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Is ethnic density associated with risk of child pedestrian injury? A comparison of inter-census changes in ethnic populations and injury rates

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Objectives. Research on inequalities in child pedestrian injury risk has identified some puzzling trends: although, in general, living in more affluent areas protects children from injury, this is not true for those in some minority ethnic groups. This study aimed to identify whether 'group density' effects are associated with injury risk, and whether taking these into account alters the relationship between area deprivation and injury risk. 'Group density' effects exist when ethnic minorities living in an area with a higher proportion of people from a similar ethnic group enjoy better health than those who live in areas with a lower proportion, even though areas with dense minority ethnic populations can be relatively more materially disadvantaged.
Design. This study utilised variation in minority ethnic densities in London between two census periods to identify any associations between group density and injury risk. Using police data on road traffic injury and population census data from 2001 to 2011, the numbers of 'White,' 'Asian' and 'Black' child pedestrian injuries in an area were modelled as a function of the percentage of the population in that area that are 'White,' 'Asian' and 'Black,' controlling for socio-economic disadvantage and characteristics of the road environment.
Results. There was strong evidence ($p < 0.001$) of a negative association between 'Black' population density and 'Black' child pedestrian injury risk [incidence (of injury) rate ratios (IRR) 0.575, 95% CI 0.515–0.642]. There was weak evidence ($p = 0.083$) of a negative association between 'Asian' density and 'Asian' child pedestrian injury risk (IRR 0.901, 95% CI 0.801–1.014) and no evidence ($p = 0.412$) of an association between 'White' density and 'White' child pedestrian injury risk (IRR 1.075, 95% CI 0.904–1.279). When group density effects are taken into account, area deprivation is associated with injury risk of all ethnic groups.
Conclusions. Group density appears to protect 'Black' children living in London against pedestrian injury risk. These findings suggest that future research should focus on structural properties of societies to explain the relationships between minority ethnicity and risk.

Keywords: children; ethnic density; injury

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Background

A large literature links socio-economic disadvantage with increased risk of child pedestrian injury (Laflamme, Hasselberg, and Burrows 2010; Laflamme and Diderichsen 2000). Increasingly, a number of studies in a range of countries have also suggested ethnic differences in child pedestrian injury risk, with most (Abdalla 2002; Campos-Outcalt et al. 2002; Harrop et al. 2007; Rivara and Barber 1985; Savitsky, Aharonson-Daniel, and Giveon 2007; Stirbu et al. 2006; Abdel-Rahman et al. 2013), but not all (Al-Madani and Al-Janahi 2006), studies reporting that minority ethnic groups are at greater risk than their majority counterparts. Given that minority ethnic status is often correlated with both individual and area deprivation, it is perhaps unsurprising that minority children are often at higher risk. However, recent research to unpick the links between socio-economic disadvantage, ethnicity and child pedestrian injury (Steinbach et al. 2010) suggests that the relationships are complex: material disadvantage does not explain differences in injury rates across ethnic groups.

In London, for example, home to half of the UK's ethnic minority population, our previous work reported that pedestrian injury rates are associated with area deprivation, and that pedestrian injury rates among 'Black' children are 50% higher than rates among 'White' children. Although there was a clear gradient of risk for 'White' and 'Asian' children, with those in more deprived areas at higher risk than those in the most affluent areas, this gradient did not hold for 'Black' children, whose risk remained the same across all levels of deprivation. That is, although minority ethnic populations are disproportionately located in least affluent areas, while area affluence appears to protect 'White' and 'Asian' children from increased road injury risk, 'Black' children face higher risks of injury across the city (Steinbach et al. 2010). Explaining both the high risk of 'Black' children in London, and the lack of any apparent area deprivation effect, has been challenging. We have found little evidence to date that the quality of the road environment (Steinbach et al. 2010), the quantity of pedestrian exposure (Steinbach, Green, and Edwards 2012) or potential differences in vulnerability to risk by time of day (Steinbach et al. 2014) can account for overall differences in risk, or explain why living in more affluent areas does not also protect 'Black' children from risk. Indeed, when we control for the quantity and quality of pedestrian exposure (i.e., the distances travelled and the kinds of roads walked) it appears that 'Black' children in the most affluent areas of London face *higher* injury risks than 'Black' children living in more deprived areas (Steinbach, Edwards, and Green 2014).

This negative association between affluence and risk is puzzling in the light of the majority of research which associates high risk with deprivation. One potential explanation lies in the very different experiences of 'Black' children in less affluent areas, where they may be more likely to be living with people from the same ethnic group. Given that ethnic minorities in London tend to live in more deprived areas (Jivraj and Khan 2013), the findings that higher levels of area deprivation appear to have a protective effect on 'Black' child pedestrian injury rates may be evidence of the effects of social composition itself on a health outcome. One candidate explanation is 'group density' effects.

Group density effects arise from the compositional and/or contextual consequences of living in an area with a higher proportion of people 'like you' (Pickett and Wilkinson 2008), and can be identified when individuals living in areas with a high proportion of people from the same ethnic group enjoy better health than those who live in areas with a

lower proportion, even though areas with dense minority ethnic populations can be relatively more materially disadvantaged (Becares and Nazroo 2013; Das-Munshi et al. 2010; Shaw et al. 2012). Theoretically, compositional explanations for such effects relate primarily to different components of social capital and social cohesion (Kawachi and Berkman 2000). The adequate theorisation and operationalization of social capital in terms of its likely relation to health outcomes is controversial (Portes and Vickstrom 2011; Szreter and Woolcock 2004), and whether such effects are found depends in part on the measure of social capital used (Becares and Nazroo 2013) but, briefly, hypothetical consequences of ethnic density include increased social cohesion, trust, social reciprocity and social integration, which are associated with positive health outcomes. Contextual correlates of living in areas of high ethnic density theoretically include better access to services and goods that are important determinants of health, such as preferred foods, appropriate and respectful health services or opportunities to engage in sports or leisure. Conversely, living in areas with low proportions of similar people may be associated with higher levels of stigma, disrespect and overt discrimination (Bécares, Cormack, and Harris 2013), as well as potential psychosocial impacts from visible social inequality (Wilkinson, Kawachi, and Kennedy 1998). Minority ethnic individuals may face fewer experiences of racism in ethnically dense areas, buffering the adverse effects of racism on health (Bécares, Nazroo, and Stafford 2009). Whether, and to what extent, any of these theoretical pathways are likely to be salient depends on the political and historical context of ethnic segregation and density (Smaje 1995). Given the putative psychosocial pathways that link elements of social capital to health, group density effects have been mostly consistently found for mental health outcomes such as psychoses (Shaw et al. 2012). However, some empirical studies have also suggested group density effects on physical health, mortality and health behaviours (Bécares, Shaw et al. 2012) and self-reported health (Smaje 1995). Stigma and a lack of social integration (shared culture, social networks and social capital), are hypothesised as the mechanism for such effects, whereby those living in areas with fewer people of the same ethnic group may be less likely to encounter positive social interactions, and more likely to encounter status inconsistencies or discriminatory practices (Pickett and Wilkinson 2008).

Although pedestrian road injury is not an obvious candidate for psychosocial pathways linking social structures to health outcomes, the risks of injury are clearly socially patterned by deprivation and ethnicity. As a first step in identifying whether there is any evidence for whether there may be similar structural explanations for ethnic inequalities in injury risk, we explore whether there is any empirical evidence for group density effects on pedestrian injury rates and if so, whether these can shed light on the social epidemiological puzzle of ethnic inequalities in child pedestrian injury in London. This study aimed to determine whether the ethnic density of an area is associated with child pedestrian injury risk in London, and whether ethnic density effects can help explain the lack of relationship found between area deprivation and risk of Black children in London.

Methods

This study used a comparison between two census periods, 2001 and 2011, to investigate our hypothesised links between ethnic group density and child pedestrian injury risk in areas of London. Using police data on road traffic injury and population census data, we

modelled the rate of 'White,' 'Black' and 'Asian' child pedestrian injuries in an area as a function of the proportion of the population in that area that are 'White,' 'Black' and 'Asian,' controlling for socio-economic disadvantage and road environment characteristics. We used data from two time periods in order to provide a greater sample size of areas in London, to capitalise on changes over time and to implicitly control for area level effects on injury risk. If the ethnic density of an area is associated with injury rates, we would expect that areas with changes in population make-up between 2001 and 2011 would also experience changes in child pedestrian injury rates. We included controls for road environment characteristics, since a large literature links area attributes, such as traffic volumes and traffic speeds, to pedestrian injury risk (DiMaggio and Li 2012). Our study controlled for available road environment characteristics in London. Using data from two time periods helps isolate the effect of population make-up on pedestrian injury by implicitly controlling for road environment and other area level factors not included in our model; while populations, ethnic densities and injury events vary over time, other area level characteristics such as amounts of street furniture, access to green space or street parking are arguably less likely to change over a 10-year time period.

Unit of analysis

We analysed data at the census lower super output area (LSOA) level. LSOAs are geographic areas including an average of 1500 people, defined by the Office of National Statistics (ONS) using measures of population size, mutual proximity and homogeneity of characteristics such as dwelling types and tenure. There were 4765 LSOAs in London in the 2001 census. Due to some significant changes in population, the ONS redrew LSOA boundaries in 2011. There were a total of 4835 LSOAs in London in 2011, including 4642 (96%) LSOAs with the same boundaries used in 2001. In some cases, the 2001 LSOA boundaries were split into multiple LSOAs in 2011, in other cases multiple 2001 LSOA boundaries were merged together to form one 2011 LSOA boundary, and in 25 cases 2011 boundaries were redrawn in a way that did not map onto 2001 LSOA boundaries. In order to include as many areas as possible in the analyses, we determined the largest geographic area common in 2001 and 2011. We then computed average figures for these areas. For 2001 boundaries that were subsequently merged in 2011 this meant summing all of the figures from all 2001 boundaries included within a 2011 boundary and dividing by the number of 2001 boundaries. For 2001 boundaries that were subsequently split into multiple 2011 boundaries this meant summing the figures from all 2011 boundaries included within a 2001 boundary and dividing by the number of 2011 boundaries. In total, we included 4723 areas in our analysis.

Injury events

We obtained a data-set of police STATS19 data for the periods 2000–2002 and 2010–2012 that included all reported casualties and traffic collisions occurring in from Transport for London. Since 1995, London Metropolitan Police have included information on the ethnicity of casualties in their reports. The classification of ethnicity used is the six-category Police National Computer 'Identity Code,' which is designed for descriptive purposes in crime detection and prevention, rather than for monitoring purposes. Police rely on physical attributes to categorise casualties into one of the six

codes: White-skinned European, Dark-skinned European, Afro-Caribbean, Asian, Arab or Oriental. This classification of ethnicity has a number of disadvantages: there are no other routine population level data that use them, they do not reflect how most people would define their ethnicity identity and there are uncertainties as to how, in practice, police officers distinguish people using these codes. However, by carefully grouping identity codes into broad ethnic groupings and employing a number of sensitivity analyses to test these groupings, we have successfully used them to investigate ethnic differences in road traffic injury risk in a number of circumstances (Steinbach, Edwards, and Green 2014; Steinbach et al. 2010, 2014). In these previous analyses we found that using numerous plausible groupings of identity codes did not substantially change our results. For this analysis, we grouped casualties into four broad categories based on groupings used in previous research: 'White' (White-skinned European, Dark-skinned European); 'Black' (Afro-Caribbean); 'Asian' (Asian); and 'Other' (Arab, Oriental, missing ethnicity). The category 'Other' is omitted from this analysis as the heterogeneity of the grouping does not allow for reliable comparisons with population data: it is impossible to map population data to a missing identity code and ethnicity codes in the population data do not easily map on to Oriental and Arab identity codes.

Consistent with previous work on inequalities in child pedestrian injury in London, casualties were included in the analysis if aged 0–15 years and injured as pedestrians. In order to calculate injury rates, casualties must be assigned to population denominators at an LSOA level. There are two candidate assignment methods: the location of collision assignment method assigns casualties to the area in which children were injured as a pedestrian using the Ordnance Survey grid reference of each collision; the location of residence assignment method assigns casualties to the area in which children live using the centroid of the postcode of residence. The most appropriate assignment method is under debate (Hewson 2004, 2005). The location of residence assignment method ensures that population denominators are appropriate; however, information on location of residence is missing from over 40% of the casualty data, making the location of collision assignment method attractive in order to make use of more data. Additionally, there is evidence that in London child pedestrians tend to be injured close to home (Steinbach, Edwards, and Grundy 2013). We therefore decided to assign casualties to a LSOA using the location of collision assignment method. A sensitivity analysis was conducted to compare results when assigning casualties using the location of residence assignment method. We used three years of casualty data around the 2001 census (2000–2002) and the 2011 census (2010–2012) in order to minimise the impact of random yearly fluctuations in number of injury events.

Child population estimates

Age-specific population data are not available at LSOA level by ethnic group, so the population of 'White,' 'Black' and 'Asian' children in each LSOA was estimated by multiplying the numbers of children aged 0–15 years resident in each LSOA in 2001 and 2011 by the proportion of residents of all ages that are 'White,' 'Black' or 'Asian' (as described below). The estimates of LSOA-level ethnic group child populations were then scaled to sum to the total child population estimates [available at borough level in 2001 and 2011; supplied by the Greater London Authority (GLA)], to allow for ethnic differences in family size.

Ethnic density

We obtained estimates of the population of all ages living in each LSOA by ethnic group in 2001 and 2011 from the population censuses. To derive proportions of the population by ethnicity, we used mappings reported in previous research (Steinbach et al. 2010) to assign STATS19 identity codes to the aggregated ethnicity groupings used by the GLA drawn from 2001 census categories. For a full discussion on mappings of STATS19, GLA and census ethnicity categories, see Steinbach et al. (2010). Based on these mappings, we then estimated ethnic density as the proportion of residents of all ages that are 'White'(British, Irish, Other White), 'Black' (Caribbean, African, Other Black, Mixed-White & Black Caribbean, Mixed-White & Black African) and 'Asian' (Indian, Pakistani, Bangladeshi, Other Asian, Mixed-White & Asian) in each LSOA in 2001 and 2011. We used a logarithmic transformation of the ethnic density variable in analyses as the data were highly skewed.

Socio-economic disadvantage

The average level of deprivation of each LSOA was scored using the Index of Multiple Deprivation (IMD) which brings together 36 indicators across seven domains of deprivation into an overall score of relative deprivation for each geographical area. We assigned IMD scores from 2004 to our 2001 data and IMD scores from 2010 to our 2011 data. Because of small changes in the way IMD was calculated in 2004 and 2010, the scores are not directly comparable. However, ranks of geographical areas can be compared (McLennan et al. 2011). For our analysis we ranked LSOAs according to their IMD score (from 1 to 4762; higher ranks indicate more deprived areas) in 2001 and 2011, and we also used three other specifications of the IMD variable: raw score (1.7–76.78), normal score (–3.5–3.5) and IMD deciles (1–10) in sensitivity analyses.

Road environment variables

We included available road environment and area characteristic variables found to be associated with injury events in the literature (DiMaggio and Li 2012). These included: density of road junctions in the LSOA; density of A roads in the LSOA; density of minor roads in the LSOA, the proportion of postcodes in an LSOA characterised as 'business,' the area (in square metres) of an LSOA, average vehicle speed (kilometre per hour) and traffic volume (in 1000s of vehicles per day). To create variables describing the road environment in an LSOA, current road network information from the Integrated Transport Network supplied by Ordnance Survey was overlaid with LSOA boundaries provided by the census in ArcView GIS. Data on average traffic speed and volume came from the London Greenhouse Gas Inventory (LEGGI). To calculate LSOA summaries of average speeds and volumes, the LEGGI road network was overlaid with LSOA boundaries.

Statistical analysis

The data-set comprised one observation per LSOA per broad ethnic grouping per year. The outcomes which were modelled in the analysis were the ethnic group specific counts of child pedestrians injured for each of the two years. To accommodate over-dispersion and the repeated measures nature of the data, negative binomial multivariable log-linear

regression models were used with robust (sandwich) estimates of error. The denominators, which defined the offsets for the analyses, were the corresponding populations by ethnic group. Independent variables included in the models were: logarithm of ethnic density, rank of IMD, year and road environment variables. We included a term for each local authority in the model, to allow for aspects of road engineering and road danger reduction specific to each of the 33 London boroughs. We ran three models, one for each ethnic group (Model 1 – 'White'; Model 2 – 'Asian'; Model 3 – 'Black'). To examine whether any associations between the independent variables and the numbers of children injured differed by ethnic group, we fitted a fourth model that included all three ethnic groups and we used Wald tests to examine interaction effects: between ethnicity and ethnic density; between ethnicity and area deprivation; and between ethnicity and year. The coefficients estimated by the models are presented here as incidence (of injury) rate ratios (IRRs) with 95% confidence intervals (CIs).

Results

Between 2000 and 2002, there were 3320 'White' children, 1667 'Black' children and 727 'Asian' children injured as pedestrians in London. By 2010–2012, the numbers had fallen substantially: 1221 'White' children, 990 'Black' children and 450 'Asian' children. Pedestrian injury rates declined from 123 (95% CI 118–127) per 100,000 children in 2001 to 64 (95% CI 61–68) per 100,000 in 2011; 'Black' child pedestrian injury rates declined from 194 (95% CI 185–204) per 100,000 in 2001 to 76 (95% CI 71–81) per 100,000 in 2011; 'Asian' child pedestrian injury rates declined from 95 (95% CI 88–102) per 100,000 in 2001 to 37 (95% CI 33–40) per 100,000 in 2011.

Ethnic density also changed considerably from 2001 to 2011 in London. The mean proportion of residents that identify as 'White' fell from 71% (range 5–99%, median 75%, interquartile range 59–87%) in 2001 to 61% (range 4–98%, median 63%, interquartile range 46–78%) in 2011. The mean proportion of residents that identify as 'Black' increased from 12% (range 0–65%, median 7%, interquartile range 4–18%) in 2001 to 15% (range 0–68%, median 11%, interquartile range 6–22%) in 2011. The mean proportion of residents that identify as 'Asian' increased from 13% (range 0–87%, median 7%, interquartile range 4–14%) to 17% (range 1–88%, median 12%, interquartile range 7–21%). Ethnic minority populations were still concentrated in similar geographical areas in London in 2011 compared to 2001; however, the number of those areas appeared to grow (Figure 1).

If the ethnic density of an area is associated with injury rates, we would expect that areas with changes in population make-up between 2001 and 2011 would also experience changes in child pedestrian injury rates. Figure 2 shows changes in ethnic density from 2001 to 2011 against changes in ethnic specific child pedestrian injury rates from 2001 to 2011. Specifically, the plots show on the *x*-axis the logarithm of the change in proportion of residents who are 'White,' 'Black' and 'Asian' from 2001 to 2011 and on the *y*-axis the logarithm of the change in 'White,' 'Black' and 'Asian' child pedestrian injury rates from 2001 to 2011. Figure 2 shows little evidence of a relationship between change in ethnic density and change in injury rates among 'White' children, but suggest a relationship of decreased injury rates with increased ethnic density among 'Black' children, and a similar, but weaker, relationship among 'Asian' children.
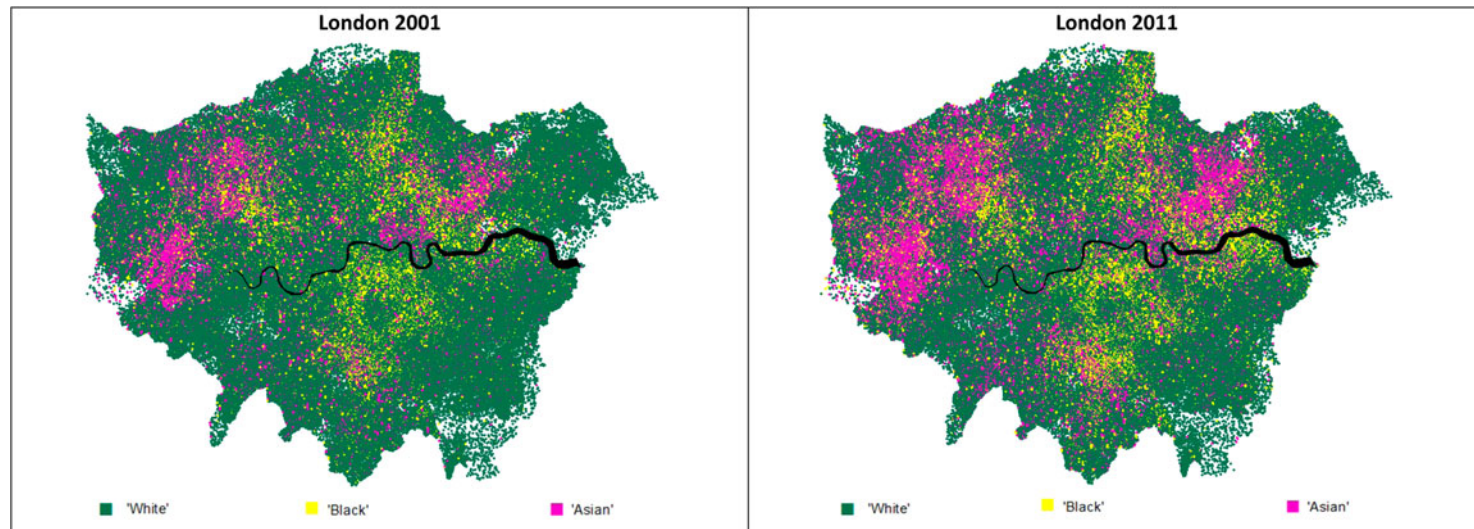
Figure 1. Map of London population by ethnic group (each dot represents 10 people).
Contains National Statistics data © Crown copyright and database right 2012. Contains Ordnance Survey data © Crown copyright and database right 2012.
[To view this figure in colour, please visit the online version of this Journal.]
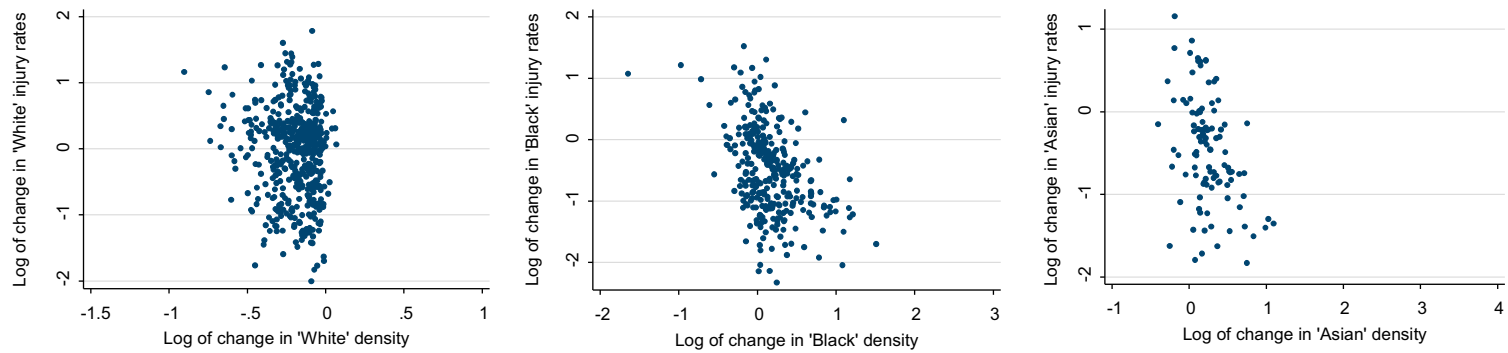
Figure 2. Scatter plots of the change in ethnic density 2001–2011 and the change in child pedestrian injury rates 2001–2011.

Table 1 presents the IRRs from Models 1–3 which model the number of 'White' (Model 1), 'Asian' (Model 2) and 'Black' (Model 3) child pedestrian injuries in an area as a function of the percentage of the population in that area that are 'White,' 'Asian' and 'Black,' controlling for area disadvantage and characteristics of the road environment. Models 1–3 confirm the trends suggested by the descriptive analysis shown in Figure 2. The models indicated strong evidence ($p < 0.001$) of a negative association between 'Black' density and 'Black' child pedestrian injury risk (IRR 0.575, 95% CI 0.515–0.642; Table 1). There was weak evidence ($p = 0.083$) of a negative association between 'Asian' density and 'Asian' child pedestrian injury risk (IRR 0.901, 95% CI 0.801–1.014) and no evidence ($p = 0.412$) of an association between 'White' density and 'White' child pedestrian injury risk (IRR 1.075, 95% CI 0.904–1.279). There was a positive association between injury risk and rank of the IMD among 'White,' 'Asian' and 'Black' children, although the association appears slightly larger in 'White' children compared to 'Black' and 'Asian' children. Sensitivity analyses (not shown) using the different specifications of the area disadvantage variable also identified positive associations between risk and IMD scores among all three groupings. There was evidence that injury risk declined by more than a half between 2001 and 2011 among 'White,' 'Asian' and 'Black' children with the greatest decline among 'Asian' children.

In terms of the road environment, there was evidence that the density of A roads and the proportion of postcodes that are business was associated with increased injury risk among 'White,' 'Black' and 'Asian' children. The density of minor roads and road traffic speeds were associated with decreased injury risk among all three ethnic groupings. There was weak evidence that the density of road junctions was positively associated with injury risk among 'White' and 'Black' children.

A fourth model (results not shown), which examined interaction effects between ethnicity and a selection of independent variables found strong evidence ($p < 0.001$) that the effect of ethnic density differed by ethnic group, good evidence ($p = 0.016$) that the association between injury risk and area deprivation differed by ethnic group, and good evidence ($p = 0.037$) that the decline in injury risk over time differed by ethnic group.

A sensitivity analysis assigning casualties to areas based on postcode of residence rather than postcode of injury found broadly similar results to Models 1–3 (Appendix Table A1), although some relationships were weakened. Ethnic density continued to be associated with lower pedestrian injury risk in 'Black' children (IRR 0.811, 95% CI 0.713–0.922), but there was no evidence of a relationship between ethnic density and injury risk among 'White' or 'Asian' children. Area disadvantage also continued to be positively associated with 'White,' 'Asian' and 'Black' injury risk, with similar magnitude to the relationship found in Table 1. Injury risk was estimated to decline significantly in 2011 compared to 2001 among 'White' (IRR 0.790, 95% CI 0.722–0.866), 'Asian' (IRR 0.676, 95% CI 0.575–0.794) and 'Black' (IRR 0.722, 95% CI 0.648–0.805) children.

Discussion

After controlling for area disadvantage and the road environment, we found strong evidence for a group density effect in 'Black' children: pedestrian injury risk was substantially lower in areas with a higher percentage of 'Black' population. We found weak evidence of more moderate group density effects in 'Asian' children and no

Table 1. Rate ratios showing changes in child pedestrian injury rates associated with characteristics of LSOAs.

Variable	Model 1 – 'White'			Model 2 – 'Asian'			Model 3 – 'Black'		
	IRR	95% CI	*p*-value	IRR	95% CI	*p*-value	IRR	95% CI	*p*-value
Density									
Natural log of the percentage of residents that are of a similar ethnic group	1.075	(0.904–1.279)	0.412	0.901	(0.801–1.014)	0.083	0.575	(0.515–0.642)	<0.001
Area deprivation									
Rank of IMD (100s)	1.020	(1.015–1.024)	<0.001	1.015	(1.007–1.022)	<0.001	1.014	(1.007–1.021)	<0.001
Year									
2001		Reference group			Reference group			Reference group	
2011	0.488	(0.453–0.526)	<0.001	0.420	(0.368–0.481)	<0.001	0.489	(0.448–0.534)	<0.001
Road environment variables									
Density of A roads	1.007	(1.004–1.009)	<0.001	1.009	(1.005–1.012)	<0.001	1.008	(1.005–1.010)	<0.001
Proportion of business postcodes	1.044	(1.039–1.050)	<0.001	1.041	(1.032–1.050)	<0.001	1.041	(1.034–1.049)	<0.001
Density of minor roads	0.997	(0.996–0.998)	<0.001	0.998	(0.996–1.000)	0.040	0.997	(0.995–0.998)	<0.001
Speed (kilometres per hour)	0.958	(0.938–0.979)	<0.001	0.964	(0.925–1.004)	0.081	0.956	(0.931–0.983)	0.001
Junction density	1.103	(1.024–1.189)	0.010	1.034	(0.948–1.127)	0.454	1.086	(1.002–1.178)	0.046
Area (square metres)	1.000	(0.999–1.001)	0.832	1.000	(0.999–1.002)	0.869	1.000	(0.999–1.001)	0.752
Traffic volume (1000 vehicles)	1.007	(0.996–1.018)	0.234	0.999	(0.979–1.020)	0.949	1.013	(0.997–1.029)	0.114
Local authority fixed effects		Not shown			Not shown			Not shown	

evidence for a relationship between ethnic density and 'White' child pedestrian injury risk.

Similar to other studies we found that pedestrian injury risk is declining over time for children from all three ethnic groups (Malhotra, Hutchings, and Edwards 2008); however, unlike other work, we found evidence that this decline differs by ethnic group: injury risk has fallen more quickly in 'Asian' children compared to 'White' and 'Black' children. Our study compares injury risk in 2001 to injury risk in 2011, while Malhotra and colleagues compare risk in 2001 through 2006. Injury risk may have declined at different rates for 'White,' 'Asian' and 'Black' children between 2007 and 2011.

Our findings of associations between characteristics of the road environment and child pedestrian injury concur with much of the literature on environmental correlates of pedestrian injury (DiMaggio and Li 2012). An important exception is findings on speed. While most other studies report that increased vehicle speeds are associated with increased injury risk, our results suggest an association between increased vehicle speeds and decreased injury risk. London has a unique urban environment where recorded traffic speeds rarely exceed 20 mph (30 kph) apart from arterial roads (Transport for London 2012). Our findings may reflect decreased child pedestrian exposure on to injury on arterial roads with higher speeds (if, for instance, these roads are less likely to have pavements or parents or children perceive them as more dangerous to walk on). Our sensitivity analysis using the location of residence to assign casualties to LSOAs found few relationships between environmental characteristics and injury among 'White,' 'Black' and 'Asian' children, possibly due to the large number of casualties missing information on location of residence (40%) that were necessarily excluded.

Interestingly, our results suggest that after taking population make-up into account, part of the social epidemiological puzzle of ethnic inequalities in injury risk disappeared: area affluence appeared to protect 'White,' 'Asian' and 'Black' children from injury risk. Our findings are now therefore congruent with the many studies that have suggested that area disadvantage increases pedestrian injury risk (Laflamme and Diderichsen 2000). However, we did find evidence that the protective effect of area affluence was not as strong among 'Black' and 'Asian' children as it is among 'White' children.

As 'Black' children in London tend to live in more deprived areas (Jivraj and Khan 2013), this finding may suggest ethnic density helps protect 'Black' children against the increased injury risk associated with high deprivation, providing some insight into why 'Black' children appear to face similar child pedestrian injury risks across London in studies that do not take ethnic density into account. Accounting for why ethnic density may protect Black children (and have less apparent effect for 'Asian' children) is more challenging, and inevitably speculative. Whereas mechanisms such as the effects of stigma or social recognition are plausible for mental health outcomes, and for health outcomes such as heart disease, it is more difficult to conceptualise how psychosocial factors could mediate child pedestrian injury risk. However, it should be noted that direct evidence of psychosocial factors as mediators for mental health outcomes is often lacking. Das-Munshi et al. (2010), for instance, found ethnic density effects for mental health in England, concluding that those living in areas of high own group density not only experienced less stigma and improved social support, but also found that these factors did not appear to mediate the density effect. Given the lack of clear evidence to date on what does link aggregate structural effects to individual health outcomes, it is therefore plausible that analogous structural mechanisms might operate to link ethnicity

with injury. These include two candidate possibilities. One relates to the contextual effects of ethnic density. In areas where there are few people of a similar ethnicity, there is evidence that adults travel further in order to access culturally appropriate or valued services and goods (Whitley et al. 2006). This is likely to apply to children and young people, who may be travelling further from low-ethnic density areas in order to access (for example) Black churches (Krause 2009), youth clubs or supplementary schools (Mirza and Reay 2000). This would extend the time in which children are exposed to pedestrian injury risk. The other possibility relates to the more compositional elements of ethnic density, and how the meanings of either ethnic identity or minority status might change with density, and the implications this might have for pedestrian exposure. Given that Black youth report, for instance, feeling less 'safe' in areas where there are fewer Black people (Reynolds 2013), this might have implications for how young people walk, play or 'hang out' in the road environment; whether they are likely to move more or less quickly when crossing roads, or whether they are more or less likely to travel with others. There is a need for more detailed ethnographic work on what ethnic density means in terms of young people's travel across different ethnic groups.

Limitations

Our data sources have some limitations that may have affected our results. A weakness of STATS19 is the under-reporting of road traffic injuries, which may differ by ethnicity or area deprivation. However, reporting in London has been found to be good compared with the rest of the country (Ward, Lyons, and Thoreau 2006) and differences in reporting would only affect our results on the relationship between ethnicity, ethnic density and pedestrian injury if the within-ethnic group propensity to report or record an injury differs by the population make-up of an area. Further limitations arise from our choice of assigning casualties to the area in which they occurred, rather than the area in which the child resides. The resident population is only a proxy for the number of children exposed to pedestrian injury risk in that area, and any ethnic differences in travel patterns may mean that our estimates are more valid for some ethnic groups than others. However, our sensitivity analysis using LSOA of residence produced broadly similar results to our models assigning casualties to LSOA of collision. The finding that 'Black' density appears to have a large protective effect on 'Black' child pedestrian injury risk was robust to the assignment method; however, the weak finding of a relationship between 'Asian' density and 'Asian' child pedestrian injury risk was not replicated in our sensitivity analysis and should be interpreted with caution.

The main limitation of our analyses is the broad categories of 'White,' 'Asian' and 'Black' children. It was necessary to use these broad groupings in order to pragmatically map police ethnicity codes onto population data, to estimate injury rates. However, these groupings do not represent any real communities (with shared culture, social networks or social capital) in London. Given that other studies have found that separating out the effects of, for instance, Caribbean ethnic density and Black ethnic density changes the relationship found between density and health outcomes (Bécares, Nazroo et al. 2012), we cannot know whether our analyses would hold for more homogenous ethnic groups. For instance, 'Black African' Londoners and 'Black Caribbean' Londoners may face similar structural environments, leading to similar experiences of racism, but may have different orientations to, for instance, education, affecting whether children are travelling

long distances to school or not. Similarly, the broad category 'Asian' aggregates diverse communities with known differences in terms of health outcomes (Smith et al. 2000). Utilising broad categories could possibly have diluted the psychosocial benefits of living in areas with people 'like you,' thus making our analysis somewhat conservative. Alternatively, and given the range of findings for different groups and outcomes in the literature (Bécares, Shaw, et al. 2012), it is probable that we have underestimated strong group density effects for some ethnic groups within these groupings, and missed negative associations for others. More research to identify possible group density effects in homogenous ethnic groups is needed.

Implications

To our knowledge, this is the first study to identify ethnic density effects for road traffic injury. It has been noted that fewer studies in the UK, compared with the USA, have identified density effects (Bécares, Shaw, et al. 2012), and that this may reflect both the smaller range of ethnic densities in the UK population and the smaller sample sizes, which are under-powered to identify structural effects. This case study used London, where there is a range of ethnic densities, and where they have changed between two censuses, and where there are (unfortunately) sufficient injury events to provide an analysis by broad ethnic groupings.

While a number of studies have empirically investigated plausible mechanisms to explain ethnic differences in child pedestrian injury risk, research has yet to uncover any conclusive evidence to explain the higher risk to minority ethnic children. This may be, perhaps, in part due to the way ethnicity has been theorised to relate to injury risk. First, there are well-known conceptual difficulties of defining ethnicity: the many structural and identity 'factors' of ethnicity may have different, and even conflicting implications, for child pedestrian injury risk. Theoretical models tend to focus on two main mechanisms: exposure to risk, and risk behaviour. Minority ethnic status may lead to greater exposure to risk through either structural associations with individual socio-economic disadvantage leading to more time spent in the road environment (Roberts, Norton, and Taua 1996), or through structural associations with neighbourhood disadvantage and more dangerous road environments (Steinbach et al. 2010). Behavioural explanations have focused on the way cultural identity may lead to ethnic differences in individual risk behaviour (Chen, Lin, and Loo 2012).

Despite acknowledging that the mechanisms linking minority ethnicity to injury risk are interrelated (Steinbach et al. 2010), empirical studies tend to focus on one mechanism or another (with more or less sophistication in accounting for potential confounding). However, it is very difficult to theoretically isolate particular pathways. For example, structural associations with socio-economic disadvantage suggest that ethnic minorities are more likely to live in deprived areas. Deprived areas may be more likely to have more dangerous road environments (which we would expect to increase risk). However, living in areas with dangerous road environments may affect children's choice of leisure activities if they (or their parents) choose not to (allow them to) play or hang out outside. This, in turn, may decrease the amount of time children in these areas are exposed to risk (which we would expect to decrease risk). The 'danger' of the road environment may also change the meaning of exposure in those environments, leading to differences in risk behaviour. Disentangling the relative contributions of road environments, exposure and

behaviour is therefore challenging, and is exacerbated by the well-documented measurement difficulties with ethnicity, exposure and behaviour, leading researchers to use imperfect proxies in empirical investigations.

This study's finding that 'Black' child pedestrian injury risk is associated with ethnic group density, in addition to the methodological and conceptual challenges of exploring individual mechanisms, suggests that we may need to rethink the way we examine explanations for ethnic differences in risk. Our findings that the ethnic make-up of an area can help predict child pedestrian injury risk of some ethnic groups, but not others, suggests that not only is injury risk determined by relationships between individuals and the environment, but also interdependencies between individuals.

These findings suggest that further investigation of individual causal explanations may have diminishing returns. Rather, a broader focus on the 'system' may prove more fruitful. Systems approaches emphasise that population health is a function of many interrelated components at different levels of influence (Galea, Riddle, and Kaplan 2010, Koopman and Lynch 1999). Within public health, these systems can be quite complex: characterised by heterogeneous interdependent units, related in non-linear ways with feedback loops and their own emergent properties. As Diez Roux (2011) suggests, systems approaches can be particularly useful for examining health inequalities when traditional epidemiological methods have failed to provide satisfying explanations. In systems approaches, she notes 'because the effect of a given input depends on other conditions in the system, emphasis shifts from isolating the causal effect of a single factor to comprehending the functioning of the system as a whole' (Diez Roux 2011).

If we begin to conceptualise ethnic inequalities in child pedestrian injury using a systems approach, the risk of injury would be a function of not only an individual's circumstances (e.g. socio-economic position, travel preferences), but also interdependencies between individuals (transmission of social norms about meaning of 'walking,' playing or 'hanging out' on roads; the meaning of being exposed in particular social environments) and emergent properties of the 'system' (such as those arising from, for example, the social organisation of transport or the traffic environment) and the dynamic relationship between individual behaviour and the environment (e.g. whether walking or risk taking is more appealing in different types of environments). Systems approaches would also conceptualise how these different levels of influence affect vehicle driver behaviour: whether different physical or social environments prompt more or less attention to the road, greater or fewer traffic volumes or faster or slower traffic speeds. Thinking more explicitly about these dynamic processes may not only help further our understanding of pedestrian injury risk but may also help to identify new intervention points to not only reduce ethnic inequalities in road injury but also injury risk overall.

Key messages

(1) Black ethnicity and area deprivation both increase the risk of pedestrian injury for children in London.
(2) Ethnic density has a protective effect on Black children's injury risk.
(3) For Black children, there is a gradient of risk by area deprivation only when ethnic density is taken into account.
(4) More ethnographic research is needed on how density relates to road injury risk.

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Appendix

Table A1. Rate ratios showing changes in child pedestrian injury rates associated with characteristics of LSOAs (assigned by postcode of residence).

Variable	Model 1 – 'White'			Model 2 – 'Asian'			Model 3 – 'Black'		
	IRR	95% CI	*p*-value	IRR	95% CI	*p*-value	IRR	95% CI	*p*-value
Density									
Natural log of the percentage of residents that are of a similar ethnic group	1.132	(0.936–1.37)	0.200	0.950	(0.815–1.107)	0.510	0.811	(0.713–0.922)	0.001
Area deprivation									
Rank of IMD (100s)	1.022	(1.018–1.027)	<0.001	1.015	(1.006–1.025)	0.001	1.014	(1.006–1.022)	<0.001
Year									
2001		Reference group			Reference group			Reference group	
2011	0.790	(0.722–0.866)	<0.001	0.676	(0.575–0.794)	<0.001	0.722	(0.648–0.805)	<0.001
Road environment variables									
Density of A roads	1.001	(0.998–1.004)	0.536	1.005	(1.000–1.009)	0.073	0.999	(0.995–1.002)	0.516
Proportion of business postcodes	0.998	(0.988–1.008)	0.681	1.010	(0.995–1.024)	0.190	1.020	(1.006–1.034)	0.004
Density of minor roads	1.000	(0.998–1.001)	0.677	1.003	(1.000–1.005)	0.025	0.999	(0.997–1.001)	0.375
Speed (kilometre per hour)	0.993	(0.972–1.014)	0.503	1.010	(0.963–1.059)	0.681	1.010	(0.975–1.046)	0.588
Junction density	1.027	(0.951–1.108)	0.496	0.890	(0.798–0.993)	0.037	0.967	(0.877–1.067)	0.503
Area (square metres)	1.000	(0.999–1.001)	0.753	1.000	(0.998–1.001)	0.650	0.999	(0.997–1.000)	0.106
Traffic volume (1000 vehicles)	1.005	(0.992–1.018)	0.494	0.987	(0.961–1.013)	0.328	1.001	(0.981–1.021)	0.949
Local authority fixed effects		Not shown			Not shown			Not shown	