Fatality rates associated with driving and cycling for all road users in Great Britain 2005–2013

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ABSTRACT

Fatality rates based on deaths only to the drivers themselves do not accurately portray the impact of driving on road traffic deaths. We characterised more fully the impact of driving and cycling on road traffic fatalities by including deaths to all the other road users in fatal car or cycle crashes. We used crash data from the Great Britain National Road Accident Database (STATS19) and exposure data from the National Travel Survey. Rates were estimated as the ratio of fatalities to the amount of time travelled: fatalities per million hours' use (f/mhu). Rates in 2005-07, 2008-10, and 2011-13 were calculated based on deaths to: (1) the drivers or cyclists themselves (persons 'in charge' of vehicles), (2) other, i.e. 'third-party', road users (e.g. passengers, drivers or riders of other vehicles, and pedestrians), and (3) both of these groups combined, i.e. all road users. Rates were stratified by the sex and age of the drivers or cyclists involved in the fatal crashes.

Rates based on deaths to persons in charge of vehicles were higher for cyclists than for drivers, whereas those based on deaths to third-party road users showed the opposite. The inclusion of third-party deaths increased the overall rates considerably more for drivers than for cyclists. Nevertheless, the overall rate for male cyclists (2011-13: 0.425 f/mhu; 95% Confidence Interval (CI): 0.377–0.478) exceeded that for male drivers (0.257 f/mhu; 95% CI: 0.248–0.267). A similar pattern was observed for females (cycling: 0.216 f/mhu; 95% CI: 0.158–0.287; driving: 0.127 f/mhu; 95% CI: 0.120–0.135). These differences between cars and cycles were overestimated as the safer travel on motorways could not be disaggregated in the estimates for driving. The higher rates for cycling - mainly borne by the cyclists themselves - need to be balanced against the substantially lower risks to other road users.

1. Introduction

Road traffic injuries were the ninth leading cause of Disability Adjusted Life Years (DALYs) worldwide at the turn of the 21st century, and they contribute disproportionately to deaths among young people (Krug et al., 2000). Several studies have combined data on the numbers of road crash injuries and the amount of travel exposure to compare rates of injury by travel mode (Beck et al.,

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2007; Bouaoun et al., 2015; Mindell et al., 2012; Pucher and Dijkstra, 2003; Teschke et al., 2013). The majority have found cycling to be associated with higher rates of road crash fatality than driving when calculated across all ages (Beck et al., 2007; Bouaoun et al., 2015; Mindell et al., 2012), although it has been noted in Britain that rates for persons aged 17–20 years were higher for driving than for cycling (Mindell et al., 2012; Feleke et al., 2017).

These analyses have tended to be based on injuries only to the drivers or cyclists themselves. The risks of injury for all the other road users in the same traffic collisions (hereafter referred to as other, i.e. 'third-party' road users) have to date received little attention in transport safety research (Evans, 2000). Evidence suggests that young car drivers in particular are associated with increased risk of death not only to themselves but also to their passengers (especially of similar age), and also to other persons struck by the car, e.g. pedestrians, drivers or riders of other vehicles, or cyclists (Chen et al., 2000; Department for Transport, 2012; Jones et al., 2015; McCartt and Teoh, 2015; Tefft, 2008). For example, McCartt and Teoh reported that 39% of the deaths in fatal crashes involving the drivers of passenger vehicles aged 16–19 in the United States in 2012 were the 16–19 year-old drivers themselves, 24% were their passengers, and 37% were occupants of other vehicles, cyclists, pedestrians, or other road users (McCartt and Teoh, 2015).

Fatality rates based therefore only on the deaths of the drivers themselves do not accurately portray the full impact of driving on road traffic deaths. To date, no study has used the data available on fatal car or cycle crashes to estimate road traffic fatality rates based on the deaths to all road users (i.e. not just the drivers or cyclists themselves) by the sex and the age of the drivers or cyclists involved. We addressed this gap by combining numerator data on the number of road traffic fatalities with survey-based denominator data, collected in Britain over a nine-year period (2005-13). We aimed to characterise more fully the impact of driving and cycling on traffic fatalities by estimating the magnitude of road traffic fatality rates based on deaths to: (1) drivers or cyclists themselves, (2) 'third-party' road users (e.g. passengers, drivers or riders of other vehicles, and pedestrians), and (3) 'all road users' (i.e. overall rates that combined both of these groups).

2. Methods

2.1. Road traffic crash data

Road traffic crash data were obtained from the Great Britain National Road Accident Database (STATS19). STATS19 is the national road crash database of casualties (fatal, serious, and slight injuries) reported by the police on any road where motor vehicles are allowed to travel. The present study focused on road traffic fatalities. STATS19 is generally acknowledged to accurately cover all road traffic fatalities (Keep and Rutherford, 2013).

STATS19 contains data on crashes involving personal injury that involved at least one road vehicle: the definition of 'road vehicle' includes pedal cycles. In accordance with the STATS19 convention, the types of vehicle classed in the present study as 'cars' include taxi / private hire car and minibus (less than 17 passenger seats), and excludes vans / goods vehicles. Specifically, the persons 'in charge' of vehicles in the present study were either car drivers or cyclists, whereas third-party fatalities in car or cycle crashes could include occupants or riders of any vehicle, and pedestrians. The database contains information on the characteristics of the crash, vehicle(s) involved, and the person(s) injured or killed.

The present study included both single- and multi-vehicle road traffic crashes that resulted in at least one fatality to any road user. More specifically, we focused on the subset of fatal crashes that involved ≥1 car or ≥1 cycle. For fatal crashes involving ≥1 car, we extracted the number of:

- driver fatalities (persons 'in charge' of the vehicle(s)); and
- fatalities to **all** the third-party road users travelling in or struck by cars (including car passengers, drivers or riders of any other road vehicle, pedestrians, or any other road user).

These death counts were stratified by the sex and the age of the drivers involved in the crash. For example, a fatally struck pedestrian aged 50–59 years involved in a collision with a car driven by a male aged 30–39 years would be counted as a third-party death in the estimation of the fatality rates for male drivers aged 30–39 years. Age was grouped as follows: 17–20, 21–25, 26–29, 30–39, 40–49, 50–59, 60–64, 65–69, 70–74, 75–79 and ≥80 years. 6% of drivers involved in fatal crashes were excluded from our analysis because of missing demographic data.

A driver fatality in a multi-vehicle collision in which at least one other car driver was killed would potentially be double-counted: as a driver themselves and as a third-party (through being the driver of another car involved in the same fatal collision). To avoid such double-counting, the number of deaths in multi-vehicle collisions were weighted by the reciprocal of the number of car drivers involved to ensure that the number of driver and third-party fatalities summed over all driver sex/age groups matched the actual total number of deaths in car crashes.

Similarly, for fatal crashes involving ≥1 cycle, we extracted the number of:

- cyclist fatalities (persons 'in charge' of the vehicle(s)); and
- fatalities to *all* the third-party road users riding on or struck by the cycle(s).

These death counts were stratified based on the sex and the age (using the same age bands described above) of the cyclists involved in the crash.

2.2. Travel exposure data

Comparisons of road traffic fatality rates across population subgroups and/or travel modes must control for the amount of road users' travel (Beck et al., 2007; Mindell et al., 2012). The amount of time spent travelling was used in the present study as it is the most similar across travel modes with different average speeds: the mean trip duration on Britain's roads for cycling and driving is 23 and 22 min respectively (Department for Transport, 2014a; Department for Transport, 2014b).

Travelling time data were extracted from the National Travel Survey (NTS), the primary source of data on personal travel patterns. The nationally-representative sample of 8000 households (containing 15,000 adults) is selected annually using a stratified two-stage random probability sample of private households. Data collection comprises a face-to-face interview and a one-week self-completed written travel diary. Each NTS respondent therefore provided travel data for a maximum of seven travel days. Estimates of yearly travel are obtained from the weekly information, as data collection takes place continuously throughout the year: this allows the survey to capture any seasonal changes in travel. Data are weighted to be nationally-representative of the civilian, non-institutionalized population. The annual response rate ranges between 55% and 65% (Department for Transport, 2015b). The basic unit of travel in the NTS is a trip, defined as a one-way course of travel with a single main purpose. A trip consists of at least one stage; a new stage is defined when persons change travel mode (Kunert et al., 2002).

The age- and sex-specific amount of time spent travelling by each mode (car driver and cyclist) was based on stage data (Department for Transport, 2015d), and was estimated by multiplying the average hours travelled per person-year by the mid-year population estimates available from the Office for National Statistics. The amount of time travelled was therefore expressed in the present study as million hours' use (mhu). The NTS stage data used in this study covered all road classes (stage data is not available by the type of road).

2.3. Population and time-period

STATS19 and NTS data were extracted for the same population: persons aged ≥ 17 years, over a nine-year period (2005-13). Annual data were aggregated into three, non-overlapping periods (2005-07, 2008-10, 2011-13) to examine changes over time and to improve precision, especially for fatal crashes involving ≥ 1 cycle for which the total numbers of fatalities were relatively small.

2.4. Statistical analysis

Road traffic fatality rates were estimated as a ratio of the number of deaths to the amount of travelling time, expressed as fatalities per million hours' use (f/mhu). Car- and cycle-crashes were analysed separately. Within each type of crash, f/mhu rates were based on the number of deaths to:

1. drivers or cyclists themselves (persons 'in charge' of vehicles);
2. 'third-party' road users; and
3. all road users (i.e. overall rates that combined both of these groups).

Rates were stratified based on the sex and the age of the drivers or cyclists involved in fatal crashes. Differences between the f/mhu rates in relative terms were tested for statistical significance using rate ratios (RRs) and accompanying 95% Confidence Intervals (CIs). RRs according to sex (females as reference), travel mode (driving as reference), and time-period (2005-07 as reference) were computed holding the other variables constant.

No minimum age limit was used for the deaths to third-party road users. However, the f/mhu rates for drivers were restricted to drivers aged ≥ 17 years, reflecting the minimum age limit for licensed drivers. Fatality rates for cyclists were therefore also restricted to cyclists aged ≥ 17 years to ensure comparability between the travel modes with respect to age. This resulted in the exclusion of 27 driver- and 138 cyclist-fatalities from the 'person in charge of the vehicle' analyses. Deaths to seven drivers and two cyclists were also excluded from our analysis due to missing demographic data. As described above, the number of fatalities, the amount of travel exposure, and the corresponding f/mhu rates were stratified by the sex and the age of the drivers or cyclists involved in fatal crashes. In addition to the age-specific rates, we also calculated the f/mhu rates for drivers and for cyclists of all-ages (i.e. aged ≥ 17 years).

Data management was conducted in SPSS Version 20.0 (SPSS Inc., Chicago, Illinois). Rates and 95% CIs were calculated in Microsoft Excel (Microsoft Corporation) using the formulae for weighted sums (Dobson et al., 1991). RRs and their 95% CIs were computed using Stata v13.0 (StataCorp LP, College Station, Texas, USA).

3. Results

3.1. Fatalities by type of crash and by road user type

For the fatal crashes that involved ≥ 1 car or ≥ 1 cycle, Fig. 1 shows the absolute number of fatalities (disaggregated by road user type) by three types of crash: (1) ≥ 1 car, no cycle, (2) ≥ 1 cycle, no car, and (3) ≥ 1 car and ≥ 1 cycle. Just over two-fifths (42%) of the 16,431 fatalities in crashes involving ≥ 1 car but no cycle were the car drivers themselves (n=6,949). The largest categories of third-party deaths were passengers (n=3,380; 21% of all fatalities), pedestrians (n=3,367; 20%), and motor cyclists (n=2,432;
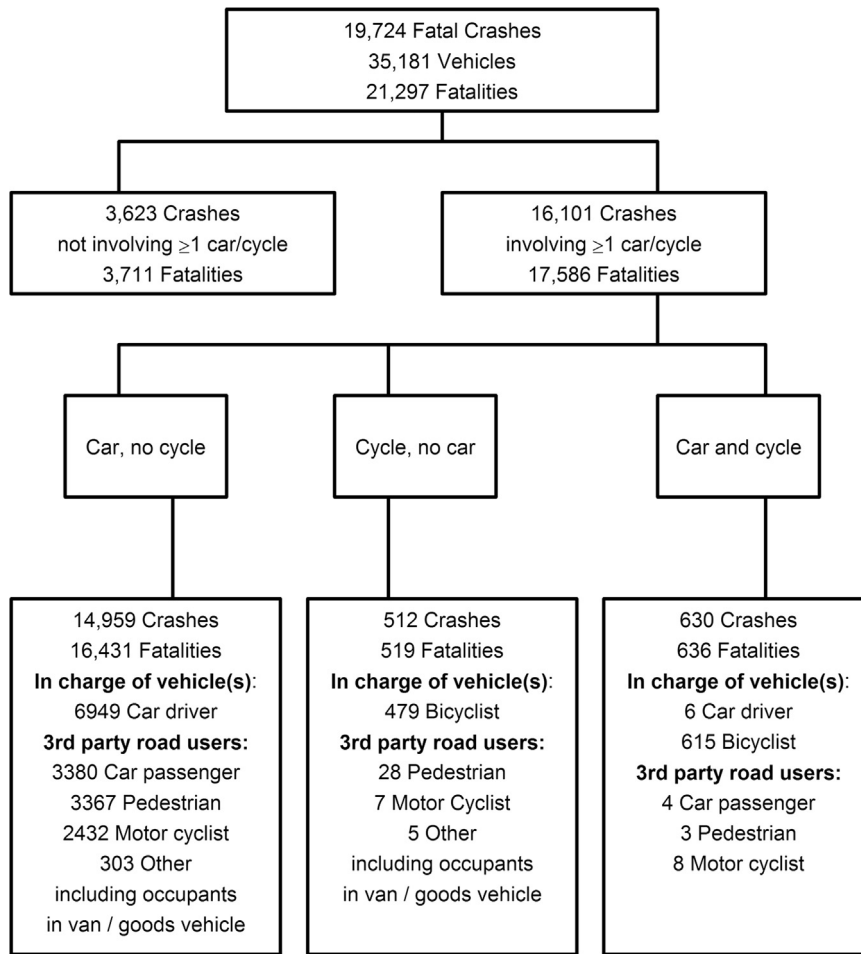
Fig. 1. Number of road traffic fatalities in car or cycle crashes, by type of crash and by road user type, Great Britain, 2005–2013.

15%). The overwhelming majority of the 519 fatalities in collisions involving ≥1 cycle but no car were the cyclists (n = 479; 92%).[1] Likewise, the majority of the 636 fatalities in the multi-vehicle collisions involving ≥1 car and ≥1 cycle were cyclists (n = 615; 97%).

3.2. Fatalities in car crashes by driver sex/age and by time-period

Overall, as Fig. 1 shows, 15,589 fatal crashes over the study period involved at least ≥1 car: 14,959 of these crashes did not involve a cycle; 630 crashes involved at least ≥1 cycle. For the fatal crashes involving ≥1 car, Table 1 shows the numbers of car driver and third-party fatalities, and the estimated amount of time travelled (on any road) by the sex and the age of the drivers involved.[2] In the most recent three-year period (2011-13), 1,327 drivers aged ≥17 years were killed, of whom 1,021 were male (77%), and 370 (28%) were aged 17–25 years. 2,686 third-party road users were killed. Of these, 611 (23%) were killed in crashes involving ≥1 driver aged 17–25 years (476 and 135 male and female drivers aged 17–25 years, respectively).

3.3. Fatalities in cycle crashes by cyclist sex/age and by time-period

Overall, as Fig. 1 shows, 1,142 fatal crashes over the study period involved at least ≥1 cycle: 630 of these crashes involved at least ≥1 car; no car was involved in 512 crashes. For the fatal crashes involving ≥1 cycle, Table 2 shows the numbers of cyclist and third-party fatalities, and the estimated amount of time spent cycling by the sex and the age of the cyclists involved. In the most recent three-year period (2011-13), 301 cyclists aged ≥17 years were killed, of whom 258 (86%) were male. 47 cyclists were aged 17–25 years (16%). 30 third-party fatalities occurred in cycle crashes, of which 25 (83%) involved a male cyclist.

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[1] Note that vans and goods vehicles may have been involved in these collisions involving ≥1 cycle.

[2] Due to the weighting applied to avoid the double-counting of driver fatalities in multi-vehicle collisions the total number of driver deaths in Table 1 does not match the absolute number shown in Fig. 1.

Table 1

Distribution of car driver and third-party fatalities and amount of travel exposure (million hours' use), by driver sex/age, and time-period, in Great Britain, 2005-2013[a].

Driver sex / age	2005–2007			2008–2010			2011–2013		
	No. of Deaths		mhu	No. of Deaths		mhu	No. of Deaths		mhu
	Drivers	Third-party		Drivers	Third-party		Drivers	Third-party	
Males									
Age-group, years									
17–20	361	585	390.3	214	329	339.5	128	205	286.1
21–25	344	543	873.3	219	379	745.6	167	271	696.3
26–29	163	308	880.0	106	226	877.7	97	177	819.0
30–39	335	617	3182.2	204	449	2785.4	147	330	2610.3
40–49	208	602	3755.3	138	453	3570.5	126	334	3430.4
50–59	173	458	3223.5	110	292	2963.4	108	266	3041.1
60–64	71	163	1258.7	39	150	1273.1	37	99	1295.0
65–69	47	121	843.9	45	88	841.5	33	72	996.9
70–74	49	88	632.5	32	69	617.1	46	69	627.4
75–79	45	71	372.3	47	65	386.2	40	55	437.6
≥80	97	80	252.2	82	64	258.6	92	75	341.0
Total	*1894*	*3655*	*12,327.0*	*1237*	*2570*	*11,613.6*	*1021*	*1961*	*11,581.4*
Females									
Age-group, years									
17–20	78	130	308.7	60	91	336.7	37	61	280.8
21–25	73	157	726.7	47	108	714.7	38	74	723.0
26–29	42	105	726.2	28	90	713.4	28	47	666.8
30–39	60	245	2445.7	61	197	2179.5	40	125	2045.6
40–49	77	215	2610.9	57	162	2612.5	43	156	2677.5
50–59	54	149	1778.9	44	115	1825.2	34	117	1868.3
60–64	23	48	531.0	24	45	620.2	14	48	638.4
65–69	16	25	321.7	11	24	339.5	16	32	448.7
70–74	17	31	215.7	19	21	211.2	14	28	251.8
75–79	15	23	119.0	14	16	143.1	19	14	166.5
≥80	34	18	77.1	30	16	110.3	24	24	134.8
Total	*487*	*1145*	*8005.0*	*395*	*884*	*8000.1*	*306*	*725*	*8100.7*

Abbreviations: mhu, million hours' use

[a] Excludes 34 driver fatalities (27 persons aged 0–16; 7 persons with missing age). Total estimates of mhu based on the average hours use for all persons and so does not equal the sum of the age-specific totals.

3.4. Fatalities per million hours use for drivers and for cyclists of all ages, third-parties, and all road users

In this section we present the road traffic fatality rates (deaths / amount of time spent travelled) that were calculated for drivers and for cyclists of *all-ages* (aged ≥ 17 years). Patterns in the age-specific fatalities per million hours' use (f/mhu) rates are presented in the following section (Section 3.5).

Separately for the drivers and the cyclists involved in a crash that resulted in at least one fatality to any road user, Table 3 shows the f/mhu rates calculated for drivers and for cyclists of all-ages in each time-period based on the number of deaths to: (1) drivers or cyclists themselves (persons 'in charge' of vehicles); (2) 'third-party' road users; and (3) all road users (i.e. overall rates that combined both of these groups).

The f/mhu rates are shown graphically in Figs. 2–4. Statistically significant differences between the f/mhu rates are highlighted in this and the following section (Section 3.5) by the estimated rate ratio (RRs) and the accompanying 95% Confidence Interval (95% CI). For simplicity, the RRs are available as Supplementary Data. Table S1 shows the RRs comparing males versus females. Tables S2 and S3 show the RRs comparing the travel modes (driving as reference), and time period (2005-07 as reference), respectively. Each comparison is made holding the other two variables constant. For example, comparisons between the sexes are made within the same travel mode and time-period.

3.4.1. Differences in the all-ages f/mhu for persons 'in charge' of the vehicle by driver or cyclist sex, mode of travel, and time-period

In this section we present the all-ages f/mhu rates for persons 'in charge' of the vehicle (i.e. drivers and cyclists). The all-ages f/mhu rates are shown in Table 3. Comparisons in the rates via RRs are made by sex (males versus females); by travel mode (cycling versus driving); and by time-period (2005-07 as reference).

Firstly, the f/mhu rates for persons 'in charge' of the vehicle differed significantly by sex. Within each time-period, the f/mhu rates for drivers were over twice as high for males than for females (e.g. 2011-13 RR = 2.34; 95% CI: 2.05–2.65). Similarly, the f/mhu rates for cyclists were 1.5–2.0 times higher for males than for females (e.g. 2011-13 RR = 1.99; 95% CI: 1.44–2.76) (Table S1).

Secondly, the f/mhu rates for persons 'in charge' of the vehicle differed significantly by travel mode: being 3.6–5.3 times higher for cyclists than for drivers. For example, the f/mhu rate for male cyclists was over four times as high as that for male drivers in 2011-

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S. Scholes et al.　　　　　　　　　　　　　　　　　　　　　　　　　　　Journal of Transport & Health xxx (xxxx) xxx–xxx

Table 2

Distribution of cyclist and third-party fatalities and amount of travel exposure (million hours' use), by cyclist sex/age and time-period, in Great Britain, 2005-2013[a].

Cyclist sex / age	2005–2007			2008–2010			2011–2013		
	No. of Deaths		mhu	No. of Deaths		mhu	No. of Deaths		mhu
	Cyclists	Third-party		Cyclists	Third-party		Cyclists	Third-party	
Males									
Age-group, years									
17–20	12	1	40.0	16	3	45.0	15	2	43.5
21–25	19	3	47.1	17	3	46.7	23	2	61.9
26–29	17	3	53.1	12	2	51.9	17	3	63.1
30–39	64	5	127.5	35	2	134.8	29	8	146.5
40–49	46	2	130.3	38	4	167.7	58	3	171.6
50–59	65	6	70.0	47	3	91.5	48	4	128.9
60–64	16	2	23.3	17	1	28.2	21	0	47.5
65–69	8	0	17.1	9	1	20.9	14	2	47.0
70–74	12	0	13.8	15	0	14.4	15	1	12.7
75–79	15	0	4.8	10	0	4.9	8	0	9.2
≥80	19	0	5.8	14	0	5.8	12	1	4.3
Total	*293*	*21*	*524.1*	*228*	*20*	*582.2*	*258*	*25*	*664.1*
Females									
Age-group, years									
17–20	3	0	9.6	5	0	9.6	1	0	7.6
21–25	3	0	22.5	7	0	23.2	8	1	19.9
26–29	5	0	11.5	7	0	24.6	2	0	16.0
30–39	10	0	38.9	12	0	41.7	9	1	58.7
40–49	12	1	31.7	9	0	50.4	10	3	54.5
50–59	8	0	32.6	8	1	39.2	4	0	44.6
60–64	4	0	10.8	2	1	11.5	0	0	14.5
65–69	3	0	5.8	2	0	4.7	6	0	7.5
70–74	2	0	5.4	3	0	1.9	0	0	3.0
75–79	4	0	2.0	0	0	3.5	4	0	1.0
≥80	1	0	2.1	2	0	1.9	0	0	0.0
Total	*54*	*2*	*177.6*	*56*	*2*	*212.7*	*43*	*5*	*218.0*

Abbreviations: mhu, million hours' use

[a] Excludes 140 cyclist fatalities (138 persons aged 0–16; 2 persons with missing age). Total estimates of mhu based on the average hours use for all persons and so does not equal the sum of the age-specific totals.

Table 3

All-ages fatalities per million hours' use (f/mhu) for persons in charge of vehicle, third-party road users, and all road users in fatal car or cycle crashes, by driver or cyclist sex and time-period, Great Britain, 2005–2013.

Driver or cyclist sex	Fatal crashes involving ≥1 car						Fatal crashes involving ≥1 cycle					
	Drivers		Third-Party		All road users		Cyclists		Third-Party		All road users	
	Rate	95% CI	Rate	95% CI	Rate	95% CI	Rate	95% CI	Rate	95% CI	Rate	95% CI
2005–2007:												
Males	0.154	0.147–0.161	0.297	0.287–0.306	0.450	0.438–0.462	0.558	0.496–0.626	0.047	0.030–0.069	0.605	0.540–0.675
Females	0.061	0.056–0.066	0.143	0.135–0.152	0.204	0.194–0.214	0.304	0.228–0.397	0.011	0.001–0.041	0.315	0.238–0.409
2008–2010:												
Males	0.107	0.101–0.113	0.221	0.213–0.230	0.328	0.317–0.338	0.392	0.342–0.446	0.033	0.020–0.052	0.425	0.374–0.481
Females	0.049	0.045- 0.054	0.110	0.103–0.118	0.160	0.151–0.169	0.261	0.197–0.339	0.007	0.001–0.030	0.268	0.203–0.347
2011–2013:												
Males	0.088	0.083- 0.094	0.169	0.162–0.177	0.257	0.248–0.267	0.388	0.343–0.439	0.037	0.024–0.055	0.425	0.377–0.478
Females	0.038	0.034-−0.042	0.089	0.083–0.096	0.127	0.120–0.135	0.195	0.141–0.263	0.021	0.006–0.050	0.216	0.158–0.287

Abbreviations: CI, confidence interval

13 (RR = 4.41; 95% CI: 3.84–5.05). A similar finding was observed for females (RR = 5.16; 95% CI: 3.75–7.12) (Table S2).

Thirdly, the f/mhu rates for drivers and for cyclists decreased significantly over the study period. Compared with 2005-07, the f/mhu rate for drivers in 2011-13 was 43% lower for males (RR = 0.57; 95% CI: 0.53–0.62) and 38% lower for females (RR = 0.62; 95% CI: 0.54–0.72). The corresponding f/mhu rate for cyclists was 30% lower (RR = 0.70; 95% CI: 0.59–0.82) and 36% lower (RR = 0.64; 95% CI: 0.43–0.96) (Table S3).
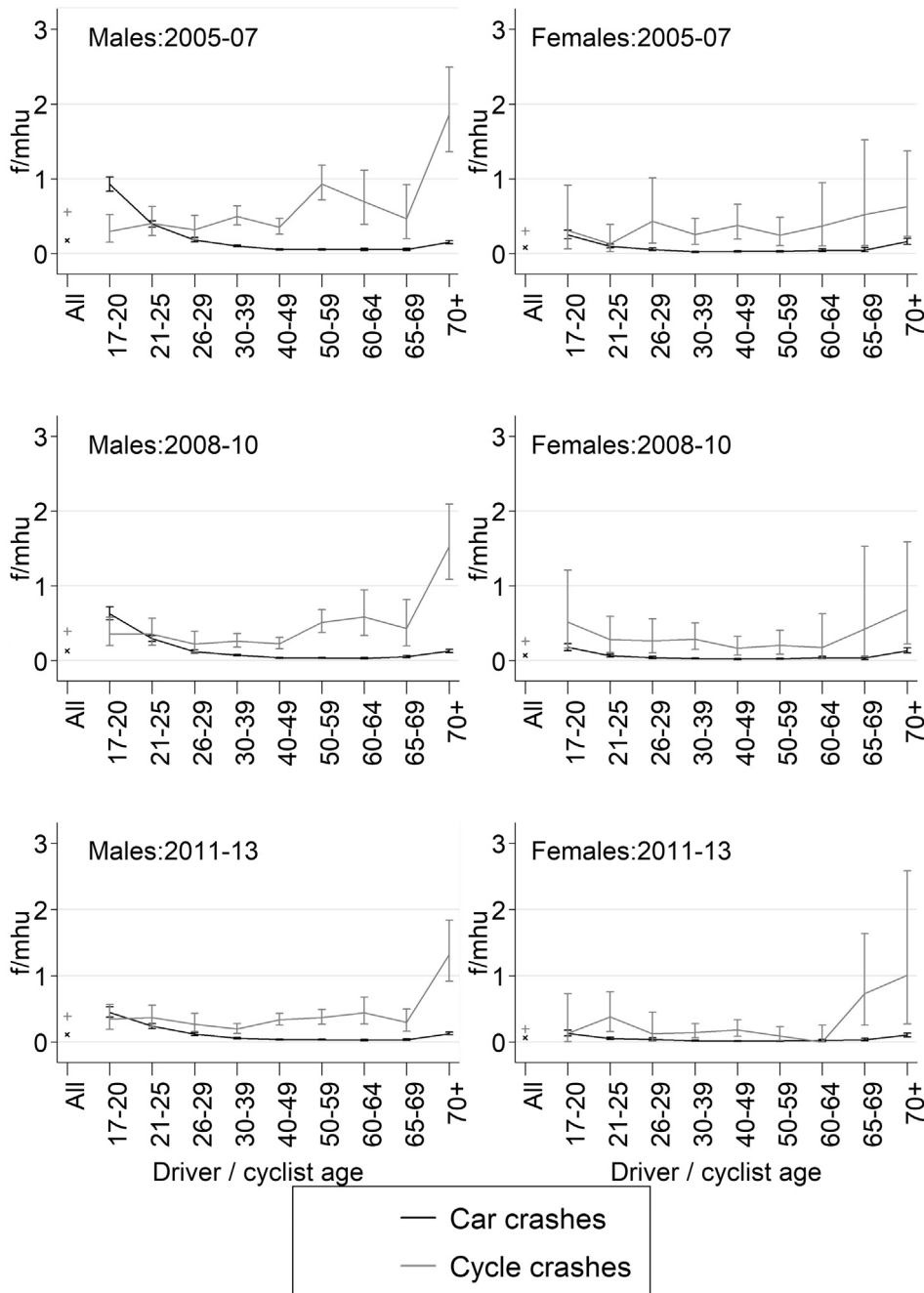
Fig. 2. Fatalities per million hours use (f/mhu) for persons in charge of vehicle by travel mode, age, and sex, Great Britain, 2005–2013.

3.4.2. Differences in the all-ages f/mhu for third-party road users by driver or cyclist sex, mode of travel, and time-period

In this section we present the all-ages f/mhu rates based on the number of deaths to third-party road users. These rates are stratified by the sex of the drivers or cyclists involved in fatal crashes. As in the previous section, comparisons are made by sex (males versus females); by travel mode (cycling versus driving); and by time-period (2005-07 as reference).

Firstly, with regards to differences by the sex of the driver, the estimated fatality rates based on the deaths to third-party road users were higher for males, being 1.9 to 2.1 times higher than for females (e.g. 2011-13 RR = 1.89; 95% CI: 1.74–2.06) (Table S1). Differences in the third-party f/mhu rates by the sex of the cyclists involved in the fatal crashes involving at least one cyclist were not statistically significant in part due to the low number of fatalities to non-cyclists (e.g. 2011-13 RR = 1.79; 95% CI: 0.65–4.88) (Table S2).

Secondly, with regards to differences by travel mode, the f/mhu rates based on third-party deaths showed the opposite pattern to
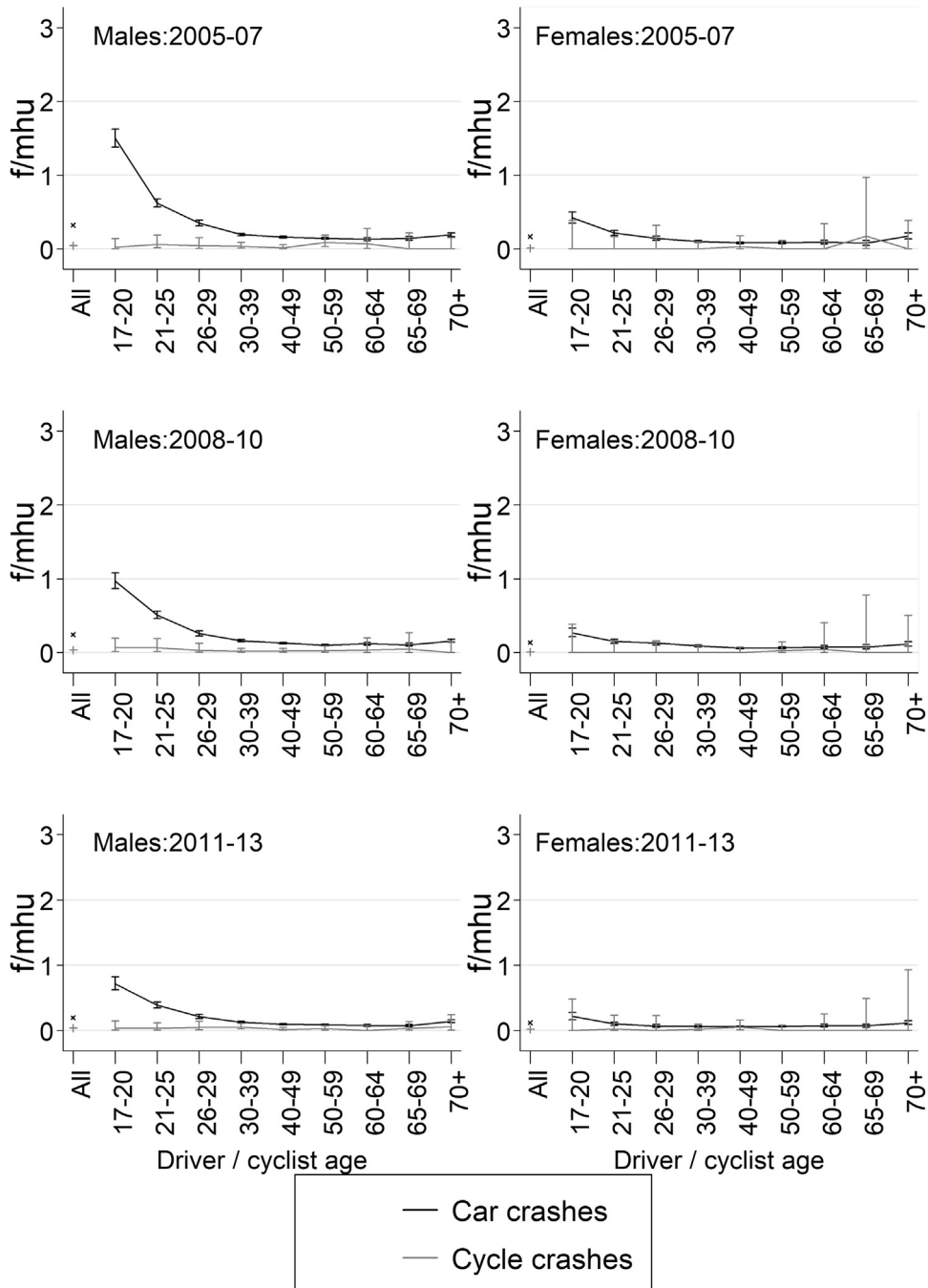
Fig. 3. Fatalities per million hours use (f/mhu) for third-party road users by travel mode, age, and sex of person in charge of the vehicle, Great Britain, 2005–2013.

those based only on the deaths to drivers or cyclists. For example, compared with the rates for drivers, the f/mhu rate based on third-party deaths was 78% lower for male cyclists (2011-13 RR = 0.22; 95% CI: 0.15–0.32) and 77% lower for female cyclists (2011-13 RR = 0.23; 95% CI: 0.09–0.58) (Table S2).

Thirdly, the f/mhu rates based on third-party deaths decreased significantly over the study period for driving. Compared with 2005-07, the f/mhu rate based on the deaths to third-party road users in 2011-13 was 43% lower for male drivers (RR = 0.57; 95% CI: 0.54–0.60) and 37% lower for female drivers (RR = 0.63; 95% CI: 0.57–0.69) (Table S3). The corresponding rates for male and female cyclists were not statistically significant in part due to the low number of fatalities to other road users in fatal cycle crashes.
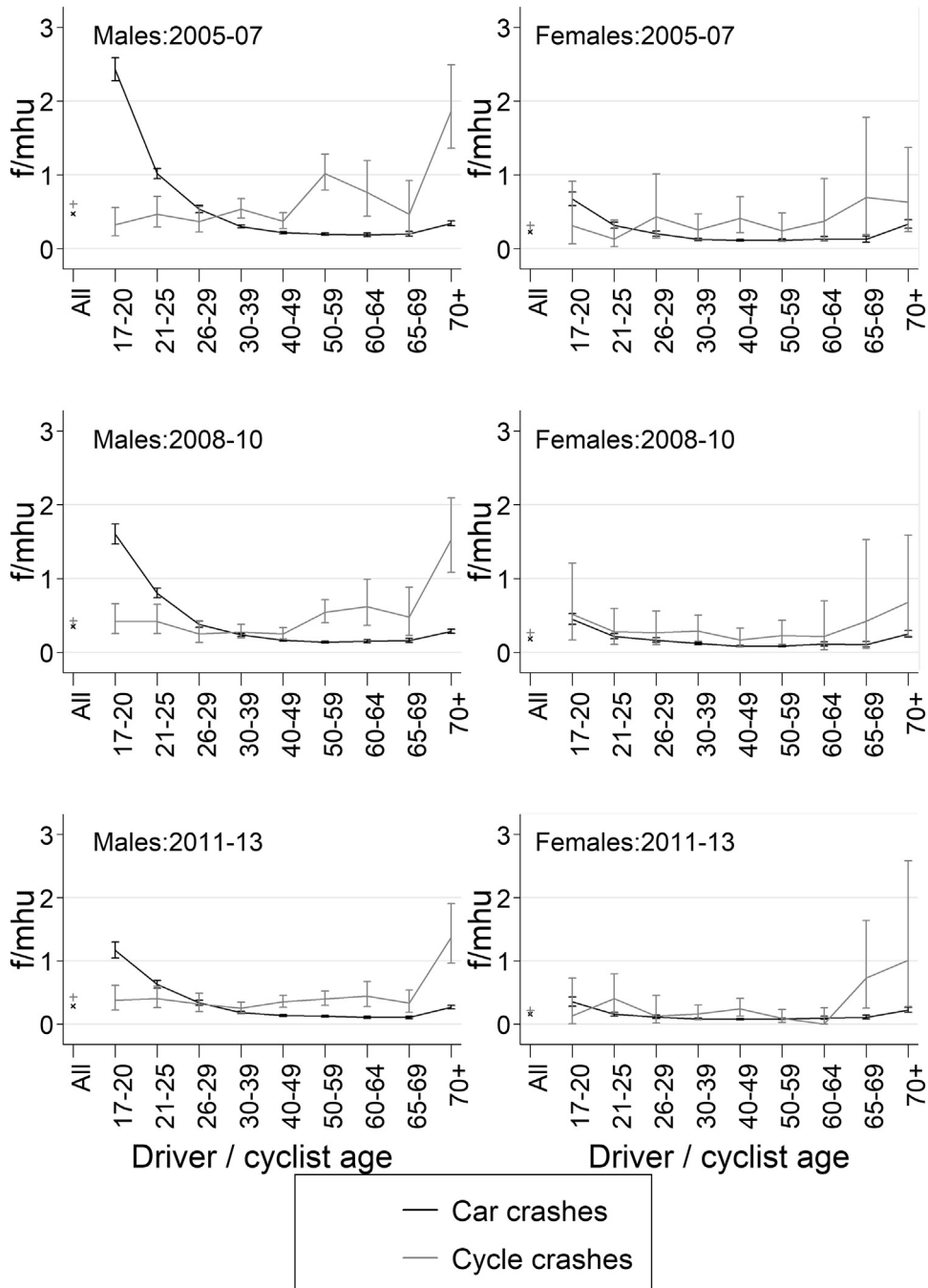
Fig. 4. Fatalities per million hours use (f/mhu) for all road users by travel mode, age, and sex of person in charge of the vehicle, Great Britain, 2005–2013.

3.4.3. Differences in the all-ages f/mhu rates for all road users by driver or cyclist sex, mode of travel, and time-period

In this section we present the all-ages f/mhu rates based on the number of deaths to all road users (i.e. persons 'in charge' of vehicles and third-parties).

Compared to the rates based only on the deaths to drivers or cyclists, including third-party deaths increased the overall f/mhu rates (i.e. both of these groups combined) considerably more for driving than for cycling. Nevertheless, the overall f/mhu rate for male cyclists in 2011-13 (0.425 f/mhu; 95% CI: 0.377–0.478) exceeded that for male drivers (0.257 f/mhu; 95% CI: 0.248–0.267): this corresponded to a RR of 1.65 (95% CI: 1.46–1.87) (Table 3 shows the f/mhu rates; Table S2 shows the corresponding RRs). A similar pattern was observed for females (cyclists: 0.216 f/mhu; 95% CI: 0.158–0.287; drivers: 0.127 f/mhu; 95% CI: 0.120–0.135). This difference corresponded to a RR of 1.69 (95% CI: 1.27–2.27).

3.5. Age-specific f/mhu rates for drivers or cyclists, third-party road users, and all road users

3.5.1. Differences in the age-specific f/mhu for persons 'in charge' of the vehicle: by driver or cyclist sex, mode of travel, and time-period

In this section we present the age-specific f/mhu rates for persons 'in charge' of the vehicle (i.e. drivers and cyclists). Comparisons in the age-specific rates via RRs are made by sex (males versus females); by travel mode (cycling versus driving); and by time-period (2005–07 as reference).

The highest age-specific fatality rate for drivers was observed for males aged 17–20 years in 2005-07 (0.93 f/mhu; 95% CI: 0.83–1.03). Fatality rates for drivers showed a U-shaped pattern with driver age; in contrast, the rates for cyclists increased with age, especially for males (Fig. 2).

With regard to differences by driver sex, the f/mhu rates for males were higher than for females in the younger age-groups (drivers aged 17–59 years) in each time-period. No significant sex differences were found in the older age-groups. Among cyclists aged 50–59 years, the rates for males were higher than for females (e.g. 2011-13 RR = 4.11; 95% CI: 1.48–11.40) (Table S1; Fig. 2). No significant sex differences among cyclists were observed in the other age-groups.

Differences between drivers and cyclists were largest among males aged 17–20 years in the earlier time-periods: the f/mhu rate for male cyclists aged 17–20 years was lower than the rate for male drivers aged 17–20 years in 2005-07 (RR = 0.32; 95% CI: 0.18–0.58), and in 2008-10 (RR = 0.57; 95% CI: 0.34–0.94). This difference did not reach significance in 2011-13 due to the steeper decrease in the fatality rate for male drivers aged 17–20 years over the study period. With the exception of younger males, the age-specific f/mhu rates were higher for cyclists than for drivers among both sexes (Table S2).

3.5.2. Differences in the age-specific f/mhu for third-party road users: by driver or cyclist sex, mode of travel, and time-period

In this section we present the age-specific f/mhu rates based on the number of deaths to third-party road users. Similar to the pattern for rates based on the deaths to drivers, the age-specific rates based on the deaths to third-party road users in fatal car crashes showed a U-shaped pattern with driver age. The differences by driver sex were largest amongst drivers aged 17–59 years; no significant sex differences were found in the older age groups (Table S1; Fig. 3).

The age-specific rates based on the deaths to third-party road users were higher than the rates based on the deaths to the drivers themselves within the same driver age strata, except for the oldest age category. The corresponding age-specific rates in the fatal crashes involving ≥1 cycle showed no consistent pattern with the age of cyclists involved, reflecting the lower numbers of deaths to non-cyclists in cycle crashes.

3.5.3. Differences in the age-specific f/mhu for all road users by driver or cyclist sex, mode of travel, and time-period

In this section we present the age-specific f/mhu rates based on the number of deaths to all road users (i.e. persons 'in charge' of vehicles and third-parties). For younger males especially, including the deaths to third-party road users in the numerator data accentuated the higher overall fatality rates associated with driving (Fig. 4). At middle- and older-ages, including third-party deaths reduced the absolute difference in the rates between driving and cycling. Nevertheless, the age-specific rates calculated for all road users were significantly higher for cycling than for driving among males in the middle and the oldest age bands. The pattern was similar for females, especially in the middle age bands (30–49 years), but generally the fewer number of deaths resulted in less precision for the estimates calculated within age strata.

4. Discussion

Fatality rates based on the deaths only to drivers do not accurately portray the full impact of driving on road traffic deaths. Stratifying by the sex and the age of the drivers or cyclists involved in fatal crashes, we aimed to characterise more fully the impact of driving and cycling on road traffic fatalities, by including the deaths to all the other road users in fatal car or cycle crashes. The key finding of the present study was that including deaths to all the road users in fatal car or cycle crashes increased the road traffic fatality rates considerably more for motorists than for cyclists. The higher death rates associated with male drivers aged 17–20 years shown in the present study is particularly noteworthy. Nevertheless, considering the estimates calculated for drivers or cyclists of all-ages (aged ≥ 17 years), the number of fatalities per million hours spent travelling - even when including third-party deaths - were in the region of 1.3 to 1.7 times higher for cycling than for driving.

At 2.9 deaths per 100,000 population, the UK currently has the fourth lowest road traffic death rate worldwide (WHO, 2016). Our finding of improvement in road traffic fatality rates over the nine-year study period agrees with the long-term trend documented in other highly motorised countries such as the US (Harper et al., 2015; Sivak and Schoettle, 2010; Sivak and Schoettle, 2011) and the Netherlands (Brude and Elvik, 2015), reflecting improvements in vehicle engineering, road design, road safety legislation and its enforcement, and medical technology (Centers for Disease Control and Prevention, 1999; Farmer and Lund, 2006).

Our finding of the highest road traffic fatality rates for young male drivers compared with middle- and older-aged drivers is in agreement with those from other studies conducted in Britain (Box and Wengraf, 2013; Mindell et al., 2012; Rolison et al., 2012), United States (McCartt and Teoh, 2015), France (Bouaoun et al., 2015), and the Netherlands (Institute for Road Safety Research, 2016), reflecting their higher rates of crash involvement (e.g. defined by McCartt and Teoh (McCartt and Teoh, 2015) as the ratio of the number of drivers involved in fatal crashes to the average number of passenger vehicle miles driven) linked to risk-taking behaviours and to lower levels of driving experience (Jones et al., 2015). In contrast, higher case-fatality rates due to increased physical frailty and pre-existing co-morbidity are largely responsible for the high fatality rates at older ages (Li et al., 2003).

Our finding of significantly higher all-ages road traffic fatality rates for cyclists versus drivers is in agreement with those from

other studies (Beck et al., 2007; Bouaoun et al., 2015; Elvik and Vaa, 2004; Mindell et al., 2012). In comparison with motor vehicle occupants, the increased likelihood of injury (given the involvement in a crash) probably contributes to the vulnerability of cyclists (Beck et al., 2007; Elvik and Vaa, 2004).

However, a difference in the type of road used by car drivers and cyclists is another possible explanation for the differences in fatality rates by travel mode found in the present study. The fatalities in crashes involving ≥1 car included in STATS19 occurred on any road where motor vehicles are allowed to travel: this included non-motorway roads that are shared with cyclists, as well as those that occurred on motorways that are not shared with cyclists. Department for Transport data for 2013 show that mile per mile, the risk of death on motorways in Britain was around five times lower than the equivalent figure for rural roads and three times lower than for urban roads (Department for Transport, 2015a). Of the 1775 fatalities on Britain's roads in 2014, 50% occurred on non-built-up roads (speed limits over 40 miles-per-hour (mph)) and 44% occurred on built-up roads (speed limits of 40 mph or less). Whilst containing 21% of all traffic, only 5% of road traffic fatalities occurred on motorways (Department for Transport, 2015c). The numerator data for this study covered all road crash fatalities, and the denominator data (estimated by NTS stage data) covered trips on all roads. Disaggregation of the amount of time travelled by road type is not currently possible using UK data, preventing us from restricting our analysis to the amount of time travelled on non-motorways. The higher road traffic fatality rates for cycling shown in the present study – even after accounting for the deaths to third-party road users in car crashes - therefore represent a significant overestimate of the difference between the travel modes on non-motorways.

Our finding that over half of the deaths in car crashes were to road users other than the drivers themselves lends support for the adoption of a 'safe systems approach' to road infrastructure in the UK (Scott-Parker et al., 2015). In contrast to the traditional driver-centric approach, a safe-systems approach typically aims for the development of road systems better able to accommodate human error through better management of crash energy, so that all road users are not exposed to a crash force that is likely to result in death or serious injury (Box and Wengraf, 2013; OECD, 2008). Other initiatives relevant to the prevention of crashes include the application of new technologies in vehicle construction, education in the area of road traffic safety, and the implementation and exercising of legal regulations concerning road safety (Goniewicz et al., 2016). In addition, our finding that the overwhelming majority of deaths in those multi-vehicle collisions involving at least ≥1 car and ≥1 cycle were to cyclists highlights the importance of cycling infrastructure that separates cyclists from motor vehicles (Teschke et al., 2012).

The higher road traffic fatality rates for cyclists versus drivers documented in the present study should be viewed alongside the health benefits of cycling that extend lifespan substantially more than the estimated life-years lost due to the excess risk of collision-related death (Buekers et al., 2015; Johan et al., 2010; Maizlish et al., 2017; Tainio, 2015).

Increasing levels of cycling through measures such as improvements to infrastructure would be expected to result in a relatively lower estimated per cyclist risk of injury / collision (Schepers et al., 2015). One explanation for the 'safety-in-numbers' effect (a lower risk of injury / collision at higher levels of bicycle flow) is that an increasing number of cyclists directly influences the hazardous behaviours of car drivers (Bhatia and Wier, 2011; Jacobsen, 2015).

4.1. Strengths and limitations

The present study has a number of strengths. Data from complementary sources (STATS19 and NTS) were integrated, and covered a nine-year period, enabling the examination of changes over time. Whilst the STATS19 database provides an incomplete count of road traffic incidents and casualties, it is acknowledged as an accurate source of road traffic fatalities (House of Commons Transport Committee, 2008). Travel diary data collected as part of the NTS enabled estimation of the amount of time spent travelling. This measure of exposure is more similar across travel modes with different average speeds than the distance travelled or the number of trips taken (Bouaoun et al., 2015).

Our findings must be viewed in the light of several limitations. First, although unlicensed drivers face high risk, and impose high risk on other road users, we excluded deaths to drivers aged < 17 years due to the under-recording of the denominator data. Deaths to cyclists aged < 17 years (one-eighth of cyclist fatalities over the study period) were also excluded to ensure comparability between the travel modes with respect to the age of the person 'in charge' of the vehicle. Our findings therefore can only be generalized to the population aged ≥17 years.

Secondly, the small number of cyclist fatalities, and the very small numbers of deaths of third-party road users in the fatal crashes involving ≥1 cycle, resulted in imprecision (wide CIs) despite pooling three years of annual data.

Thirdly, STATS19 contained a sizeable number of cases (6%) with missing demographic data for car drivers that were recorded as being involved, but not themselves injured, in fatal crashes. Bias could have been introduced in our comparisons of road traffic fatality rates by the sex and the age of the drivers or cyclists involved in the fatal car or cycle crashes if the probability of having missing data varied by those demographics.

Fourthly, travel exposure was estimated using self-report data, albeit with the use of a seven-day written travel diary to aid recall, possibly introducing measurement error. Any underestimation of the amount of time travelled would have resulted in an over-estimation of road traffic fatality rates. Annual response rates for the NTS are lower than ideal (55%-65%), but the analysis weights used for estimation of the denominator data included an adjustment factor to reduce the impact of non-response bias (Department for Transport, 2015b).

Fifthly, as described earlier, we could not examine the influence of road type as a potential confounder of the differences in fatality rates between driving and cycling. Finally, as in other analyses of road traffic fatalities, our analysis did not account for which person(s) was most likely at fault for the collision (Rolison et al., 2014).

4.2. Implications for analysing road traffic fatality rates

In the present study we presented a novel way of analysing road traffic fatality rates by considering the deaths to third-party road users stratified by the sex and the age of the drivers or cyclists involved in fatal crashes. A more widespread application of this method of analysis could potentially assist transport researchers and policy-makers to more accurately monitor the unequal distribution of third-party deaths by sex, age, and travel mode, and evaluate any changes over time. The Reported Road Casualties in Great Britain (RRCGB) Annual Reports provide some, but minimal, information on the number of third-party fatalities in car crashes. For example, the Summary statistics table in the 2010 report (RAS40006) showed the number of fatalities in crashes involving car drivers aged 17–24. These were disaggregated by three categories of road user: driver aged 17–24, passenger of driver aged 17–24, and other road user. Given the complex data manipulation that was necessary to perform our analyses – including the attachment of the demographics for each of the car drivers involved in the crash to the same database record as the fatal casualty - we recommend that the Department for Transport routinely provide this data across all driver age/sex groups in their annual reports. Successful application of this method beyond the UK requires greater progress in harmonising the data collected by the police on road traffic deaths. For example, the latest WHO Global Status Report on Road Safety observed that only 15 of the 43 participating African countries provided data on deaths by type of road user (WHO, 2016).

5. Conclusion

In conclusion, in the present study, we found that road traffic fatality rates were higher for young males when driving than when cycling, and at the same time, this group of drivers imposes substantially greater risk on third-party road users. Risk assessments across travel modes finding higher fatality rates for cyclists on Britain's roads should make explicit the reduced risk faced by third-party road users, and the considerable health benefits.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.jth.2017.11.143.

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