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Comparative fatality risk for different travel modes by age, sex, and deprivation

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ABSTRACT

Background: Cycling is perceived as an unsafe travel mode in many countries. However, road deaths in England have fallen sharply since 2007. We explored whether differences in fatality rates by age, gender and mode persist, and the associations of deprivation with these.
Methods: Using ONS (cycling, pedestrian) and Stats19 (driving) 2007–2012 data for travel-related deaths, including pedestrian falls, and National Travel Surveys 2007–2012 travel data, we calculated fatality rates for England by distance (f/bnkm) and time travelled (million hours' use, f/mhu) by age, travel mode, and gender or residential Index of Multiple Deprivation.
Results: Fatality rates fell significantly 2007–2009 to 2010–2012: male f/bnkm from 2.8 (95%CI 2.7–2.9) to 2.0 (1.9–2.1) for driving; 32.1 (28.5–36.0) to 20.8 (18.1–23.9) for cycling; and 51.4 (48.5–54.4) to 36.7 (34.3–39.3) for walking. Fatality rates varied by age, gender, and mode. Driving and walking fatality rate ratios were generally higher for males than females. For males 17–20y, fatality rates were 0.76 (0.69–0.83)/mhu for driving and 0.28 (0.18–0.42)/mhu for cycling but were similar by distance. Age-specific rates were J-shape for cycling, U-shape for driving, and increased exponentially with age for walking. Fatality rates aged 80+ were an order of magnitude higher in each mode than the all-age mean. Compared with those aged 17–20, rate ratios were significantly lower for male drivers 21+ and female drivers 21–74, but were higher for male cyclists aged 55+ and pedestrians 45+ (male) and 65+ (female). People living in the most deprived quintile generally had higher fatality rates than those in the least deprived quintile overall (three modes combined) and for walking but not for cycling; Rate ratios were highest for pedestrians 35–64 and drivers 35–54.
Conclusions: Fatality rates for walking, cycling and driving are higher for males than females at almost every age and vary more by age than by travel mode. Deprivation exacerbates walking and driving fatality rates.

1. Introduction

Despite the health benefits of cycling (de Nazelle et al., 2011; Jarrett et al., 2012; Woodcock et al., 2009) and high bicycle ownership in high income countries (Oke et al., 2015), cycling is a little used form of transport in many high income countries (Lindsay et al., 2011; Pucher and Buehler, 2008). Common perceptions of risk may be one of the reasons for this (Koglin and Rye, 2014), and for the marginalisation of walking (Pooley et al., 2014). Cycle deaths are rare – which is a reason for receiving much press

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coverage (Wallop, 2016) that generates or perpetuates perceptions of risk among non-cyclists (Carnall, 2000).

Worldwide, 23–24 million people are injured annually in road crashes each year. Road deaths have increased from 750,000–880,000 in 1999 (Jacobs et al., 2004) to 1.24 million in 2010 (World Health Organization, 2013). 85% of these occur in low and middle income countries (Jacobs et al., 2004) - for example, road travel deaths are the third highest cause of loss of life expectancy in Brazilian males, after homicide and stroke (Auger et al., 2016) - and over one-third are among pedestrians and cyclists (World Health Organization, 2013). The fatality rate among this group is increasing, particularly among countries with low but rising numbers of private motor vehicles and poor infrastructure (Obeng-Atuah et al., 2017).

Although half to one-third lower, and falling, the burden in high income countries remains substantial, at 8.7 fatalities per 100,000 population (World Health Organization, 2013). There are also major social inequalities in road traffic deaths in most countries (Hjern and Bremberg, 2002), particularly for pedestrians and children (Laflamme and Diderichsen, 2000; Roberts, 1997), although these have been falling (Jones et al., 2005).

We have shown previously that road traffic fatality rates in England vary as much by age and sex as they do by travel mode, although hospital admission rates were an order of magnitude higher for walking and cycling than for driving (Mindell et al., 2012). Similar results were found in France, although the difference between cycling and driving was much less (Bouaoun et al., 2015). Since then, road travel fatality rates have fallen substantially in Great Britain. We therefore analysed data for England in 2007–2012, to ascertain whether all road users have benefited equally from the reductions in fatalities. Using six years of data, we have been able to examine narrower age bands, to investigate particularly the fatality rates for younger and older travellers and address some of the drawbacks of earlier work. We have also investigated the associations of deprivation with travel fatality rates by age and travel mode in this six year period.

2. Methods

2.1. Participants and data

In England and Wales, deaths from external causes are always referred to a coroner for the circumstances of the death to be examined. The coroner determines the cause of death, normally after an inquest. The death is then registered and the data recorded then is sent to ONS, (formerly the Office for National Statistics). The ONS database stores details of the deceased, including the causes of death. ONS convert the information recorded on the causes of each death into codes, using the International Classification of Diseases (ICD-10). One code is selected as the underlying cause of death (the disease or injury which initiated the chain or morbid events leading directly to death).

Numerator data for fatalities for England were extracted from ONS mortality data for 2007 to 2012 with external ICD-10 codes indicating a road-related death for cyclists, and pedestrians. To be comparable with single vehicle motor vehicle crashes and single vehicle crashes and falls for cyclists, we included pedestrian falls that occurred on a public highway. Others have shown that for travel-related, non-fatal injuries requiring hospital treatment, falls on the pavement were five times as frequent as collisions with a motor vehicle (Naumann et al., 2011). The codes used are listed in Supplementary Table S1.

The ONS mortality file also contains the postcode of usual residence of the deceased which made it possible to link individual deaths with the Index of Multiple Deprivation (IMD) of residence, based on Census lower super output areas (LSOAs). [Deprivation is measured using seven domains incorporating 38 indicators. Each LSOA contains around 1500 residents.] The record-level mortality data linkage was done at Public Health England before the aggregated data were released for analysis for this study.

Some deaths of car/van occupants in ONS mortality data were coded neither as driver nor passenger but 'unknown occupant'. Comparison with numbers of car/van driver fatalities in the police Stats 19 dataset for the same years showed that the number of drivers killed, by age and sex was virtually identical between the ONS and Stats 19 datasets for drivers aged 30+. For drivers aged 17–29, the number of driver fatalities in the Stats 19 dataset equalled the number of drivers plus 'unknown occupant' deaths in the ONS data. As the police investigate fatal car crashes, while hospitals and those certifying deaths are more concerned with the medical state of injured patients, we decided the Stats 19 data were more likely to be correct, so used those as the numerator data for driver deaths. We were unable to make a similar comparison for pedestrians, as police data are collected only for collisions and injuries involving a vehicle, thus excluding pedestrian-only incidents.

Denominator data for a nationally-representative sample of the general population in England were provided by the Department for Transport National Travel Survey team, as mean distance travelled and time spent travelling as a pedestrian, cyclist or driver by sex, five-year age group, and quintile of IMD 2010 of home address for each three-year period 2007–09 and 2010–12 inclusive. Stage (not trip) data were used, to obtain the most accurate record of travel. These figures were multiplied by the ONS population estimates for the relevant age-sex group for each year to provide data on the total distance travelled and time spent travelling by travel mode for each age-sex group.

2.2. Analysis

We summed the number of fatalities by age, travel mode and either sex or IMD quintile for each period (three years by sex, six years by IMD). We divided these by the total distance travelled over that period for that age-group, travel mode and sex or IMD quintile to yield fatalities per billion km (f/bnkm) or by time spent travelling (fatality rate per million hours use, f/mhu).

As driving is not legal below the age of 17, denominator data are very unreliable, so analyses of driving by age group and comparison of the all-ages rates for the three modes were restricted to those aged 17 and over. Because of small numbers, analyses by

IMD quintile considered all persons, not separated by sex, combined over the whole six years.

Fatalities are rare events, and therefore we assumed a Poisson distribution, in line with previous research (Bouaoun et al. 2015). We therefore calculated Poisson parameter 95% confidence intervals (CIs) using the formulae for weighted sums (Dobson et al. 1991). We compared the rates by age and sex over the two three-year time periods for each travel mode, using broad age groups, and across mode within time period. For a more precise estimate of the associations with age group, we combined the data for the entire six years. We then calculated rate ratios (RR) with 95% CIs again based on Poisson parameters: a rate ratio whose 95% CI did not include 1.0 was considered to differ significantly from the comparator condition. To assess the associations with deprivation, we compared deaths among those resident in the most and least deprived quintiles. Analyses were conducted in Excel or-Stata13.1(StataCorp LP, College Station, Texas).

3. Results

There were a total of 7242 road travel deaths in England between 2007 and 2012, of which 586 were cyclists, 3133 pedestrians and 3523 drivers. Males accounted for most deaths overall (72%), including 84% of cycling deaths, 65% of pedestrian deaths and 76% of driving deaths. Supplementary Tables S2 to S5 show the number of deaths, aggregated travel data, and the fatality rates by travel mode, age, sex, and period by distance (S2, S3) and time spent travelling (S4, S5).

3.1. Changes between the two time periods

3.1.1. Travel pattern

The average distance travelled in all modes between 2007–09 and 2010–12 fell by 3% (from 11,100 km/person/year in 2007–09 to 10,750 km in 2010–12, Tables S2 and S3). The decline was most notable for pedestrians, at 5%, while the mean distance cycled increased by 10%. The mean distance driven declined by 5% in males and 1% in females (all ages). The distance driven by 17–20 year olds decreased by about 20% in both males and females.

3.1.2. Travel fatality rates

There was a 29% reduction in the total number of road deaths from 4247 in 2007–09 to 2995 in 2010–12 (Tables S2 and S3). The proportion of fatalities by sex remained similar, with males accounting for most deaths in both time periods. The pattern by age-group for each mode also remained unchanged, although the largest falls were in the groups with the highest fatality rates in the earlier period. The fatality rates by distance and by time also showed reductions for all-ages both in males and females for each mode, apart from female cyclists where reductions in rates were small and not statistically significant.

There were no significant differences in female cycling fatality rates for any age- group between 2007–09 and 2010–12. In males aged 21–69, reductions in fatality rates by distance and by time were significant, eg rate ratio 0.60 (95%CI 0.45–0.81 aged 21–49 by distance, Tables S2-S5, Fig. 1).

There were significant reductions in fatality rates for male pedestrians for each age-group apart from those aged 50–59, in whom

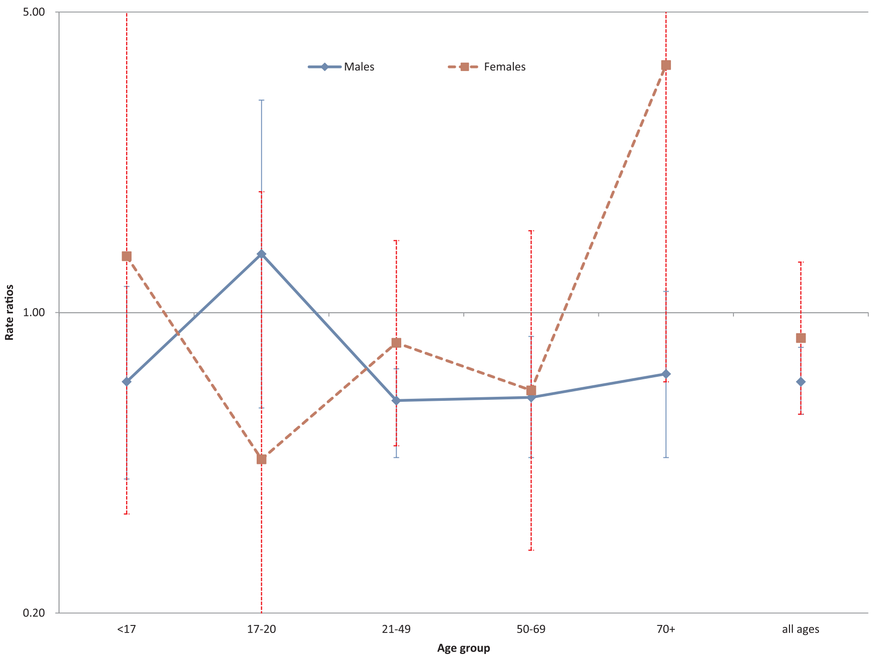

Fig. 1. Cycling fatality by time spent travelling, rate ratios 2010–12 compared with 2007–09. a) Males; b) females.

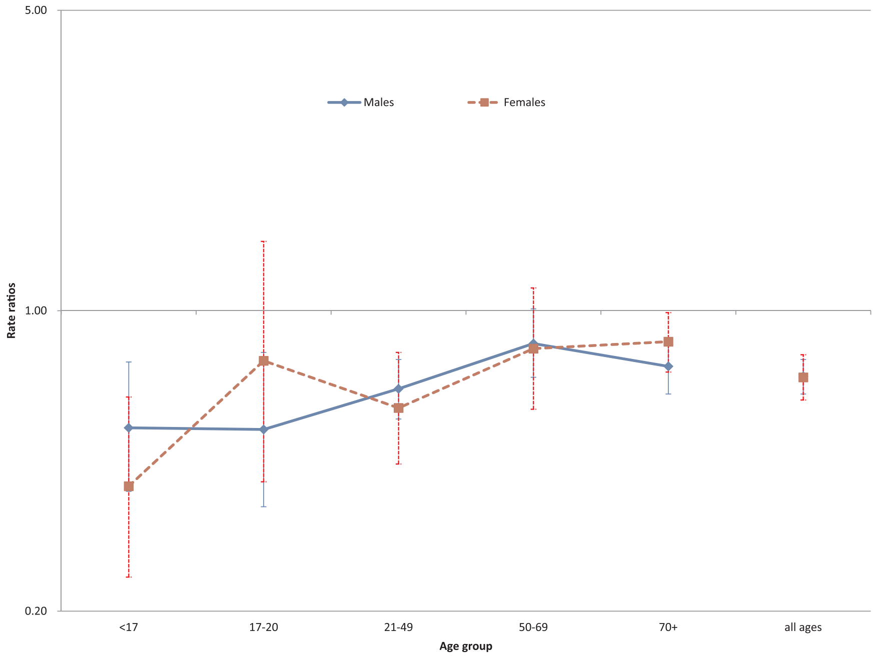

Fig. 2. Pedestrian fatality by time spent travelling, rate ratios 2010–12 compared with 2007–09. a) Males; b) females.

the fall by time travelled was non-significant. In females, fatality rates fell, with significant reductions observed for all ages and those aged under 17, 21–49, and 70+ (Fig. 2).

For driving, there was a significant reduction in fatality rates for males of every age (e.g. from 22.5/bnkm in 2007–09 to 16.0/bnkm in 2010–12), except 70+, in whom there was a non-significant rise (Fig. 3). In females, reductions were observed in fatality rates for each age group, significant for those aged 21–49, 70+, and at all ages.

3.2. Age and sex groups with highest fatality rates

The fatality rates by both distance and time in 2007–12 for cycling and walking were lower for younger age groups but the rates increased exponentially with age, especially in the upper age bands (70+) (Supplementary Tables S6-S9). The fatality rates (f/mhu)

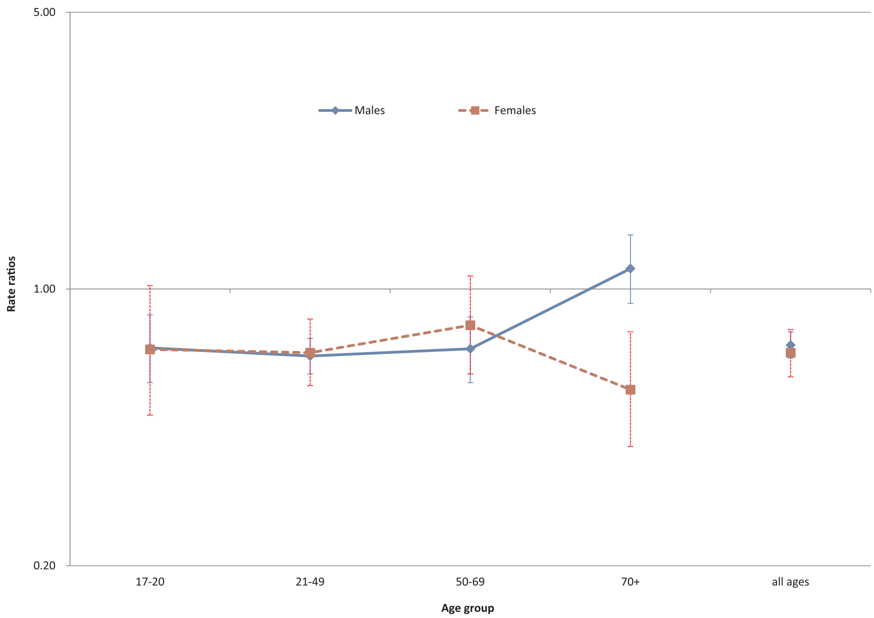

Fig. 3. Driver fatality by time spent travelling, rate ratios 2010–12 compared with 2007–09. a) Males, b) females.

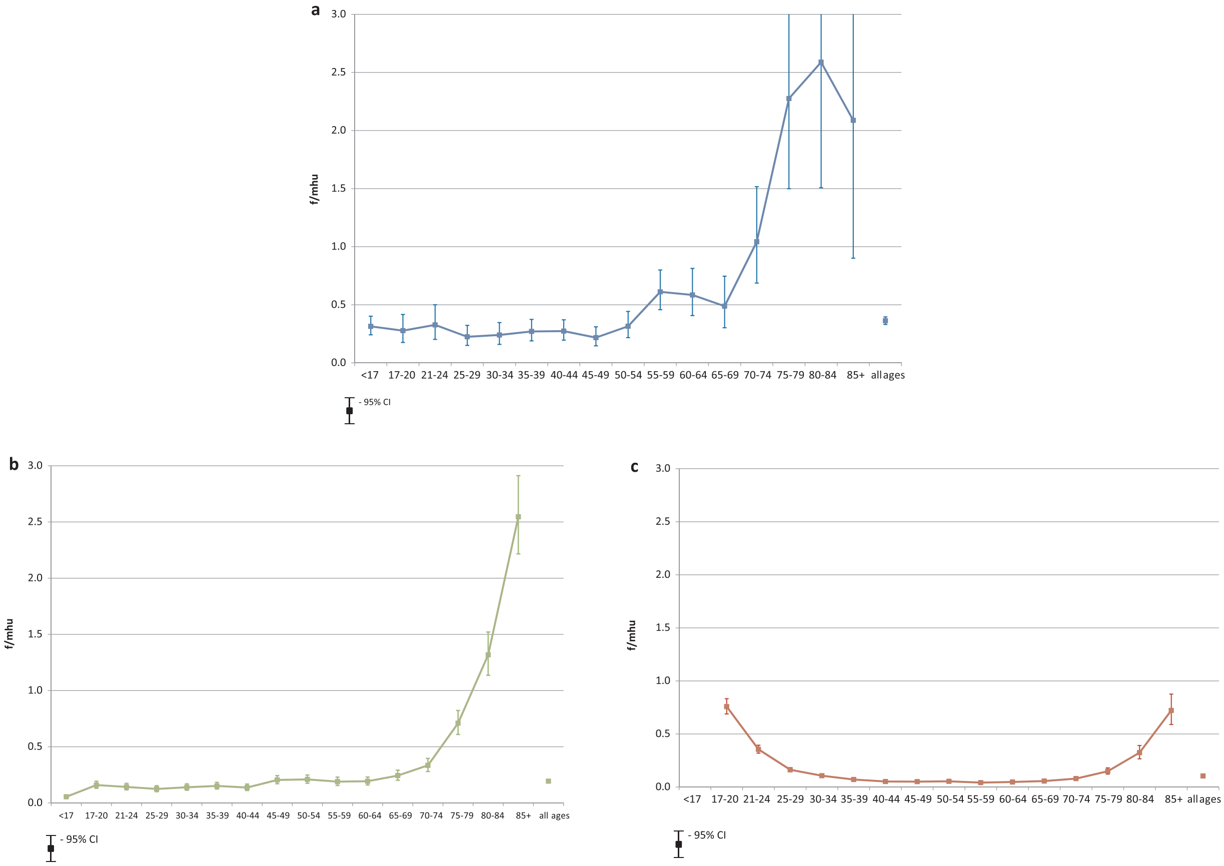

Fig. 4. Fatality rates by time spent travelling by age, males 2007–12. a) Cycling, b) walking, c) driving.

of a male cyclist aged 80–84 were eight to 10 times higher than for a male cyclist under 50 (Fig. 4a). The rates in females showed a similar pattern, but with wide confidence intervals (Fig. 5a).

Fatalities by time travelled were significantly higher for male than female pedestrians for almost all age groups (Figs. 4b and 5b, Tables S6 and S7). As with cycling, the rate of fatality in pedestrians also increased considerably for upper age bands (75+).

Driving fatality rates were not calculated for under 17s for either sex due to underreporting of the distance and time travelled. For driving, younger drivers (17–25) and older drivers (75+) had the highest fatality rates. The fatality rates (f/mhu) of a male driver aged 17–20 were ~14 to 18 times higher than of middle aged male drivers. For women under 55, the f/mhu was significantly lower than for men but for women aged 60+, the rate was similar to or greater than for men (Figs. 4c and 5c).

3.3. Travel mode with highest fatality rate

For most age groups, pedestrians had the highest fatality rates and rate ratios for comparison with cycling, considering the rate by distance (Fig. 6, Table 1). The rate for all-ages was significantly higher for pedestrians than for driving in both sexes and higher for male pedestrians than male cyclists.

The fatality rates by time gave a different pattern however, especially in males (Fig. 4, Tables 1 and 2): although cycling had higher fatality rates than walking at every age (except women aged 85+), cycling had a substantially lower fatality rate/mhu than driving for males 17–20. Driving was the mode with the lowest rate for middle aged men and older age groups.

For females, both f/bn km and f/mhu showed cycling as the mode of travel with the highest fatality rates for most age groups (Tables 1 and 2, Figs. 5 and 6). In contrast to males, the f/mhu was second highest for driving for females under 25. Driving and walking showed similar fatality rates for females aged 30–74 but were significantly lower than cycling (for most ages), although the fatality rate for female cyclists was lower than that for male cyclists. For females 75+, the rates were similar across all modes (Tables S7 and S9).

3.4. Travel fatality rates by deprivation

People in the most deprived quintile had substantially higher fatality rates by distance for all three modes combined than those in the least deprived quintile for each age-group (Table 3). The rates by time spent travelling showed the same pattern for most age

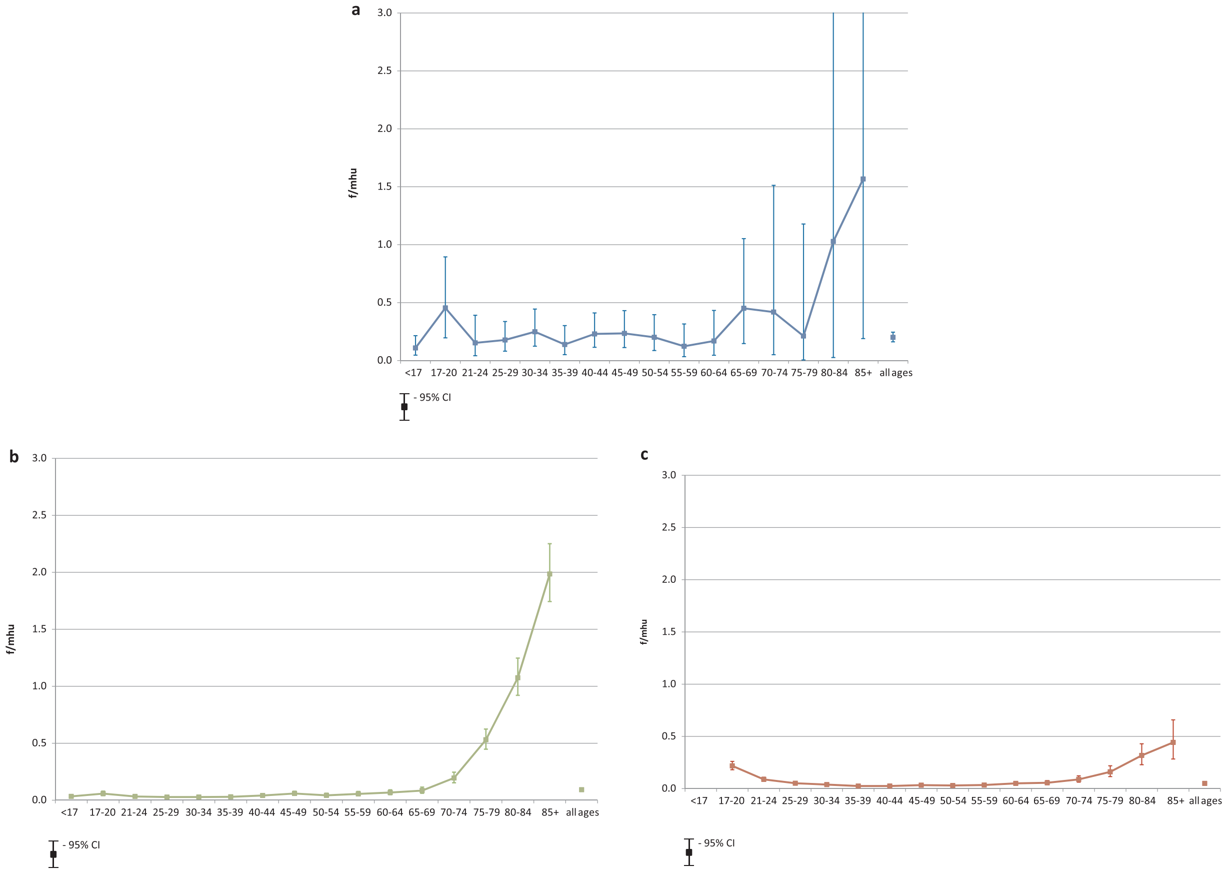

Fig. 5. Fatality rates by time spent travelling by age, females 2007-12. a) Cycling, b) walking c) driving.

groups apart from those aged 17–24; those aged 17–24 in the most deprived areas had a significantly lower fatality rate ratio (0.81, 95%CI 0.67–0.98, Fig. 7a).

There were no significant differences in fatality rates by deprivation for any adult age group for cycling but children in deprived areas had a twofold higher fatality rate; the rates were non-significantly lower for those aged 17–24 and 75 + in the most deprived group (Table 3, Fig. 7b).

The fatality rates for pedestrians in the most deprived quintile were significantly higher than for the least deprived quintile for children under 17 and for adults aged 35 +, particularly those aged 35–64 (Table 3, Fig. 7c).

For driving, the rate in the most deprived quintile was significantly higher for each age group under 65 by distance (Table 1). The fatality rate ratio between the most and least deprived quintiles by time spent travelling was significantly higher only in drivers aged 35–64 (Fig. 7d).

4. Discussion

4.1. Summary of findings

Overall, there were reductions in fatalities by time spent travelling for all age groups, sex and modes in 2010–12 compared with 2007–09 although for some age- and sex-groups the reductions were not significant. The observed number of cycling deaths in older women was two in 2007–09 and four in 2010–12; although the rates increased in 2010–12, the observed numbers were very small, with wide confidence intervals for the rates. Comparisons between older and younger female cyclists should therefore also be treated with caution. Fatality rates by deprivation showed similar patterns by age and sex, with higher rates in the most deprived quintile for both pedestrians and drivers.

4.2. Strengths and limitations

4.2.1. Strengths

The strength of this study is the quality of data used. In England and Wales, births and deaths registration is a legal requirement so data coverage is considered to be complete. There is a rigorous process of quality assurance of mortality statistics, using the clinical

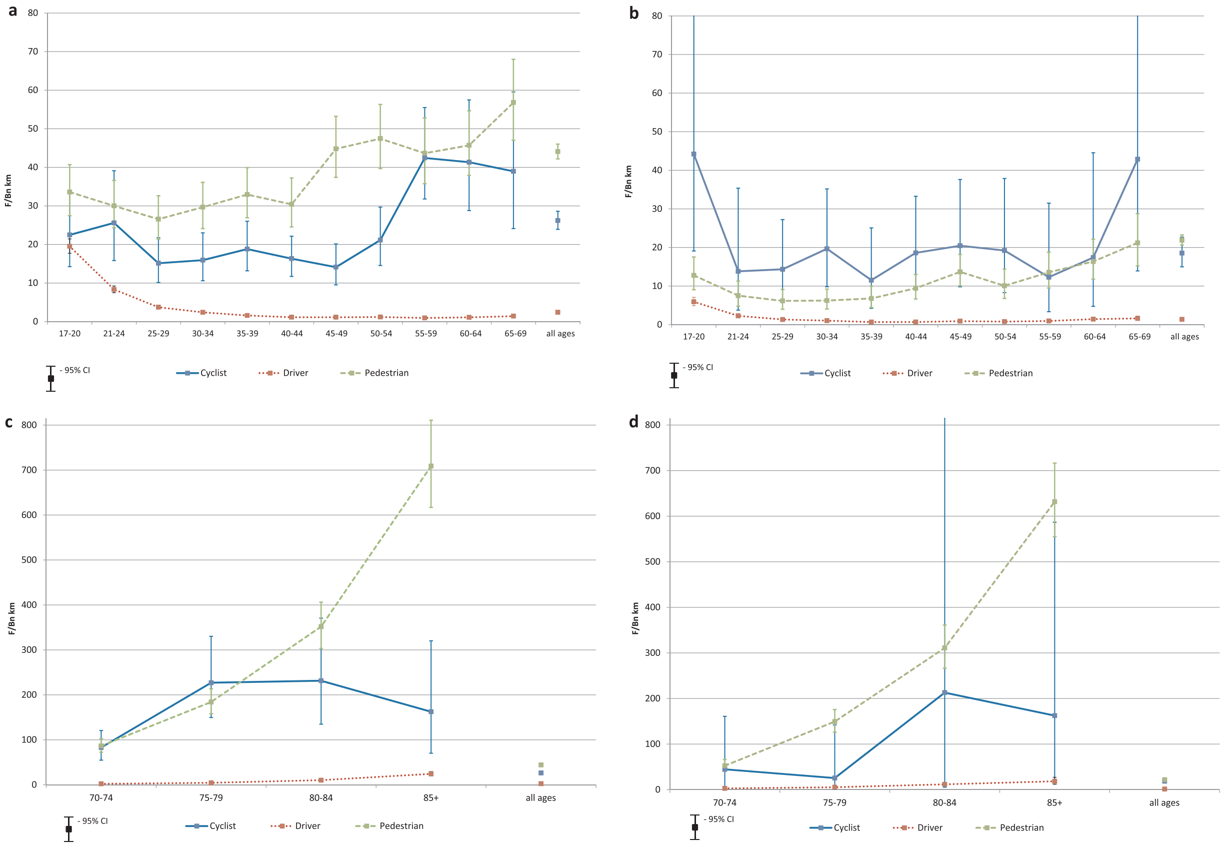

Fig. 6. Fatality rates by mode by distance travelled, 2007–12. a) Males < 70, b) females < 70, c) males 70 +, d) females 70 +.

coding of World Health Organisation's (WHO) International Classification of Diseases (tenth revision). The data provided by the NTS is from a nationally representative sample that provides the best available data on the travel patterns of the general population in Great Britain.

The results in this paper are more accurate than an earlier study (Mindell et al., 2012) for four reasons. First, it used stage (not trip) data, and therefore the denominator data was more complete. Secondly, it used time spent travelling for each travel mode, available for each specific age-group and sex or IMD quintile, whereas the earlier study used the mean speed for the mode overall to derive time spent travelling, although average speeds vary by age and sex. Thirdly, by combining six years' data, narrower age-groups could be used, highlighting the ages at which the fatality rates increase markedly. We overcame earlier problems that some of the ICD-10 codes used to extract the number of driver deaths from mortality data are not specific in terms of whether it was the driver or a car passenger that died by using Police Stats 19 data for driver deaths, as described earlier.

Like our 2012 paper, we included pedestrian falls on public highways in our numerator: there are calls for these to be included in official road travel injury data (Methorst et al., 2017). Our paper has, for the first time, also used data on the associations of residential area deprivation with national road fatality rates by age and travel mode.

4.2.2. Limitations

One of the limitations of the method used is the difficulty in distinguishing whether some pedestrian fatalities occurred on or off a public highway, while the denominator data includes only distance and time travelled on 'highways' (i.e. roads on which motor vehicles can travel). Incomplete records are coded in more general categories such as "unspecified whether traffic or non-traffic accident" in pedestrian fatalities (eg V01.9) analogous to the "unspecified occupant" in car or van fatalities (eg V49.6) described in the methods section above, making it difficult to extract the right records for this study. Therefore, the results found in this study may be understated for pedestrians.

Secondly, it is not ideal to compare fatalities for cyclists and pedestrians against drivers using currently available data. Cyclists and pedestrians travel shorter trips than drivers and mostly in built-up areas (or certainly off-motorways) where the fatality rates are considerably higher. Road injury comparisons should ideally be between cyclists or pedestrians and drivers that make similar journeys. Drivers have lower fatality rates partly due to driving on a safer environment (motorways) inaccessible to cyclists and pedestrians. Motorways carry around 21% of traffic but account for only 6% of fatalities (RCGB 2015): using distance or time substantially underestimates fatality rates for drivers on other roads, where most trips are made. For example, in 2012, fatality rates for car occupants were 1.41 per billion vehicle-miles for motorways and 6.70 per billion vehicle-miles on minor roads (Department

Table 1
Rate ratios for fatality rates for cycling vs walking, by age and gender.

Age group:	< 17	17–20	21–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85+	all ages
Male, f/bnkm																	
RR	2.5	0.7	0.9	0.6	0.5	0.6	0.5	0.3	0.4	1.0	0.9	0.7	1.0	1.2	0.7	0.2	0.6
95% CIs	1.85–3.35	0.43–1.05	0.53–1.37	0.38–0.87	0.35–0.82	0.39–0.83	0.37–0.78	0.21–0.47	0.30–0.65	0.70–1.35	0.62–1.32	0.43–1.09	0.63–1.45	0.82–1.85	0.4–1.09	0.11–0.47	0.54–0.66
Female, f/bnkm																	
RR	1.7	3.5	1.8	2.3	3.1	1.7	2.0	1.5	1.9	0.9	1.1	2.0	0.8	0.2	0.7	0.3	0.8
95% CIs	0.84–3.56	1.61–7.42	0.63–5.30	1.09–4.99	1.55–6.39	0.70–4.12	1.00–3.86	0.76–2.96	0.88–4.16	0.32–2.55	0.38–2.96	0.80–5.10	0.21–3.45	0.02–1.23	0.09–4.59	0.07–1.06	0.69–1.05
Male, f/mhu																	
RR	1.8	1.7	1.8	2.0	1.1	1.5	3.2	3.0	2.0	3.1	3.2	2.0	0.8	1.9	1.8	1.7	1.8
95% CIs	1.19–2.74	1.13–2.62	1.23–2.62	1.38–2.88	0.72–1.58	1.03–2.21	2.32–4.48	2.08–4.42	1.26–3.19	2.06–4.72	2.14–4.81	1.20–3.23	0.40–1.66	1.70–2.07	1.19–2.74	1.13–2.62	1.23–2.62
Female, f/mhu																	
RR	3.3	7.9	4.7	6.4	8.9	4.7	5.6	4.0	4.7	2.2	2.5	5.3	2.1	0.4	1.0	0.8	2.2
95% CIs	1.58–6.71	3.67–16.85	1.61–13.45	3.00–13.76	4.40–18.18	1.93–11.4	2.84–10.91	2.01–7.87	2.17–10.32	0.79–6.27	0.90–7.00	2.11–13.49	0.53–8.74	0.06–2.85	0.13–6.83	0.20–3.17	1.76–2.68

Table 2
Rate ratios for fatality rates for cycling vs driving, by age and gender.

Age group:	< 17	17–20	21–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85+	all ages
Male, f/bnkm																	
RR	–	1.2	3.1	4.1	6.6	11.9	14.4	12.6	17.8	44.9	37.5	27.6	39.0	52.1	22.6	6.7	10.9
95% CIs	–	0.76–1.75	1.98–4.77	2.78–5.96	4.48–9.81	8.35–17.04	10.20–20.27	8.51–18.58	12.21–25.99	32.21–62.69	25.57–54.91	17.12–44.46	25.22–60.10	34.07–79.52	13.66–38.01	3.28–13.82	9.88–11.97
Female, f/bnkm																	
RR	–	7.5	6.1	10.7	19.0	17.0	27.0	22.4	24.2	12.9	12.1	26.5	16.0	4.8	18.2	8.9	13.5
95% CIs	–	3.64–15.25	2.22–16.53	5.38–21.37	10.02–36.07	7.30–39.64	14.16–51.22	11.56–43.44	11.49–51.02	4.66–35.93	4.40–33.53	10.37–67.54	3.84–66.34	0.66–34.86	2.36–124.52	2.15–38.52	10.92–16.71
Male, f/mhu																	
RR	–	0.4	0.9	1.4	2.2	3.8	5.2	4.3	5.8	14.7	12.3	8.7	13.1	15.3	8.0	2.9	3.5
95% CIs	–	0.24–0.56	0.59–1.43	0.94–2.02	1.52–3.33	2.67–5.44	3.72–7.40	2.90–6.33	4.01–8.53	10.52–20.48	8.39–18.01	5.37–13.95	8.50–20.25	9.98–23.3	4.78–13.32	1.41–5.93	3.15–3.81
Female, f/mhu																	
RR	–	2.1	1.7	3.5	6.5	5.6	9.3	7.1	6.8	3.6	3.4	8.1	4.7	1.3	3.2	3.5	4.0
95% CIs	–	1.02–4.27	0.64–4.73	1.73–6.89	3.41–12.26	2.42–13.13	4.87–17.6	3.66–13.74	3.23–14.35	1.30–10.06	1.22–9.33	3.19–20.79	1.14–19.72	0.18–9.58	0.45–23.52	0.84–14.99	3.25–4.98

Table 3
Fatality rate per bn km by deprivation and rate ratios for residents of most vs least deprived areas, 2007–12.

Mode	Deprivation quintile		< 17	17–24	25–34	35–44	45–54	55–64	65–74	75+	all ages
cycle	Most deprived	No of fatalities	15	12	25	12	14	12	7	4	101
		Mean km[a]	26	64	130	100	84	59	23	10	67
		Bn km travelled	0.4	0.5	1.3	0.9	0.6	0.3	0.1	0.0	4.2
		Fatality rate/bn km	38.0	23.3	18.6	13.5	22.1	35.5	72.4	101.7	23.8
	Least deprived	No of fatalities	11	11	7	18	16	16	17	17	113
		Mean km[a]	49	64	105	136	130	76	58	16	83
		Bn km travelled	0.6	0.3	0.7	1.3	1.2	0.6	0.3	0.1	5.2
		Fatality rate/bn km	18.2	31.6	10.8	14.3	13.1	25.4	48.7	204.8	21.8
		RR (most vs least)	2.1	0.7	1.7	0.9	1.7	1.4	1.5	0.5	1.1
		95% CIs	0.96–4.54	0.33–1.67	0.75–4.00	0.45–1.95	0.82–3.45	0.66–2.96	0.61–3.57	0.17–1.49	0.84–1.43
walk	Most deprived	No of fatalities	82	65	74	96	124	85	88	249	863
		Mean km[a]	384	405	379	333	299	264	293	156	339
		Bn km travelled	5.8	3.2	3.9	3.0	2.2	1.5	1.2	0.6	21.6
		Fatality rate/bn km	14.1	20.0	18.9	32.2	55.3	56.1	73.0	419.1	40.0
											.8
	Least deprived	No of fatalities	21	37	22	31	40	43	51	190	435
		Mean km[a]	313	337	276	293	267	291	257	163	281
		Bn km travelled	3.9	1.8	1.7	2.7	2.5	2.4	1.6	0.9	17.5
		Fatality rate/bn km	5.4	20.1	12.9	11.5	16.0	17.7	32.8	221.0	24.9
		RR (most vs least)	2.6	1.0	1.5	2.8	3.5	3.2	2.2	1.9	1.6
		95% CIs	1.62–4.22	0.66–1.49	0.91–2.37	1.88–4.22	2.43–4.95	2.19–4.56	1.57–3.14	1.57–2.29	1.43–1.81
drive	Most deprived	No of fatalities	3	111	115	71	50	32	15	25	422
		Mean km[a]	–	1,608	4,194	4,622	4,352	3,880	2,501	974	2,609
		Bn km travelled	–	12.9	43.4	41.4	32.6	22.3	10.3	3.7	165.8
		Fatality rate/bn km	–	8.6	2.7	1.7	1.5	1.4	1.5	6.7	2.5
	Least deprived	No of fatalities	0	184	123	61	73	62	58	99	660
		Mean km[a]	–	5,481	10,787	12,880	13,105	10,640	6,478	3,171	7,813
		Bn km travelled	–	29.8	66.9	119.0	122.8	88.7	39.1	16.7	487.0
		Fatality rate/bn km	–	6.2	1.8	0.5	0.6	0.7	1.5	5.9	1.4
		RR (most vs least)	–	1.4	1.4	3.3	2.6	2.1	1.0	1.1	1.9
		95% CIs	–	1.11–1.77	1.12–1.86	2.38–4.71	1.8–3.69	1.34–3.15	0.56–1.73	0.73–1.76	1.66–2.12
all modes	Most deprived	No of fatalities	100	188	214	179	188	129	110	278	1,386
		Mean km[a]	411	2,078	4,702	5,054	4,735	4,203	2,817	1,140	3,015
		Bn km travelled	6.2	16.6	48.6	45.2	35.5	24.1	11.6	4.4	191.6
		Fatality rate/bn km	16.1	11.3	4.4	4.0	5.3	5.4	9.5	63.9	7.2
	Least deprived	No of fatalities	32	232	152	110	129	121	126	306	1,208
		Mean km[a]	362	5,882	11,168	13,308	13,502	11,006	6,793	3,349	8,177
		Bn km travelled	4.5	32.0	69.3	123.0	126.5	91.8	41.0	17.7	509.7
		Fatality rate/bn km	7.1	7.2	2.2	0.9	1.0	1.3	3.1	17.3	2.4
		RR (most vs least)	2.3	1.6	2.0	4.4	5.2	4.1	3.1	3.7	3.1
		95% CIs	1.52–3.37	1.29–1.89	1.63–2.47	3.49–5.61	4.15–6.50	3.17–5.20	2.39–3.98	3.14–4.34	2.83–3.30

[a] Per person per year. Figures may not add due to rounding.

for Transport, 2012). Unfortunately, denominator travel data are not available by age-group and sex (nor IMD) by type of road, so the comparison between modes is imperfect, as fatality rates are not available by age, sex, travel mode and road type.

Thirdly, this study has not taken into account non-fatal injuries and their long-term sequelae, due to the difficulties of obtaining comparable data even for serious injuries, let alone minor injuries, as has been discussed previously (Amoros et al., 2008; Mindell et al., 2012). Short walks are under-reported in NTS, which meant lower denominator figures were available (in both distance and time) to estimate the fatality rate for pedestrians: the rate found for pedestrians is thus exaggerated to some extent (Department for Transport, 2014). The reliance on participants' own recording of their travel patterns accurately over 7 days is another limitation, for all travel modes.

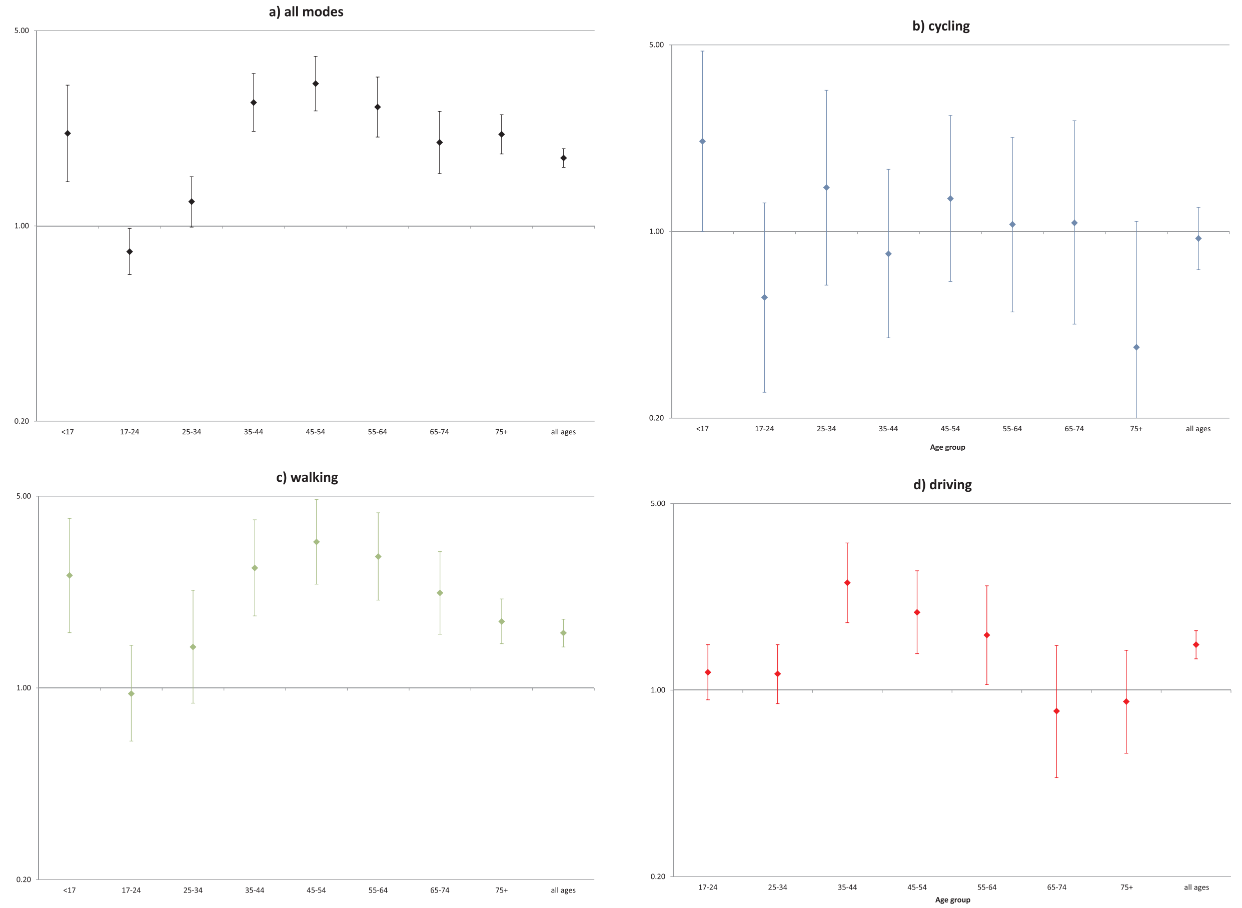

Fig. 7. Fatality rate ratios for the most vs the least deprived areas, 2007–12 by time spent travelling. a) All three travel modes combined, b) cycling, c) walking, d) driving.

While it is to be welcomed that travel deaths are falling, the numbers of deaths were too small to assess the impacts of deprivation stratified by gender, despite aggregating data for six years. Nor could we assess whether inequalities by deprivation had changed over the two three-year periods as we were provided with data by deprivation quintile aggregated over six years, for data protection reasons (small numbers). Some studies have found different effects of deprivation by gender (Laflamme et al., 2009). Similarly, the confidence intervals are very wide for older cyclists and pedestrians and female cyclists.

4.3. *Comparison with other studies*

These results confirm those of earlier studies (Mindell et al., 2012; Rolison et al., 2012). Rolison and colleagues found an increased fatality rate in older drivers and pedestrians in Great Britain 1989–2009, using NTS trip numbers as the denominator. They also noted the reduction in fatality rates over time. For drivers (and car occupants) there were U-shaped relationships with age; the fatality rates per trip for car occupants and drivers were the same for those aged 21–29 and 70+. Pedestrians showed the same exponential increase with age as in our study: those aged 70+ had more than five times the fatality rate of those aged 21–29. However, their study, being based on STATS19, excluded pedestrian falls; so did the French comparative study (Bouaoun et al., 2015).

Department for Transport figures for 2012 show the same fatality rates for pedestrian and cyclists, 38 per billion miles (24 per bnkm) (Department for Transport, 2013). This figure for Great Britain is slightly higher than our results for England, even though their figure excludes pedestrian falls.

4.3.1. *Impacts of age on fatality rates*

These data demonstrate the higher mortality rate for young drivers, particularly males. This explains the higher mortality in the youngest adults in the least deprived quintile from all three modes combined. Although young, deprived drivers had a non-significantly higher fatality rate, they drove half the time and one-third the distance as their affluent peers, for whom deaths as drivers contributed the bulk of road fatalities in our study.

We also confirmed the higher mortality rates for all three travel modes for older people. Age-related functional limitations, including deteriorating vision, hearing, and cognition could reduce balance, reduce awareness of other vehicles, through slow reaction times, increasing the risk of involvement in a collision or fall (MacLeod et al., 2014; Ryan et al., 2016). Countries that introduce screening of older drivers have higher pedestrian fatalities among older people (O'Neill, 2016). Co-morbidity increases the severity of the sequelae of a given event, except for the most severe injuries (Camilloni et al., 2008). Our study cannot distinguish between these, but others have shown increased mortality of older than younger adults from ground-level falls (Spaniolas et al., 2010) and from motor vehicle collisions (Yee et al., 2006).

The differences by gender and travel mode were an order of magnitude smaller than the difference by age. This is exemplified by Fig. 6, which shows the fatalities per bnkm separately for those aged < 70 y and 70+ because a scale that shows the fatality rates for older cyclists and pedestrians cannot show differences by travel mode for young and middle aged adults.

Older drivers travel much less, and more slowly, than middle-aged drivers, suggesting that older drivers undertake fewer, and/or shorter trips. A contributing factor for the higher fatality rates in older people may be the location of driving, i.e. less motorway driving, and 'low mileage bias' (Langford et al., 2008).

4.3.2. Socioeconomic inequalities

Socio-economic inequalities in access to the benefits of transport are well-recognised (Mackett, 2014; World Health Organisation, 2011). Transport can also contribute to social exclusion (Mackett and Thoreau, 2015). We have demonstrated mode-specific associations of travel deaths with individuals' area deprivation score.

Many studies have shown steep social gradients in road traffic casualty rates, with disadvantaged areas showing higher rates than least deprived communities (Christie et al., 2010; Green et al., 2011; Morency et al., 2012). The effects and causes of this inequality on children and young people has been a particular concern (Christie et al., 2010; Green et al., 2011; Thomas and Jones, 2014). For children aged 5–15, pedestrian deaths in 2001–03 in children of parents who had never worked or were long term unemployed was more than 20 times higher than in NS-SEC. 1; for deaths as cyclists it was 27 times higher (Edwards et al., 2006).

When assessing the rate of road casualty by deprivation, Christie et al. (2010) used the age-specific population as the denominator and not the exposure to risk. Our study investigated fatality rates using appropriate denominators by socio-economic classification, age and mode, which gives insight into the particular mode(s) and age(s) that contribute to the inequalities.

Most studies have used the area deprivation of the location of the collision (e.g. (Morency et al., 2012). We have used the individuals' residential area deprivation quintile for both numerator and denominator data. However, using an area-based rather than a personal measure of socio-economic position could misclassify some individuals if personal circumstances (education, income, and/or occupation) are more important than the relative deprivation of the area in which one lives. In Cornwall (a county in England), deprivation in the area in which collisions occurred was particularly important for pedestrian casualties, whereas deprivation in the residence of the individuals to blame was associated with increased motorist casualties, for males aged 25–54 (Hurst, 2011).

Although earlier studies found higher road injury rates for cyclists in more than less disadvantaged areas (Christie et al., 2010), we found an association with deprivation only for children's cycling fatality rates, although the numbers are small even using six years' data. We found pedestrian fatality rates for adults aged 35+ differed markedly between the most and least deprived quintiles of IMD. Environmental factors such as pedestrian and vehicular density, and lack of safe crossing sites contribute to the difference in rates (Christie et al., 2010; Green et al., 2011); the worse health associated with deprivation (Marmot, 2010; Public Health England, 2016) may also increase case-fatality rates.

Middle-aged drivers had higher fatality rates in the most than in the least deprived quintiles. Vehicles used by people in more deprived communities are often older, with fewer safety features (for occupants), and possibly lower roadworthiness.

Young drivers in Sweden with lower educational attainment had higher crash rates than their more educated peers, particularly for severe and fatal crashes (Hasselberg et al., 2005). In a study of serious crashes in the USA, higher percentages of car occupants with lower educational attainment had high blood alcohol concentrations or were not using seatbelts (Braver, 2003).

Possible explanations for the social patterning of road travel injuries and fatalities have been summarised elsewhere (Hurst, 2011). Environmental factors may also contribute to the increased risk. Deprived areas are known for increased road density, kerb parking and inadequately maintained roads (Christie et al., 2010). Lower income neighbourhoods in Belgium had higher numbers of road travel injuries, while average household income was inversely associated with risk of injury for males residents of that area (Gamble et al., 2015). Lower socio-economic position is also associated with higher hospitalisation costs for those seriously injured in road traffic events (Devos et al., 2015).

4.4. Implications of our findings

Rates of travel fatality vary by age, sex and mode, albeit the all-ages rate is the highest for cycling for both sexes (0.36 and 0.20 f/mhu for males and females respectively). Although driving appears to be the safest mode of transport for adults aged 35+, particularly for men, part of this is artefactual, as described above, because of road type. Additionally, time that drivers spend stationary because of congestion (which affects pedestrians and cyclists to a much lesser extent) will appear to reduce time-based mortality rates for drivers. Improvements to secondary safety of vehicles in protecting occupants, such as air bags and seat belts (Broughton, 2003), and the dwindling acceptability of driving under the influence of alcohol have all contributed. Slower speed limits reduce both the likelihood of a collision and the severity of consequent injuries, benefitting all road users (World Health Organisation, 2015).

Despite cycling posing a higher rate of fatality by time travelled in comparison with walking and substantially higher than driving for most age groups (with the above caveat regarding road types), the absolute fatality rate is very small. The Department for Transport estimated that there is one cyclist killed for every 3 million hours of cycling, and one killed or seriously injured for every

100,000 h spent cycling.

Most studies have found that the benefits of physical activity from cycling substantially outweigh the harms from injury, air and noise pollution (Woodcock et al., 2013), but the balance varies by location (Tainio, 2015). Even where the disbenefits are greater, little is due to injury (Tainio, 2015). Pedestrians and cyclists are exposed to lower concentrations of air pollutants than motor vehicle occupants (Chertok et al., 2004), although a study in Belgium found higher NO_2 exposure among cyclists (Dewulf et al., 2016) and the dose may be higher during exertion with increased respiration (Dewulf et al., 2016; Nyhan et al., 2014). Additionally, cycling and walking do not contribute to greenhouse-gas emissions whereas motorised transport is a major contributor.

5. Conclusion

There were significant reductions between 2007–09 and 2010–12 in fatality rates for driving and walking for both sexes and for male cyclists at all ages. While fatality rates for cycling are higher for most age groups compared with driving, the differences are small compared with the differences within a specific mode by age and gender, and are exaggerated for comparisons of travel on general purpose roads. Although cyclists face higher fatality rates than drivers and similar fatality rates to pedestrians overall (lower rates for cyclists per kilometre but higher rates per hour), our findings show that public perception of the dangers of cycling are exaggerated and that the absolute fatality rate is very low. For young men, road travel fatality rates per hour are substantially greater when driving than cycling, and are similar (non-significantly higher) per kilometre. The differences in fatality rates between cycling and walking are particularly small, and depend on the denominator used. Although travel fatality rates were higher for persons in the most deprived areas, this was not the case for cycling for adults. The net benefits of active travel outweigh the risks, but policies should strive to reduce the toll of road deaths and injuries further, particularly for children.

Contributors

JM conceptualized the study and led the writing. RF obtained the numerator data and conducted all the analyses, with guidance from SS and JM. MW advised on the identification of relevant ICD-10 codes and contributed to interpretation of the findings. Samuel Dickinson provided the National Travel Survey data. All authors contributed to interpreting the findings and the writing of the article.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.jth.2017.08.007.

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