hedman et al., 2011). As outlined in the introduction, one of the strengths of a longitudinal approach is the ability to control for residential self-selection. The fact that we find limited and unexpected changes in walking behaviour, associated with changes in walkability, is consistent with the idea that residents self-select into neighbourhoods that suit their behavioural preferences, and that these preferences do not change, despite environmental change. However, given the relatively small changes in walkability it is more likely that the changes are not substantial enough to influence behaviour or allow conclusions to be drawn regarding RSS. Given that movers increase walking, regardless of changes to walkability there is also no evidence to support a RSS effect. Further work, including attitudes to walking and perceptions of the environment, would allow this to be understood in more detail.

Perceptions of one's local neighbourhood have been shown to be as important as its objective characteristics in influencing accessibility (Curl, 2013) and mobility choices (Schwanen and Mokhtarian, 2005) so it is important to understand how changes in the built environment influence perceptions of the neighbourhood, something we have not been able to do here. For example, Curl et al. (2015) found that while reported levels of walking did not change following “home zone” interventions, perceptions of the walkability of the local area improved, which may be a precondition for behaviour change. If people are not aware of physical changes, their perceptions may not change and there may not be any change in behaviour. Further, because travel behaviour is influenced by attitudes as well as by the built environment, ‘residential dissonance’, i.e. a mismatch between one's preferred environment consonant with preferred travel mode, is said to affect travel behaviour, lowering rates of walking, cycling and use of public transport. Moreover, residential dissonance of this kind is ‘*generally higher for households with low incomes*’ (De Vos et al., 2012, p.2). This further supports the idea that physical changes alone may not be enough to influence travel behaviour, without social and behavioural interventions.

Whilst we have measured the walkability of environments at two time points, giving us a robust indicator of environmental change as an influence upon walking, other key elements of the environment are absent, in particular a measure of changes in local amenities or destinations, and perceptions of neighbourhood quality and safety. Our measure of walkability is based on a metric developed in different urban contexts (i.e. USA and Australia) and our results indicate a need to develop more appropriate measures of walkability for the UK urban context. Whilst in the United States, large contrasts in density of dwellings and intersections mean that these measures can easily distinguish walkable and less walkable environments, it is possible that, in a relatively dense urban environment, these measures do not show enough variation to predict walking behaviour adequately. In future work, it will be important to consider which measures of the built environment are most strongly associated with walking in the particular urban environment being studied. For example, it may be that quality of amenities or perceptions of safety (Mason et al., 2013) are more strongly associated with walking in deprived settings and in dense urban environments.

We have also not distinguished between transport walking and recreational walking. This is an important distinction as others have found that transport-related and recreational walking can change differentially in relation to changes in location (Giles-Corti et al., 2013). While dense, well connected urban environments are known to support utilitarian walking, they are also more likely to be congested and to experience higher crime rates, and may be unpleasant for walking. In contrast, suburban areas, which may be objectively less walkable may be more pleasant for recreational walking. This demonstrates a need to consider factors such as quality and suitability of the environment in particular contexts and for particular purposes, when designing measures of walkability. While the 800-m buffer used was appropriate given our walking measure, and has been used in other similar studies, future work should also consider that larger or smaller areas might have a more significant relationship with walking behaviour in particular urban contexts and depending on the demographics of the population.

In conclusion, while both walkability of the urban environment and walking behaviours have changed over time, there is little association between the two. Moving house was more strongly associated with increased frequency of walking than changes to the built environment, which could lend support to targeted behaviour change programmes at key points, such as when people move house. This study demonstrates the need for longitudinal research to understand how built environment interventions influence travel behaviours. There is a need to develop walkability metrics which are appropriate to the context and population being studied. Although there are strong associations between connectivity, density and walking internationally, care needs to be taken when assuming that changes in walkability will lead to changes in walking in all contexts. Not everyone will respond similarly to place based interventions and understanding who responds, and how, to changes in the urban environment is a key area for research. In dense urban environments, and deprived communities it may be that aspects of the built environment not captured in typical walkability metrics are more important.

Conflicts of interest

The authors report that they have no conflicts of interest.

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