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"The Glasgow effect?"– The result of the geographical patterning of deprived areas?

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ABSTRACT

The aim of this research was to examine whether the excess mortality found in Glasgow, compared to other cities in the UK ("Glasgow effect"), could be attributed to patterns of the distribution of deprived neighbourhoods within the cities. Data on mortality and deprivation at a neighbourhood scale were used to examine the impact of the patterning of neighbourhood deprivation on mortality in Glasgow, Liverpool and Manchester. Analysis using a combination of GIS and statistical approaches, including a Moran's I test and Conditional Auto Regressive models to capture residual spatial autocorrelation, was carried out. The pattern of deprivation was found to be more dispersed in Glasgow compared to the other cities. The impact of surrounding deprivation at two different scales shows strong impact on neighbourhood health outcomes in Glasgow and Liverpool but not in Manchester, suggesting that patterning is not a major contribution to the excess mortality in Glasgow.

1. Introduction

Scotland has the highest mortality rates in Western Europe (Leon et al., 2003;Whyte, 2007). This excess mortality has in the past been attributed to higher levels of deprivation (Carstairs and Morris, 1989;Scottish Council Foundation, 1998;Scottish Executive, 2000;Scottish Office, 1999). However, more recent research indicates that deprivation does not account for all the excess mortality (Hanlon et al., 2005;Popham et al., 2010;Popham and Boyle, 2011). Much of this excess mortality is concentrated in the West of Scotland, and in Glasgow in particular (Hanlon et al., 2005). Comparisons between Glasgow and other post-industrial deprived cities in England, such as Liverpool and Manchester, have confirmed previous findings indicating that Glasgow has an excess of mortality after controlling for deprivation. This excess is present across all deprivation categories for both genders and ages, with particularly large differences in mortality being observed for suicide, alcohol and drugs related deaths. Mortality trends since 1950s have shown that all three cities have declining mortality rates over time, but that the improving health of Glasgow's population since 1950s has been slower than that found in the other two cities (Walsh et al., 2010). The divergence between the health of the three cities has been reported to have begun in 1950s (Walsh et al., 2010). This phenomenon of excess mortality in Glasgow has been termed the "Glasgow Effect", and has been well described with comparisons to cities in England and Europe across different disease types (Walsh et al., 2013).

Research effort has recently moved away from describing this phenomenon to identifying the cause of the excess mortality found in Scotland and in Glasgow in particular. McCartney et al., 2012 have collated and reviewed the evidence for various hypotheses on the possible causes for the higher mortality rates observed in Glasgow. The research identified 17 hypotheses which addressed the higher mortality rates found in Glasgow and Scotland, and then evaluated them using the Bradford-Hill's criteria for causality. The paper suggests that the explanation for excess mortality is likely to lie in a combination of different causes. One of the hypotheses suggested is that the spatial patterning of deprivation may influence health outcomes and that the patterning in Glasgow is different from those of other deprived cities in the UK.

There is an extensive body of research which looks at the relationship between health and neighbourhood, some examining direct effects like traffic pollution (Wjst et al., 1993), traffic accidents (Edwards et al., 2008;Lyons et al., 2003) and housing quality, while other research has examined indirect effects like the availability of green spaces (Mitchell and Popham, 2008; Thompson et al., 2012), and alcohol outlets (Thompson et al., 2001). Studies have shown independent effects of neighbourhood on both the physical and mental health of those residents living in these areas (Pickett and Pearl, 2001;Truong and Ma, 2006),

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over and above that explained by the characteristics of the individuals themselves.

In seeking to understand the influence of place on health, the role of poverty and deprivation is crucial. Deprivation causes poor health through a variety of different causal pathways as a result of both personal and neighbourhood effects, and thus poorer areas generally exhibit worse health than less deprived localities. Moreover, there is an emerging body of evidence which suggests that the health of an area is influenced not just by its own level of deprivation, but also by the levels of deprivation in neighbouring areas (Cox et al., 2007;Sridharan et al., 2007;Zhang et al., 2011). Previous studies have treated neighbourhoods as independent geographical units, in effect treating neighbourhoods as 'islands' divorced from their surroundings. Yet we might expect that the wider spatial context in which a neighbourhood lies might also be an important influence on individuals and their health

We can postulate two possible and seemingly opposing mechanisms for how health might be influenced by surrounding neighbourhoods. The first is the spatial concentration of deprived neighbourhoods, which is built on the views from the literature that increasing segregation of the poorest into the most deprived neighbourhoods has a negative effect on the health of the residents in these areas. Authors such as Dorling and Rees (2003) have argued that the UK has become more segregated in recent decades, with the poorest and most affluent members of society increasingly living apart in different neighbourhoods. A deprived neighbourhood which is surrounded by a concentration of other deprived neighbourhoods might have poorer health behaviours and outcomes than one which is surrounded by, or adjacent to, more affluent neighbourhoods. Health is adversely affected by damaging behaviours like smoking, lack of exercise and poor diet, and there is strong and consistent evidence from sources like the Scottish Health Survey which show that unadjusted prevalence of smoking rates, obesity, and low levels of physical activity are higher in deprived neighbourhoods (Scottish Government, 2013). A number of authors have outlined what they call the "collective resource model", which describes the theory that those people living in poverty suffer from a lack of resources not just because of their individual situations but also because of the areas they live in. This "collective resource model" theory if true would suggest that those living in affluent areas acquire more collective resources, including public resources like health services, while those living in more deprived neighbourhoods suffer from the lack of such resources (Cox et al., 2007). They refer to this as the "pull-up or pull-down" hypothesis. Geographical concentration of deprived neighbourhoods might serve to strengthen and deepen these poor health behaviours and cultures, or to exaggerate the unequal distribution of resources. In contrast, those living in deprived neighbourhoods which are surrounded by more affluent areas may have more positive influences on their health behaviours resulting in better outcomes, or they simply may have more access to resources through their proximity to these better off neighbourhoods. Thus, it is argued that there are potential negative effects of the concentration of deprivation.

The second of these mechanisms suggests that contrasting deprivation in surrounding or adjacent neighbourhoods could adversely affect the health of those living in deprived neighbourhoods where the contrast is greatest. This 'psychosocial model' focuses on the work of Wilkinson (2005) and Wilkinson and Pickett (2009) which proposed that high levels of inequality and social comparisons lead to poorer health and social outcomes. The argument would suggest that people living in areas where differences are at their greatest have reduced self-esteem and feel more detached from society in general, compared to those living in neighbourhoods where economic differences are smallest. Wilkinson (2005) argues that these effects operate at the level of whole societies rather than that of individual neighbourhoods. Others have suggested that similar local effects may operate in urban settings (Galea and Vlahov, 2005). For example, Cox et al. (2007) argue that "those who perceive themselves as poor may experience chronic low-level stress as a result of the psycho-social impact of their perceived relative social position". There is evidence that people are aware of the social composition of the neighbourhood in which they live and this shapes judgements about themselves (Bailey et al., 2013; Oberwittler, 2007).

There is increasing evidence that deprivation in proximate neighbourhoods has a negative influence on the health outcomes in the neighbourhood. Sridharan et al. (2007), using Scottish data at a postcode sector geography, found that mortality in postcode sectors was significantly higher in those sectors which had high levels of deprivation in the proximate sectors. Similar results have been found in other studies. Cox et al. (2007) used data at low level geographies for Type 2 diabetes to examine both of the mechanisms discussed above. The research found that poorer neighbourhoods which were surrounded by more affluent neighbourhoods had lower levels of Type 2 diabetes compared with other deprived neighbourhoods, and conversely that affluent neighbourhoods surrounded by more deprived neighbourhoods had higher than expected Type 2 diabetes. Using a slightly larger geography and all-cause mortality in the North West of England, Zhang et al. (2011) examined the impact of deprivation inequality, that is the extent that derivation in the neighbourhood differs from the deprivation in the surrounding neighbourhoods. They used principle component analysis to disaggregate the impacts of within neighbourhood deprivation from the effect of the differences between neighbourhood deprivation and surrounding deprivation on mortality in the neighbourhood. This study shows that deprivation in the surrounding areas does have an impact on overall neighbourhood mortality. However, the research also demonstrates a positive linear effect of the differences between the levels of deprivation in the neighbourhood and surrounding neighbourhoods. This suggests that when differences are high between the neighbourhood and the surrounding neighbourhoods then this has a negative impact on mortality in the neighbourhood, which is keeping up with the psychosocial model suggested earlier. These studies suggest that if the patterning of deprived neighbourhoods in Glasgow was different from other similarly deprived post-industrial cities then this might in part provide an explanation for the "Glasgow Effect".

In this paper we examine whether differences in the spatial patterning of deprivation are in part responsible for the excess mortality experienced in Glasgow, by making a comparison with two similarly deprived cites in the North of England. These comparison cities are Liverpool and Manchester, which are not only shown to have similar levels of deprivation to Glasgow, but they have also been shown to have considerably lower mortality (Walsh, 2010). We test the hypothesis that the geographical patterning of deprivation in Glasgow is in part responsible for the excess mortality experienced in Glasgow compared to Liverpool and Manchester.

2. Methodology

2.1. Data source

2.1.1. Study cities

This study uses cross-section data on all three cities, which relate to the five year period from 2003 to 2007. All three cities were defined by their city council boundaries. This was done because it was the level at which data were available and also because it coincides with the comparative research done by Walsh et al. (2010) on the same three cities.

2.1.2. Neighbourhood and neighbourhood scale

Neighbourhoods in Liverpool and Manchester have been measured at the Lower Super Output Area (LSOA) level and are designed for the presentation of 'neighbourhood' statistics by the UK government. These areas are designed so that their populations are relatively homogenous in terms of deprivation. (ONS, 2012). The average population of an LSOA is around 1500 people. There are a total of 291 LSOAs in Liverpool and 259 in Manchester. The relatively small size of LSOAs, compared to other geographies such as electoral wards, makes it more likely that they represent the geographical scale at which people interact on a daily basis, and these areas are therefore a better representation of a neighbourhood than other, larger, spatial units.

In Scotland LSOAs are not available. The equivalent areas used for reporting official neighbourhood statistics are datazones. Datazones have an average population size of approximately 750 people, and are roughly half the size of English LSOAs. To enable analyses of the three cities using the same spatial scale, the project used a set of previously created areas in Glasgow that were formed by merging contiguous datazones into areas of a similar size to LSOAs. Walsh et al. (2010) created these equivalent LSOAs for Glasgow, using the Geographical Information System (GIS) ArcGIS. The criteria for merging datazones to create these pseudo LSOAs were based on identifying neighbourhoods with similar deprivation, but also in creating areas with similar population size to the LSOAs in England and Wales. The identification of which datazones to merge was completed by hand, reviewing all options before deciding on final changes. In all, 350 areas were established with an average population size of 1650. Further 131 areas were created in the surrounding rings around the city for the purposes of this project, using the same methodology as applied by Walsh et al. (2010).

In this study we also quantify deprivation in the LSOAs surrounding each LSOA for all three cities. These measures of neighbouring deprivation are based on scales as defined by Rae (2009), and are the first contiguous ring of LSOAs around a neighbourhood (Ring 1), and the second contiguous ring around the first ring (Ring 2). Fig. 1 shows a graphical illustration. This approach is commonly used in spatial tests like Moran's I test, but its weakness is that it treats all contiguous neighbourhoods equally despite varying boundary length. A different approach might be to determine a set of neighbouring LSOAs based on being within a fixed distance from the central point of each LSOA. However this approach has its own problems, such as what threshold distance should be used, and the fact that the same threshold distance will be inappropriate for all LSOAs due to their differing sizes. Therefore we chose to use contiguous neighbourhoods in this study.

2.1.3. Mortality and population data

All cause mortality and population data were provided by the Glasgow Centre for Population Health (GCPH). These were used in the original study of mortality and deprivation in the three cities by Walsh et al. (2010), and were originally obtained from the National Records of Scotland (formerly, the General Register Office for Scotland) for Glasgow, and from the Office of National Statistics (ONS) for Liverpool and Manchester. Data were provided by five year age band, gender and for a range of causes for the period 2003–2007 for each LSOA and merged datazone. Direct age and sex standardised mortality rates (SMR) were calculated for each small area in the three cities. Rates were calculated per 100,000 people.

2.1.4. Income deprivation

Both Scotland and England have sophisticated measures of deprivation in the form of the Scottish Index of Multiple Deprivation (SIMD, Scottish Executive 2004) and the Indices of Multiple Deprivation (IMD) in England (Noble et al., 2006). However, as there are differences in content and weighting between the two indices, they are not directly comparable. To produce a comparable measure of deprivation we have used the proportion of the population who are in receipt of key income-related benefits in 2005 as well as children dependent on adult recipients of these

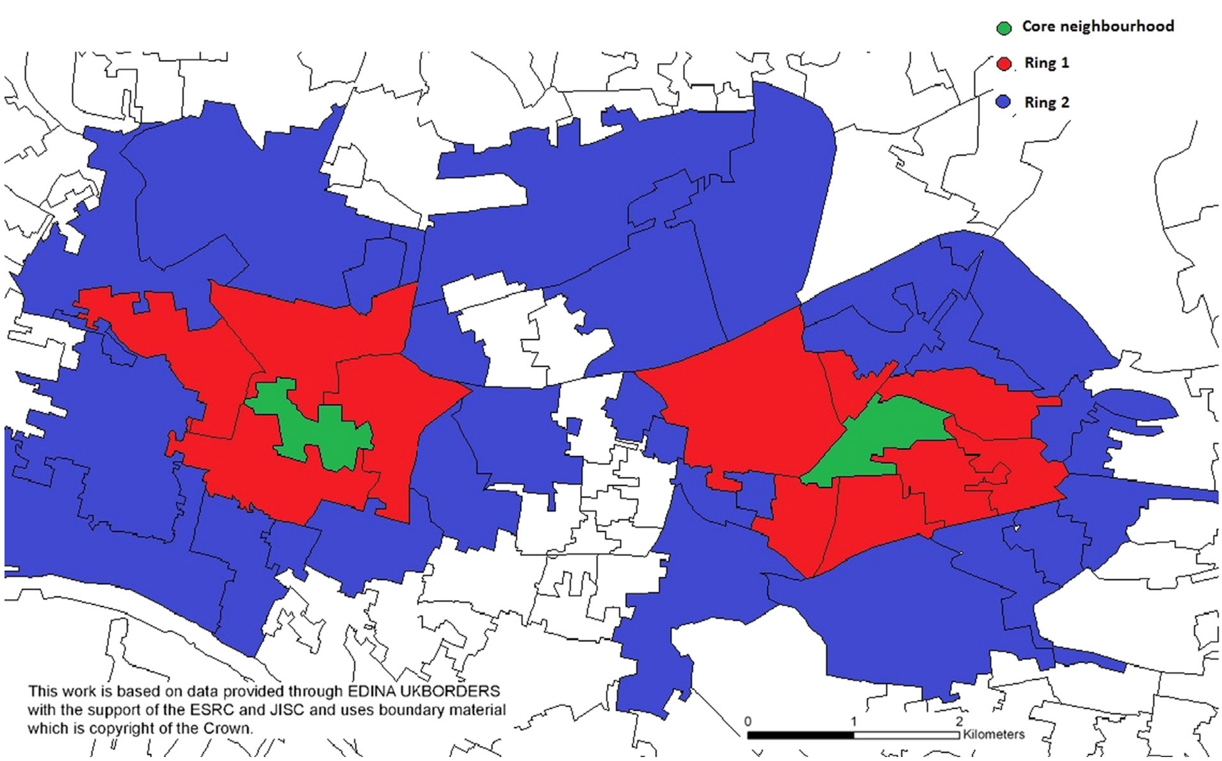

Fig. 1. Examples of two LSOAs (green) with Ring 1 (red) and Ring 2 (blue) highlighted. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

benefits. The percentages of people who are in receipt of these benefits in Glasgow were available from the SIMD and for England were obtained from the Department of Work and Pensions (DWP). This measure of deprivation is highly correlated with the national (SIMD, IMD) deprivation indices in these cities. (Correlation coefficient of 0.98 for Glasgow and 0.97 for Liverpool and Manchester). For the purposes of mapping the percentage of people who are income deprived in an LSOA, the set of LSOAs in all three cities were combined, ranked and then split into deciles to provide an index of deprivation for the three cities.

2.1.5. *Measuring the patterns of deprivation*

For the purposes of this paper we examine the patterning of deprivation in the three cities in a number of ways. We have used Geographic Information System (ARC GIS) software to map and compare levels of neighbourhood deprivation in the three cities. Also, we have used the Global Moran's I test (Moran, 1950) to examine the extent to which deprived neighbourhoods are clustered and whether there are any significant differences in the clustering in each of the three cities. The test is a measure of 'spatial autocorrelation' and thus measures the likelihood that areas in close proximity are similar to each other, based on a particular characteristic (in this case deprivation). The score runs from -1 to 1, with a score of -1 meaning that neighbourhoods are perfectly dispersed, while a score of 1 meaning that neighbourhoods are completely segregated. Values close to 0 represent a random pattern.

2.1.6. *Nursing homes*

The presence of nursing and residential homes concentrate elderly people into certain datazones elevating mortality levels. It is therefore important to control for this factor in our models. Therefore the percentage of the population in the datazone living in nursing and residential homes was also used in our study as a covariate.

2.1.7. *Analysis-modelling*

A number of statistical modelling techniques can be employed to take account of spatial autocorrelation in data relating to neighbourhoods that are geographically close. Since 1950s there has been an increasing focus on spatial statistics, which try to account for the leakage of effects across boundaries (Moran, 1950). However, it was not until computing power increased that more complex spatial autocorrelation models were possible. Spatial regression methods were first introduced in 1980s (Anselin, 1988), while the class of Conditional AutoRegressive (CAR) models for capturing residual spatial autocorrelation was introduced a few years later (Besag et al., 1991). Since then the use of spatial models has increased dramatically (Fotheringham et al., 2002; LeSage and Pace, 2009).

Initially, normal linear models were fitted to the data for each of the three cities separately, where the parameters were estimated using maximum likelihood methods. The dependent (response) variable is the natural log of the SMR, and the covarites include the percentage of people in an area who lived in a nursing home and the square root of the percentage of people defined to be income deprived. The square root transformation of deprivation was suggested from initial scatterplots of the dependent variable against deprivation, and was shown to produce a better fitting model, as measured by adjusted R-squared, than the untransformed variable. The goal of the analysis is to assess the effect of deprivation in the surrounding area on health, after the effects of deprivation within the area have been accounted for. This surrounding neighbourhood deprivation was measured for the contiguous ring of areas encircling the area in question (Ring 1), as well as the next ring of areas encircling the first ring (Ring 2), see Fig. 1. Previous studies have used gravity models to weight deprivation when aggregating deprivation in the surrounding neighbourhoods to the target neighbourhoods (Cox et al., 2007; Sridharan et al., 2007). However, this approach presumes that the population in each geographical unit is focused around its centroid, and even with population weighted centroids this may not be the case as the population is likely to be distributed throughout that geographical unit. However, to quantify the robustness of our results to how we measure deprivation in the surrounding ring, we explore a number of different summary measures of the latter, the results of which can be seen in Table 2. In both the case of Ring 1 and Ring 2 we consider the minimum, median, mean and maximum levels of deprivation in that ring in the analysis. To keep consistency with the within area deprivation covariate, each of these 8 measures of surrounding deprivation are transformed to the square root scale. However, these 8 measures are all highly correlated, so including more than one of them in a model will result in problems of collinearity. Therefore each is included in a separate model in combination with the other two covariates. Finally, we note that for Manchester analysis one observation was an outlier in terms of its Log SMR and was hence removed.

If the residuals from these models are spatially autocorrelated the independence assumption made by the normal linear model is not appropriate. In this case the residual spatial autocorrelation can be accounted for by including a set of spatially autocorrelated random effects in the model, which are represented by a CAR prior. This gives an extended linear model of the form:

$$
\begin{aligned}
LOG.SMR_k = {} & \beta_0+\beta_1 NURSE_k+\beta_2 SQRT.DEP_k \\
& +\beta_3 SQRT.NEI.DEP_k+\phi_k+\epsilon_k
\end{aligned}
$$

for LSOAs $k=1,\ldots,n$. In this equation $\mathrm{LOG}\times\mathrm{SMR}_k$ is the log SMR value for the kth LSOA, and the covariates are the percentage of people living in a nursing home (NURSE), the square root of the deprivation within the LSOA in question ($\mathrm{SQRT}\times\mathrm{DEP}$) and the square root of the deprivation within the neighbourhing LSOAs ($\mathrm{SQRT}\times\mathrm{NEI}\times\mathrm{DEP}$). In the above model equation ϵ_k is an independent normal error with mean zero and constant variance. The linear model which assumes independence is thus made up of the above equation without ϕ_k, where as this term is called a "random effect" in the statistical literature. Its existence in the above model equation is to allow for spatial autocorrelation in the dependent variable not captured by the covariates, which would violate the assumption of independence in the ordinary linear model. Each LSOA has its own random effect, and a prior distribution is placed on the set of these effects for each area to enforce them to be spatially autocorrelated. A CAR prior is used in this study because it is common place in the statistical literature, and for further details see Banerjee et al. (2004) and Wakefield (2007). The prior proposed by Leroux (Leroux et al., 1999) is used here, because a recent review by Lee (2011) suggested that it performed best out of a range of CAR priors. Inference for this model is based on a Bayesian paradigm, using Markov Chain Monte Carlo (MCMC) simulation. This is achieved using the CARBayes package (Lee, 2013) for the statistical software R. which is freely available to download from http://cran.r-project.org/web/packages/CARBayes/index.html.

Finally, we note that in this paper the analysis is cross-sectional and not longitudinal, so we are only able to quantify the impact of neighbouring deprivation on health in a single time period (2003–2007). Thus we are not able to say anything about the potentially time-varying (dynamic) effect of neighbouring deprivation on health over time. We also note that the CAR model is included in the analysis purely to account for the spatial autocorrelation in the dependent variable that is unaccounted for by the covariates, and does not directly relate to the relationship between neighbouring deprivation and health.

3. Results

Maps of the spatial patterning of deprivation for all three cities are shown in Figs. 2 and 3, and are presented as deciles for each city. The figures show that the spatial deprivation patterns in the three cities are different, as in Glasgow (Fig. 2) deprivation appears less concentrated than in the other two cities (Fig. 3). Deprivation in both Liverpool and Manchester tends to be focused near the city centres than is the case in Glasgow. In addition, in Liverpool and Manchester the transition from the most deprived areas to the most affluent tends to be gradual, with the areas nearest to the most deprived neighbourhoods tending to be as deprived or only slightly less deprived. In Glasgow the areas of deprivation are more dispersed with more evidence of less gradual/more extreme changes from deprived to affluent.

These impressions are reflected by applying a Moran's I test for spatial autocorrelation to the deprivation data in each city. Table 1 shows that the test is significant for all three cities, indicating that deprived neighbourhoods are significantly more likely to be near other deprived neighbourhoods. However the I statistic is lower for Glasgow than it is for the other two cities, with Liverpool having the largest I statistic. While it is not possible to tell if these differences are statistically significant it is valid to compare the I scores for the three cities, with lower values representing more dispersed deprived neighbourhoods.

Having examined the differences in the patterning of deprivation between the three cities, we then examined whether the pattern of deprivation surrounding an LSOA influenced the mortality rate in that LSOA. The aim of this analysis was to assess if the differences in the spatial patterning of deprivation between the three cities might in part explain the differences in their mortality rates. As has been stated, normal linear models were initially fitted to the data for the three cities separately, and the residuals were tested for the presence of spatial autocorrelation using a permutation test based on Moran's I statistic. The test was based on 10,000 random permutations, and yielded significant p-Values of 0.0378 (Glasgow), 0.0039 (Liverpool), and 0.0004 (Manchester) for the three cities. Therefore the assumption of independence made in the normal linear model is not appropriate, and the residual spatial autocorrelation needs to be accounted for. However, for comparison purposes with the spatial autocorrelation models implemented below, the results for the linear model are also provided in Table 2.

As these linear models are not appropriate and do not account for the residual spatial autocorrelation in the data, we added a set of spatially autocorrelated random effects to the model, which are represented by a CAR prior (see description and references in the methods section). Fitting these models removed the spatial autocorrelation from the residuals, with p-Values (again based on a permutation test using Moran's I statistic) of 0.423 (Glasgow),

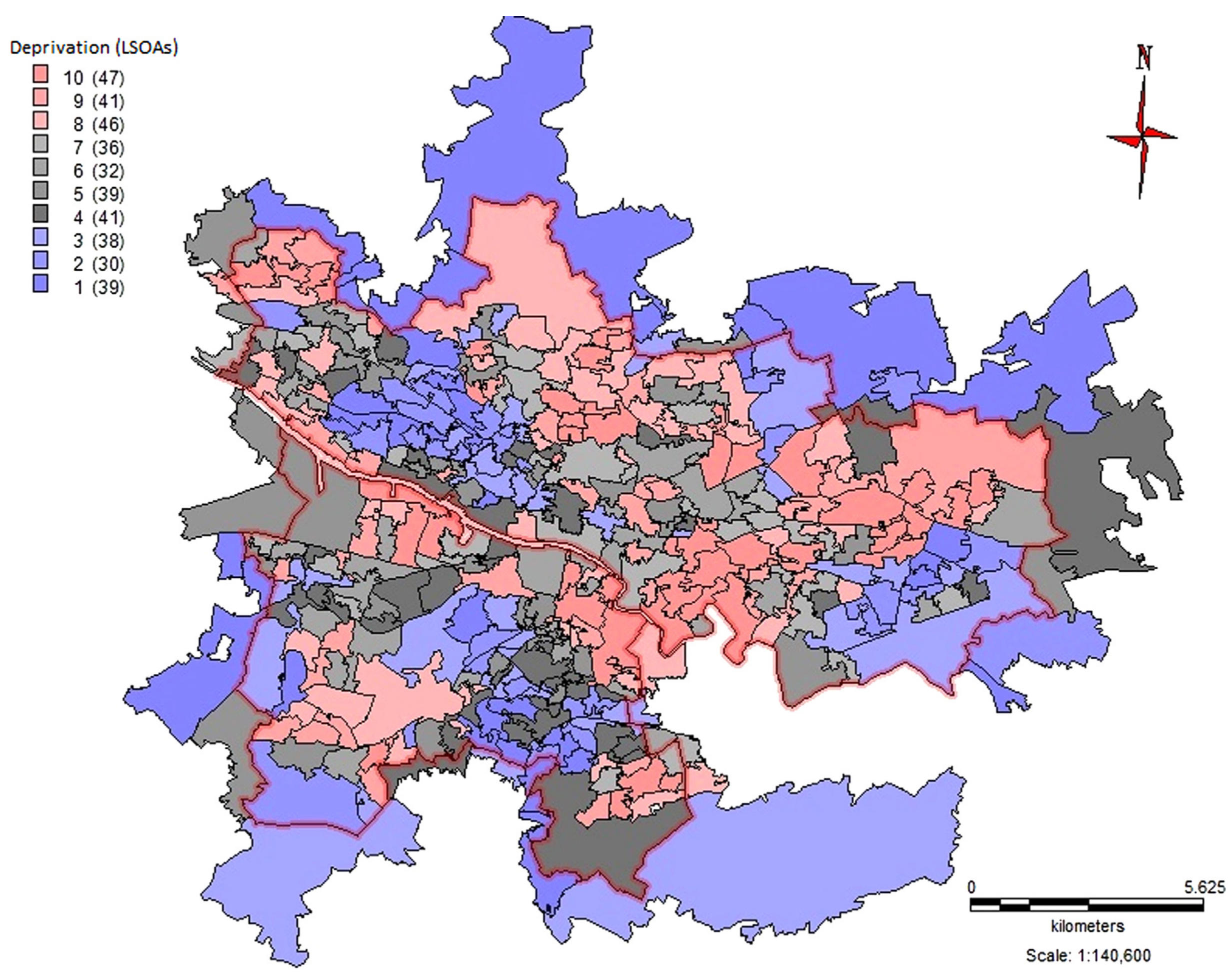

Fig. 2. Income deprivation in Glasgow (ranked across all three cities). *Notes*: City Council boundary is represented by the red line. Decile 10 is the most deprived decile and decile 1 is the least deprived. Maps are based on data provided with the support of the ESRC use boundary material which is copyright of the Crown, Post Office and the EDLINE consortium. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

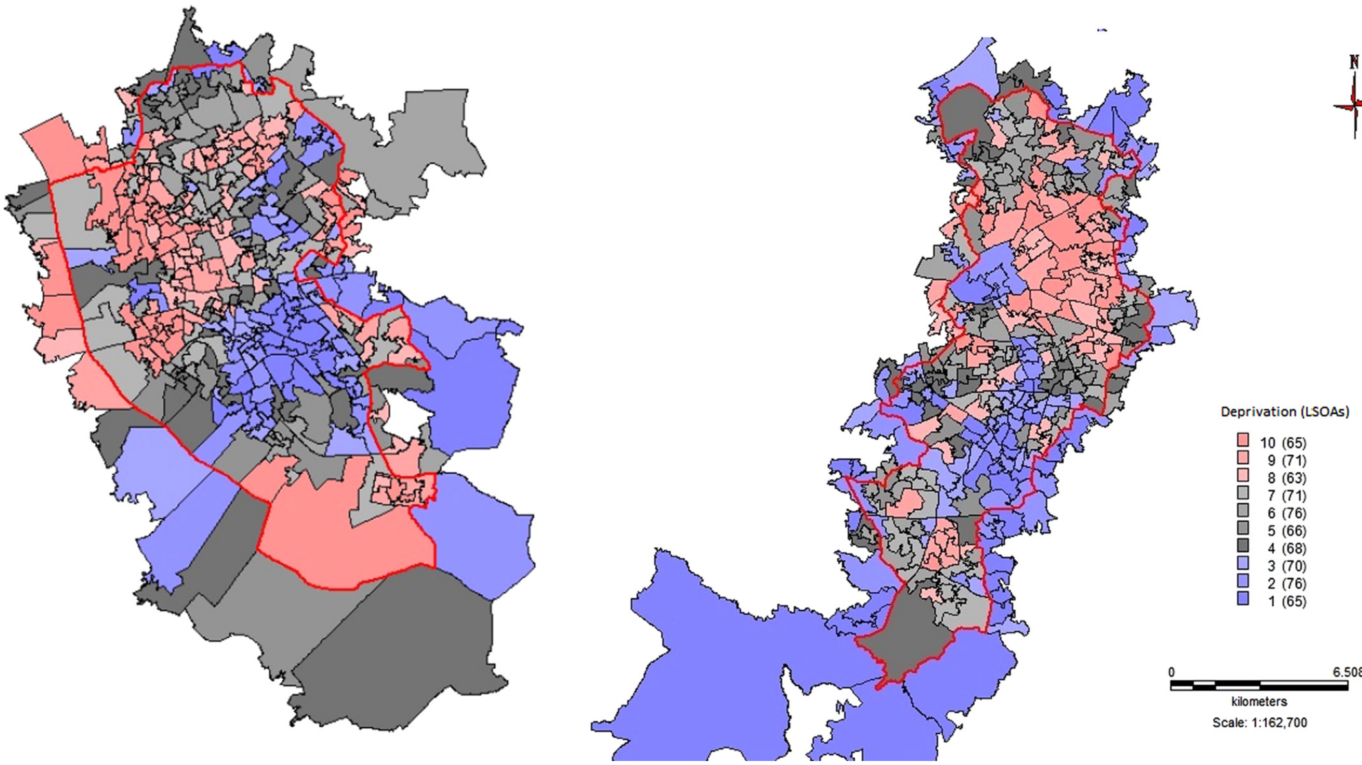

Fig. 3. Income deprivation in Liverpool (left) and Manchester (right) (ranked across all three cities). *Notes*: City Council boundary is represented by the red line. Decile 10 is the most deprived decile and decile 1 is the least deprived. Maps are based on data provided with the support of the ESRC use boundary material which is copyright of the Crown, Post Office and the EDLINE consortium. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Summary of the Moran's I test for spatial autocorrelation in income deprivation for each city.

	I	*p*-Value
Glasgow	0.077	0.000
Liverpool	0.146	0.000
Manchester	0.117	0.000

Notes: Higher values of the Moran's I test indicate a higher likelihood of nearby areas having similar levels of the characteristic measured (in this case deprivation).

0.444 (Liverpool), and 0.749 (Manchester) for the three cities. Results for these correlation models are presented in Table 2 alongside the results for the independence models, and while only the correlation model is statistically appropriate, the differences between the models in this analysis are small.

Results from the correlation model show that deprivation within the neighbourhood has the strongest association with higher mortality rates. This effect is consistent across the three cities, and although the coefficient is highest in Glasgow there are no significant differences between the coefficients from the three cities. We summarised surrounding deprivation in both Ring 1 and Ring 2 using four different measures, namely the Median, the Mean, the Minimum, and the Maximum. The use of four summary statistics allows us to assess the robustness of our results to the summary measure of surrounding deprivation used. These eight summary measures are all highly correlated, and therefore only one is entered into the model at any one time. In Glasgow all the measures of the surrounding deprivation in Ring 1 have a positive and significant result on mortality in the neighbourhood, though the effect is small compared to the more direct effect of within neighbourhood deprivation. The effects are similar in Ring 2 but the minimum and the maximum values are no longer statistically significant. Similarly in Liverpool the impact of surrounding deprivation in Ring 1 is significant (except when measured by the minimum value), as are the results for Ring 2. In Liverpool the coefficient values are larger than those in Glasgow, but as the uncertainty intervals for these coefficients between Glasgow and Liverpool overlap the differences are not significant. The results for Manchester show that there is no significant impact on neighbourhood mortality from surrounding deprivation, either at the Ring 1 or Ring 2 level. The size of the effect appears similar in Ring 2 to that in Ring 1 in all three cities. This may be a reflection of the high correlation between the two sets of rings.

The effect of within area deprivation in Glasgow is stronger than the effect of deprivation in Ring 1 (about 3.5 times stronger) but in Liverpool the effect at Ring 1 is relatively similar to the within area effect. Quantifying these results on an interpretable scale (due to the natural log of the SMR being used as the response), we can say that if the percentage of income deprivation in neighbouring areas (as measured by median ring 1) increased by 1%, then there would be the following percentage increases in SMR (estimates and 95% uncertainty intervals[1] in brackets).

- Glasgow – 3.59% (1.20%, 5.97%)
- Liverpool – 8.87% (4.91%, 12.87%)
- Manchester – 0.64% (−3.50%, 5.19%)

These results suggest that in general the impact of deprivation on mortality is strongest within a neighbourhood as would be expected, but that after accounting for this the level of surrounding deprivation has a significant effect on the mortality in the neighbourhood in Liverpool and Glasgow but not in Manchester.

[1] Conditional AutoRegressive models are fitted here in a Bayesian setting, so the uncertainty intervals are called 95% credible and not confidence intervals. However, these intervals can be interpreted in the same way as confidence intervals.

Table 2
Covariate effects from both the normal linear model (independence model) and the Conditional autoregressive model (correlation model).

Covariate	Glasgow Independence model	Correlation model	Liverpool Independence model	Correlation model	Manchester Independence model	Correlation model
Nursing home	**4.920 (3.715, 6.125)**	**4.955 (3.734, 6.137)**	**4.725 (3.105, 6.345)**	**4.535 (2.912, 6.133)**	**8.396 (5.912, 10.881)**	**8.269 (5.906, 10.684)**
Sqrt deprivation	**0.128 (0.111, 0.145)**	**0.128 (0.111, 0.145)**	**0.084 (0.055, 0.113)**	**0.084 (0.056, 0.113)**	**0.120 (0.088, 0.151)**	**0.124 (0.094, 0.155)**
Median ring 1	**0.036 (0.013, 0.058)**	**0.035 (0.012, 0.058)**	**0.091 (0.057, 0.125)**	0.086 (0.048, 0.121)	0.001 (−0.038, 0.041)	0.005 (−0.039, 0.050)
Mean ring 1	**0.041 (0.015, 0.067)**	**0.041 (0.014, 0.068)**	**0.104 (0.064 , 0.143)**	0.099 (0.055, 0.141)	−0.022 (−0.067 , 0.024)	−0.024 (−0.073, 0.026)
Min ring 1	**0.025 (0.005, 0.045)**	**0.025 (0.004, 0.046)**	**0.039 (0.008, 0.069)**	0.033 (−0.003, 0.067)	−0.021 (−0.052, 0.009)	−0.024 (−0.058, 0.009)
Max ring 1	**0.026 (0.004, 0.049)**	**0.026 (0.004, 0.051)**	**0.068 (0.035 , 0.100)**	**0.058 (0.021, 0.094)**	−0.021 (−0.058, 0.016)	−0.028 (−0.070, 0.012)
Median ring 2	**0.049 (0.025, 0.074)**	**0.050 (0.024, 0.075)**	**0.072 (0.040, 0.103)**	**0.066 (0.026, 0.104)**	0.000 (−0.033, 0.033)	−0.002 (−0.044, 0.037)
Mean ring 2	**0.047 (0.017, 0.077)**	**0.047 (0.015, 0.079)**	**0.103 (0.063, 0.143)**	**0.102 (0.056, 0.148)**	0.011 (−0.034, 0.055)	0.008 (−0.048, 0.065)
Min ring 2	0.018 (−0.008, 0.043)	0.016 (−0.012, 0.043)	**0.051 (0.015, 0.087)**	0.040 (−0.007, 0.082)	−0.011 (−0.053, 0.030)	−0.018 (−0.063, 0.028)
Max ring 2	0.026 (−0.001, 0.053)	0.026 (−0.002, 0.054)	**0.086 (0.049 , 0.122)**	**0.080 (0.036, 0.121)**	0.038 (−0.004, 0.079)	0.038 (−0.011, 0.088)
Moran's (*p*-Values)	0.0378	0.423	0.0039	0.444	0.0004	0.749
R-squared	0.604	0.712	0.510	0.732	0.367	0.822

Notes: The first number in each cell in the table is the estimated effect, and the numbers in brackets are at 95% uncertainty intervals. The intervals for the independence model are likelihood of confidence intervals, while for the correlation model they are Bayesian credible intervals. Significant results as tested at 0.05 level are shown in bold. Coefficients for the neighbourhood deprivation term and deprivation in surrounding rings are comparable but not between nursing homes and other variables. Cross city comparisons are also valid.

However, it is not possible to say that the effect is significantly different between cities as the uncertainty intervals quoted overlap. We can say that there is a small effect of surrounding deprivation on the mortality in a neighbourhood that is not significant in Manchester. Our mapping of deprivation suggests that Liverpool and Manchester have similar patterns of deprivation, with deprived neighbourhoods in each of the cities spatially concentrated near the city centre. On the other hand Glasgow's deprived neighbourhoods are much more dispersed. This suggests that differences in mortality observed between Glasgow and the other two cities are not explained by the pattern of deprivation.

4. Discussion

The aim of this research was to examine whether the spatial patterning of deprivation may in some part account for the differences in mortality experienced in Glasgow compared to Liverpool and Manchester. If the patterning of deprivation was a contributory factor to the excess mortality found in Glasgow, we would expect that results for Glasgow would be different from the other two cities. McCartney et al. (2012) hypothesise that "*deprived areas in Scotland and Glasgow form large, concentrated, monocultural communities to a greater extent than elsewhere, and this has a negative causal impact on health"*. Mapping and Moran's tests seem to indicate that Glasgow's deprivation is more dispersed than in Liverpool and Manchester. Neighbourhoods in Glasgow are less likely to be beside neighbourhoods which are similar in deprivation than the other two cities. This evidence alone contradicts McCartney et al.'s, (2012) hypothesis that Glasgow's deprived neighbourhoods are more concentrated than other similar post industrial cities. Glasgow has cleared much of the worst housing from the city centre, and moving much of the population from these areas to peripheral estates has resulted in relatively little deprivation in or near the city centre. This process began in the mid-fifties and went through to the early eighties, peaking between 1970 and 1972 (Markus, 1999; Pacione, 2013). We might suggest an amendment to the McCartney et al.'s, 2012 hypothesis by suggesting that there are two possible configurations of deprivation which explain the differences in health outcome observed between Glasgow and other cities. So as an effect of concentrated deprived neighbourhoods we might also add the possible impact of more dispersed deprived neighbourhoods where differences between the neighbourhood and their neighbours have an effect on health in the neighbourhood.

As well as the difference in patterns of deprived neighbourhoods across the three cities, the influence of the deprivation in proximate neighbourhoods is shown to be different in one of the cities compared to the other two. Deprivation in proximate neighbourhoods in Liverpool and Glasgow is associated with higher neighbourhood mortality, both at the immediate contiguous scale but also in the Ring beyond this. The estimate for Liverpool suggests that, 1% change in deprivation in the surrounding Ring 1 would lead to a change in the mortality rate in the average neighbourhood of 76 deaths per 100,000 of the population. This compares to an estimate of an increase of 35 deaths per 100,000 in the average neighbourhood for Glasgow in the same average population. The surrounding neighbourhoods in Manchester appear to have little or no effect on neighbourhood mortality over and above that of within neighbourhood deprivation. This lack of association holds true for both the inner ring (Ring 1) and also for the further ring (Ring 2). These city differences are not consistent with the hypothesis that either spatial concentration or dispersal of deprived neighbourhoods are responsible for the excess of deaths we observe in Glasgow compared to the other two cities and we would have to reject that hypothesis.

Sridharan et al. (2007) argue that differences in spatial patterning of deprivation between Scotland and England may help explain the differences in their mortality rates. They point to two possible ways in which the "Scottish Effect" may be explained, pointing to the differences in the spatial heterogeneity but also to possible differences in the spatial dependence in Scotland compared to England and Wales. How deprived areas are spatially patterned may be different and important, and also the relationship between deprivation and mortality in proximate areas may also be different and important. While not covering the whole of Scotland, England and Wales, the study does examine three major cities in Scotland and England. We find as Sridharan et al. (2007) hypothesised that the patterning of deprivation is different in Glasgow compared to Liverpool and Manchester. The patterns are not as we might have expected, and rather than Glasgow neighbourhoods forming "large, concentrated, monocultural communities to a greater extent than elsewhere", it has more diverse deprivation patterning than the other post-industrial cities in this study. So spatial patterning of deprivation is different in the three cities but not necessarily how we might have hypothesised.

The relationship between deprivation and mortality in the neighbourhood is not significantly different between the three cities. The relationship between deprivation in the surrounding neighbourhoods and mortality rates in the neighbourhood is different in the different cities, being significant in Liverpool and Glasgow but not in Manchester. The effect appears stronger in Liverpool compared to Glasgow, but as the confidence intervals overlap they are not significantly different. It should not be surprising that the deprivation of proximate neighbours is found to be significantly associated with mortality in the neighbourhood, as this reflects similar results from other studies (Allander et al. 2012; Zhang et al., 2011; Cox et al., 2007; and Sridharan et al. (2007)). However, this study indicates that the impact of deprivation in proximate neighbourhoods on the mortality of the neighbourhood is different depending on the context. Sridharan et al. (2007) found that the relationship between mortality and deprivation both in the neighbourhood and between neighbourhoods was constant across Scotland. The results in our research, while not directly contradicting this, does suggest that surrounding deprivation may have a different impact on neighbourhood mortality depending on the city. The different relationship between surrounding deprivation, at both Ring 1 and Ring 2, might be simply the way that deprivation is patterned in the three cities, though our spatial modelling should account for this. However the maps tell us that the distribution of deprived neighbourhoods is more similar in Liverpool and Manchester compared to Glasgow, but the findings in this study suggest that Liverpool and Glasgow are more alike than when each is compared to Manchester.

The main objective of this research was to test the hypothesis that the spatial patterning of deprivation contributed to the “Glasgow Effect”. Our results indicate that this is not the case, as deprivation in surrounding neighbourhoods has an effect on mortality in the neighbourhood in Liverpool and Glasgow but not in Manchester. The effect is strongest in Liverpool rather than in Glasgow which means that this is not contributing to the differences in health outcomes between Glasgow and the two English cities. The fact that the relationship is significantly different in each of the cities suggests that the effect may not be consistent across space and further research is needed to understand this relationship across a wider dataset. Therefore, in relation to the two mechanisms outlined earlier in the paper (spatial concentration and contrasting deprivation), by which the spatial patterning of deprived neighbourhoods may impact on health in the neighbourhood, there is little evidence that the results observed in this study contribute to the Glasgow effect. That is not to say that these mechanisms do not have an effect but rather there impact is small and not observed in the three cities in a way that is consistent with the hypothesis.

In summary we have observed small but significant differences in the impact of surrounding deprivation in Glasgow and Liverpool but not in Manchester. The effect on mortality in these cities is small, and represents only a very weak effect compared to the effect of deprivation within the neighbourhood. It is not at the level that it in anyway explains the excess in mortality found in Glasgow compared with the other cities, which is large and profound. If patterning was in anyway a contributing factor to the Glasgow effect we would expect Glasgow to be significantly more affected by mortality from both Ring 1 and Ring 2 than the other two cities. However, there are no significant differences between the cities and as a result we can reject the hypothesis that patterning contributes to the Glasgow effect.

4.1. *Limitations*

This study is a cross sectional examination of the spatial patterns of deprivation as they existed in 2005 and the mortality between 2003 and 2007, and as such only informs about the associations between the two in this time period. We acknowledge that the Glasgow effect is not a static unchanging phenomena, but rather one that has developed since the 1950s. However, the effect as has been described exists in this time period and as neighbourhood deprivation changes slowly we believe these results are likely to be relevant for considerable time frames both in the past and in more recent years. Another limitation to this study is the relatively rare occurrence of death in a neighbourhood, but we have compensated for this by using mortality for a five year period.

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