

## Title: Are head injuries to cyclists an important cause of death in road travel fatalities?

Short running title: Head injuries and cycling

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## Abstract

**Background:** Despite the well-recognised benefit for individuals and communities of increased active travel, cycling remains a minority travel mode in many high income countries. Fear of injury is often cited as a reason. Campaigns to promote cycle helmet wear are alleged to contribute to this.

However, there is little information on whether head injuries to cyclists are an important cause of death in road travel fatalities, compared with other road users.

**Methods:** We examined secondary causes of death for road travel deaths in England 2007-2012, comparing travel modes and grouped causes of death (from national mortality statistics) as numbers and as rates, using distance travelled and time spent travelling by mode, age, and sex from National Travel Surveys for the same six years.

**Results:** Head injury was the main cause of death for 269 cyclists, 1324 pedestrians and 1046 drivers, accounting for 46%, 42% and 25% of road travel deaths at all ages in each mode respectively. Head injury was the commonest cause of death in cyclists, but most pedestrian and driver fatalities were from multiple injuries. Rates of fatal head injury per bnkm in males aged 17+ for cycling, walking, and driving were 11.2(95% CI 9.7-12.9), 23.4(21.8-25.0) and 0.7(0.6-0.7) respectively. Female fatality rates were 8.8(6.2-12.0), 9.6(8.7-10.7) and 0.4(0.4-0.5) per bnkm respectively. Using time as the denominator, rates were 0.16(0.14-0.19), 0.10(0.10-0.11) and 0.03 (0.028-0.032) respectively in men and 0.10 (0.07-0.14), 0.04(0.037-0.045), and 0.01(0.012-0.016) respectively in women, per million hours travelled.

**Conclusion:** Answering the question 'How important are head injuries in cyclists as a cause of road travel death?' depends on the metric used for assessing importance. Pedestrians and drivers account for five and four times the number of fatal head injuries as cyclists. The fatal head injury rate is highest for cyclists by time travelled and for pedestrians using distance travelled.

**Word count: 300words**

**Keywords:** Head injury, Road travel fatality, Cycling, Walking, Driving, England

## 1. Introduction

Despite high levels of cycling in much of Europe, the UK appears to be less inclined to embrace cycling as a mode of travel (Wardlaw 2014). Since the 2012 London Olympics, cycling has received substantial publicity in Great Britain. However, the proportion of the population that cycle remains low and many people still hold reservations over its safety as a day-to-day form of transport (Department for Transport 2016).

The advantages of travel by cycling, both for an individual and for society as a whole, are well documented (Jarrett et al. 2012; J. S. Mindell et al. 2011). The benefits of the physical exercise that results from active travel are clear and substantial: increasing active travel in England and Wales is estimated to save the NHS £17bn in healthcare costs (Jarrett et al. 2012) through, for example, physical activity increasing bone strength and reducing the risk of cardiovascular disease, diabetes and cancers. In addition, many cyclists cite their enjoyment of cycling as a key motivation (Swiers et al. 2017). In an urban environment, cycling can also be faster than other modes and allow people to avoid traffic jams (Tranter 2012). Commuting by cycling also brings broader environmental benefits, reducing carbon emissions, lowering air and noise pollution and easing the congestion on roads and public transport (Rojas-Rueda et al. 2011).

Despite these benefits, there is still apprehension surrounding the health risks of cycling, notably cyclists' exposure to air pollution and travel-related injury. Concerns have been raised over the health consequences of cycling in heavily polluted areas, as exposure to particulate matter can result in adverse long term health consequences (Hankey et al. 2011). However, a 2011 study demonstrated that in areas with PM<sub>2.5</sub> (ultrafine particulate matter concentration) >100µg/m<sup>3</sup> – which is far higher than in most areas of the UK – the harm would exceed the benefit only after 2.25h of cycling per day (Rojas-Rueda et al. 2011). Therefore, in most – though not all (Tainio 2015) - situations, the health benefits of cycling far outweigh the risks posed by exposure to pollution.

It is important to have an evidence-based view of the benefits and risks of cycling in order to allow informed policy and personal decision-making. While it has been demonstrated that 'dangerizing' cycling through safety campaigns has little effect on peoples' short-term intention to cycle, health-focussed campaigns can have a positive impact on the perception of cycling's benefits (Gamble et al. 2015).

This study aimed to establish the degree to which concerns over the risk of fatal head injury when cycling in England are justified and compare the results with other travel modes (driving and walking). A road traffic crash is defined by WHO as 'a collision or incident that may or may not lead to injury, occurring on a public road and involving at least one moving vehicle' (WHO, 2004). For this study, we have also included pedestrians who fall while travelling, as advocated by Methorst and colleagues (2017) and Feleke et al (2018), analogous to cyclist falls and single vehicle collisions (Mindell et al., 2012); any reference to travel- or transport-related injuries or fatalities in this paper are a product of this extended definition. We have examined the medical ('secondary') cause of death among transport-related fatalities, with particular emphasis on fatal head injuries, to analyse age- and sex-specific causes of death by mode of travel, using both distance and time as indices of exposure.

## 2. Methods

### 2.1 Data

#### *Numerator data*

Fatalities with external ICD-10 (International Classification of Disease 10<sup>th</sup> version) codes indicating a travel-related death (including pedestrian falls on a highway<sup>i</sup>) for pedestrians, cyclists, and drivers were identified from national mortality data (Supplementary Table S1 shows external ICD-10 codes used). These were the same codes used in a recent study of death rates in England by travel mode (Feleke et al. 2018). For the current study, the numbers of deaths by secondary ('main') cause of death, aggregated over the six year period 2007-2012, were provided to us for each age/sex/travel mode group by staff at Public Health England.

Data on secondary cause of death were provided in aggregated form by age-group, sex, and travel mode (cycling, walking, and driving) for the grouped causes of deaths and S and T ICD-10 codes listed in Supplementary Table S2. The categories used were: fracture and other injuries to the head; brain injuries; neck injuries; thoracic injuries; abdominal, pelvic and lower back injuries; hip and thigh injuries; limb injuries; multiple fractures or crushing injuries; other multiple injuries; and other. As the number in most groups was small, these were aggregated further into 'head injuries'; 'multiple injuries'; and 'other injuries'. The number of deaths by age, sex, travel mode and secondary (main) cause of death for the initial aggregated groups and the final four groups are provided in Supplementary Table S3.

#### *Denominator data*

Data for the denominator came from the National Travel Surveys 2007-2012. The mean distance travelled each year (in miles) and time spent travelling (hours) were provided by staff in the Department for Transport, for each age/sex/travel mode groups for residents in England. Age groups used were <17, 17-20 (because of the legal requirement to be at least 17 to drive in the UK), then five-year age-groups to 75+. Population data were calculated from ONS (Office of National Statistics) population estimates from 2007 to 2012. Results shown are for all ages, except where otherwise specified.

### 2.2 Analyses

Analyses were conducted in Excel (Microsoft Office 2010). As [omitted for anonymisation] have shown, the fatality rates for each mode and most age-groups vary considerably by sex, so sex-specific analyses were conducted.

The mean annual distance travelled or time spent travelling for each mode by people in each age-sex group was multiplied by the total population of that age-sex group aggregated over the six years. Total distances were converted to kilometres and divided by one billion to obtain the total distance travelled (as billion km, bnkm) and total time spent travelling was divided by one million to obtain million hours' use (mhu) for each travel mode for each age-sex group.

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<sup>i</sup> In Great Britain, road travel injury statistics are limited to those occurring on 'a highway'. This term includes any road where it is legal for a motor vehicle to travel and does not indicate the type of road. The pedestrians included may have fallen when walking across or along a road, whether on the pavement (sidewalk) or the roadway itself.

The number of deaths in each age-sex group for each travel mode were divided by the total distance or the time spent travelling for that group, to yield fatalities per billion km (f/bnkm) or fatalities per million hours' use (f/mhu). As fatalities are rare events, we calculated 95% confidence intervals (95% CI) for Poisson parameters (Bouaoun et al. 2015; Dobson et al. 1991).

### 3. Results

#### 3.1 Number of deaths

During the six years 2007-12, 586 cyclists, 4229 drivers, and 3133 pedestrians died while travelling. 16% of cyclists, 26% of drivers, and 35% of pedestrians who died were female. Considering the causes of death among those with a road travel fatality in England, 269 cyclists died of a head injury. This compares with 1,045 drivers and 1,324 pedestrians. Figure 1 shows the numbers of deaths for each group of secondary causes, and demonstrates the large difference by sex.

**Figure 1. Cause of death in England 2007-2012 by travel mode (all ages)**



### 3.2 Proportion of deaths

The four categories shown in supplementary Tables S2 and S3 were used to assess the importance of head injuries as a proportion of all deaths to those travelling by that mode. The proportion of deaths due to head injury was very similar between cyclists and pedestrians (46% and 42% respectively, rate ratio 0.91 (95% CI 0.80-1.04, p=0.174)(Table 1). Head injuries accounted for one-quarter of deaths of drivers; more than half of drivers died due to multiple injuries, which accounted for two-fifths of deaths of cyclists and pedestrians.

**Table 1. Proportions of travel deaths by cause, mode and sex**

Cause of death	Travel mode	Males		Females		All	
		N	%	N	%	N	%
<i>Head injury</i>	<i>Cycling</i>	227	46%	42	45%	269	46%
	<i>Driving</i>	789	25%	256	24%	1045	25%
	<i>Walking</i>	902	44%	422	39%	1324	42%
Multiple injury	Cycling	195	40%	39	41%	234	40%
	Driving	1712	54%	589	54%	2301	54%
	Walking	816	40%	428	39%	1244	40%
Other injury	Cycling	70	14%	13	14%	83	14%
	Driving	643	20%	241	22%	884	21%
	Walking	326	16%	239	22%	565	18%

### 3.3 Fatality rates

When examining fatality rates in relation to distance, those for walking were more than twice as high as those for cycling for each of the three grouped causes, while fatality rates for drivers were an order of magnitude lower (Figure 2). However, when using time spent travelling as the denominator, the fatality rates for cyclists for head injury and for multiple injury were around 50% higher than the rates for walking. The difference in fatality rates for driving for each cause was less marked than when using distance as the denominator (Figure 3).

Figure 2. Fatality rates by distance for causes of death and travel mode, aged 17+

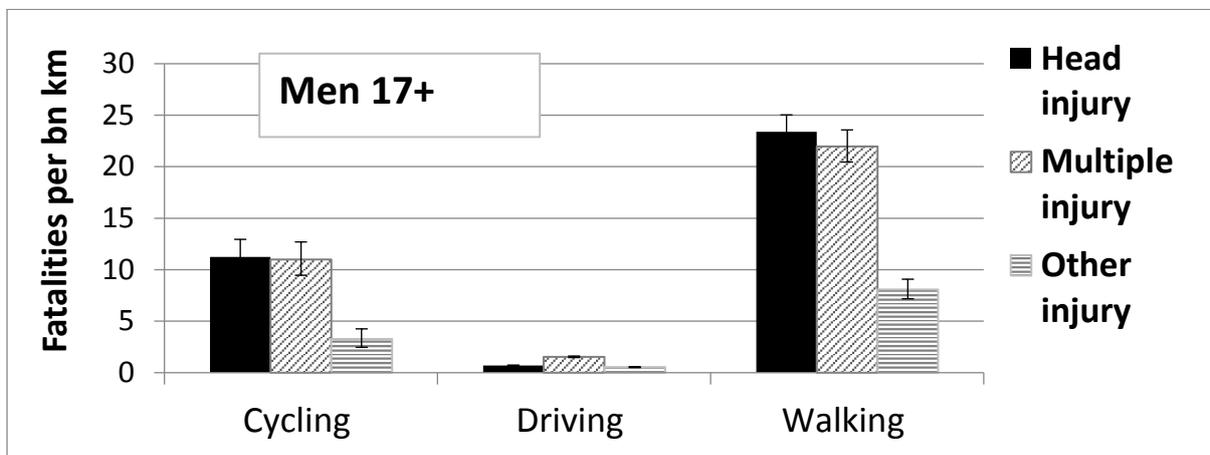
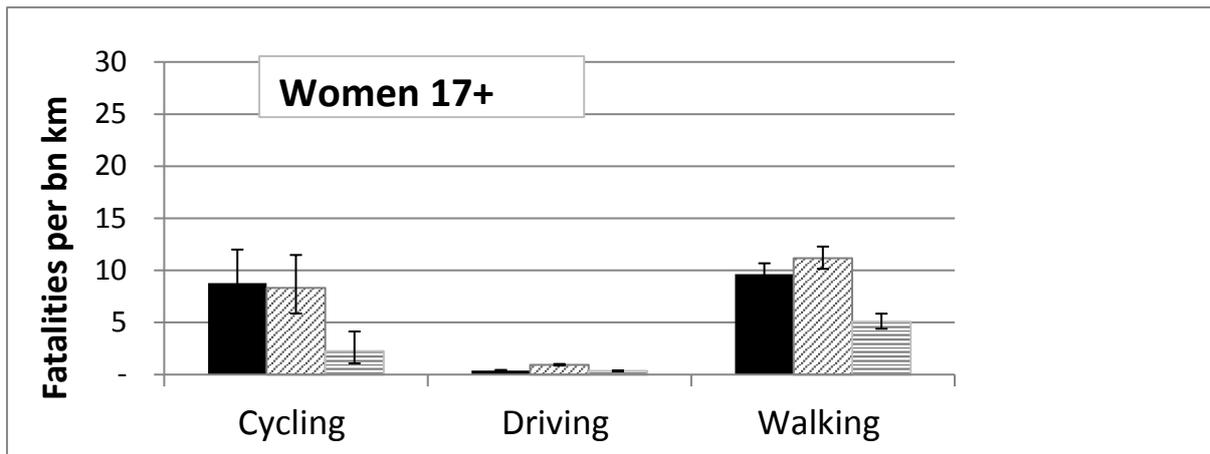
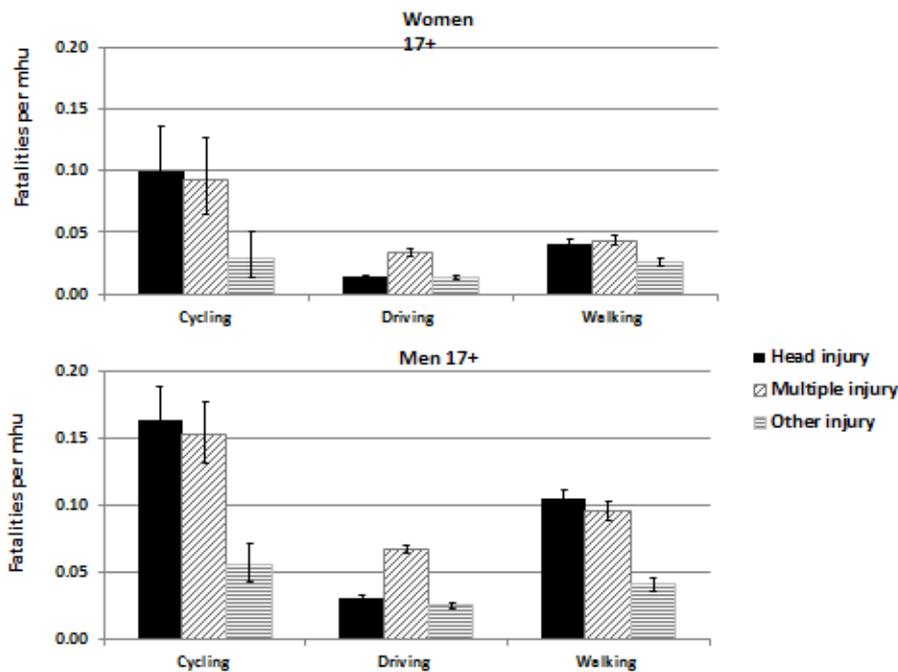
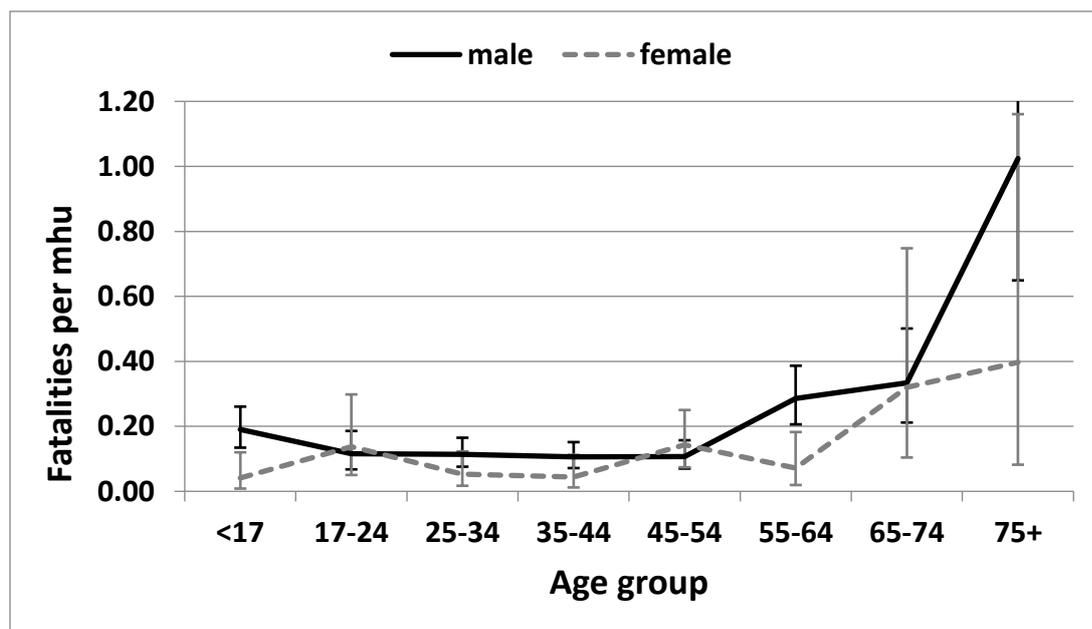


Figure 3. Fatality rates by time spent travelling, for causes of death and travel mode, aged 17+



There was little difference in the rate of head injury fatalities by time spent travelling by age or sex, except for a marked increase in men aged 75+, but the confidence intervals were wide for older cyclists (Figure 4). Rates by age and sex for other travel modes and secondary causes of death are shown in supplementary data Tables S4 (for fatality rates by distance travelled) and Table S5 (for fatality rates by time spent travelling).

Figure 4. Fatal head injury rate by time spent travelling among cyclists of all ages



## 4. Discussion

### 4.1 Strengths

This study uses a similar method to that used by Mindell et al 2012 and Feleke et al (2018) to identify secondary causes of death among people fatally injured while travelling as cyclists, drivers, or pedestrians. Strengths include the use of complete national data for numerators, as road travel fatalities are considered complete, and nationally-representative data for the denominators for rates. Using the two different denominators of distance and time travelled reduces the distorting effects of factors such as long distance car journeys and different level of use of different modes. In addition, we included pedestrian falls, to maintain comparability between modes (Methorst et al. 2017) as cyclist falls and single vehicle collisions are included in road travel injury statistics.

### 4.2 Limitations

The study has a number of limitations. The low numbers of fatal injury among cyclists, even over a six-year period, means a greater level of uncertainty and wider confidence intervals, particularly among women of all ages and elderly people. Although analyses of cause of death used ICD-10 codes, a considerable proportion of the head injuries were coded using non-specific codes, identifying the cause of death as head injury but without specific codes. Similarly, the group categorised as multiple injuries included many with the 'dustbin coding' of 'other multiple injuries'. We changed our initial attempts to use more, specific categories for injuries of different types or to different body areas because each of these categories comprised few fatalities (Table S2). These data are affected by 'dustbin coding', where a broad or vague ICD-10 code is chosen when the true cause of death is unknown to the coder or is complicated. The category 'other multiple injuries' is formed largely from fatalities coded as T07 'unspecified multiple injuries'. This likely includes various fatalities which could have been accounted for elsewhere. For driving, our data identify only harm to drivers, which fails to account for injury to passengers and third parties; cycling and walking are rarely a risk to others (Scholes et al. 2018). Nor did we have data on the vehicle type involved in fatal collisions, when fatalities involved other road users. This study excluded non-fatal injuries as, even if limited to serious injury (defined as resulting in hospital admission), it is not known whether travellers using different modes are equally likely to be taken to and admitted to hospital for the same severity of injury. One survey of a non-random sample of almost 5,000 cyclists found that more than half reported having had a cycling-related injury in the previous five years; the 5,880 injuries included 842 head injuries (Hollingworth et al. 2015).

As has been discussed elsewhere (J. S. Mindell et al. 2012);(Ref A), the discrepancy in fatality rates between drivers and others, using either denominator, is exaggerated as the furthest distances and longest duration trips are driven on motorways, which have fatality rates five- to nine-fold lower (Department for Transport 2016), thus underestimating the rates for drivers on general purpose roads, where walking and cycling occurs. There was probable overestimation of the distances travelled and time spent travelling in the oldest two age groups because the denominator was based on the population of England but the National Travel Survey covers only the free-living general population; it is likely that those in hospital or residential care walk less, and are unlikely to be cycling or driving very much, on average, thus the markedly higher fatality rates in the oldest travellers could be an underestimation.

### 4.3 Comparison with others

A study in Victoria, Australia, found death rates from head injuries in 1990 were 0.19/mhu for cyclists, 0.34/mhu for pedestrians, 0.17/mhu for motor vehicle occupants (drivers and passengers

combined) and 2.9/mhu for motorcyclists (D. L. Robinson 1996b). These are slightly higher than our findings for cyclists England in 2007-12 of 0.16/mhu (95% CI (0.14-0.19/mhu)) and much higher than our results for pedestrians (0.10/mhu (0.097-0.112/mhu)) or car drivers (0.03/mhu (0.028-0.032/mhu)).

Head injuries accounted for 46%, 43%, 36% and 38% of road travel fatalities respectively in the four travel modes in Victoria in 1990 (D. L. Robinson 1996b). For cyclists and pedestrians, these are almost identical to our findings of 46% and 44% respectively. However, head injuries caused a smaller proportion of deaths (25%) of car drivers in our study. Whether this reflects differences between injuries to car drivers compared with other motor vehicle occupants or differences in the circumstances of the crash and/or subsequent healthcare cannot be determined in this study. In the USA, however, three-quarters of cycling fatalities around the 1980s were due to head injuries (Thompson et al. 1989).

There are few studies that have examined fatal head injuries by travel mode, so we also considered the published literature on non-fatal head injuries. Hospital admission rates for head injuries were 2.2/mhu for cyclists, 2.0/mhu for pedestrians, 1.6/mhu for motor vehicle occupants and 18.0/mhu for motorcyclists in Victoria in 1990 (D. L. Robinson 1996b). In Sweden, 20% of people aged 16-64 who had specialised or inpatient treatment after a cycle crash then took sickness absence for more than 14 days; traumatic brain injury accounted for 1.4% of those receiving such healthcare and 15% of people taking more than 180 days of sickness absence (Ohlin et al. 2018). Our study did not examine non-fatal injuries, for which the data are much less complete – and currently exclude pedestrian falls for official road casualty statistics.

## 4.4 Policy Implications

### Potential benefits of active travel, relative to potential harms

From a public health policy perspective, the benefits of increased physical activity outweigh the harms from injury and air pollution by an order of magnitude (Doorley et al. 2017; Johan de Hartog et al. 2010; Rojas-Rueda et al. 2011).

### Injury prevention

DL Robinson (1996) pointed out that 17 times as many motor vehicle occupants as cyclists died from head injuries in Victoria in 1988. This figure depends on both the risks by travel mode and the relative number of travellers by each mode. Compared with cyclists, our figures for 2007-2012 equate to four times as many drivers and five times as many pedestrians dying from head injuries. It should be noted that seatbelt wear, which reduces head injury rates among car occupants in a collision, has probably increased since 1988. DL Robinson (1996) commented that mandatory helmet laws for motor vehicles could prevent at least 17 times as many lives as mandatory cycle helmet laws, and conceivably considerably more, given the marked reduction overall in cycling since the law was implemented (with implications for physical activity) and diversion of road safety funding and enforcement to focus on helmet wear enforcement rather than poor or dangerous driving and cycling (D. L. Robinson 1996b).

There is much contention around the safety of cycling on roads and on the role of protective equipment such as helmets, and in what circumstances they may be helpful (Bambach et al. 2013; Goldacre and Spiegelhalter 2013; Karkhaneh et al. 2013; B. Robinson 1996a). Safety concerns appear to play a large part in people's decision of whether or not to cycle (Swiers et al. 2017). For example, in the Department for Transport's 2014 survey, 64% of respondents agreed that it is too dangerous for them to cycle on road (DfT 2015). Many campaigns attempt to communicate the risks of cycling

and encourage the use of protective equipment to prevent or minimise injury (Gamble et al. 2015). The efficacy of high-visibility clothing (Miller et al. 2017) and protective equipment and the extent to which the latter should be the subject of legislation or indeed exhortation has been much debated. While a legislative approach in Italy mandating visibility aids for cyclists had no effect (Prati 2018), a randomised controlled trial in Denmark showed that a yellow cycle jacket reduced the collision and personal injury rates (Lahrmann et al. 2017).

This debate, while important, is beyond the scope of this study. The data in this study demonstrate the rate of fatal head injury by mode of travel but cannot differentiate by the use of protective equipment. Nor can it distinguish differences between fatality rates according to the behaviour and risk-taking of travellers, which may vary systematically between those who choose to use or not use protective equipment (Bambach et al. 2013). A survey of cyclists found no effect of helmet wear on sustaining a head or facial fracture; it did find lower odds of being admitted overnight with a head injury among helmet wearers – but an even lower odds ratio for them of overnight admission for a back/spinal injury (Hollingworth et al. 2015).

The evidence for the benefit of helmet-wearing while cycling is disputed, both regarding efficacy at an individual level and the balance of population health benefits of mandating or encouraging helmet use (Goldacre and Spiegelhalter 2013). Although a recent systematic review found a 65% reduction in fatal head injury among cyclists who were wearing a helmet (Olivier and Creighton 2017), case control studies cannot distinguish between the effect of the helmet and differences between people who choose to wear or not wear a helmet. It is difficult to assess the underlying likelihood of being involved in a crash or being injured: ‘risk compensation’, where those wearing protective clothing are postulated to take more risks, might increase the risk of a crash among helmet-wearers, whereas the ‘risk-aversion’ theory suggests that those wearing helmets, when it is not universal (even if mandated), are more likely to be cautious and may have a lower crash risk. Even if helmets do provide some protection, this will depend on the circumstances, and not all types of head injury will be prevented. For example, a cycle helmet is unlikely to prevent fracture of the nasal bones or base of skull or crushing injuries of the head. A post-mortem study concluded that 37% of fatally injured Czech cyclists could have survived had they been wearing a cycle helmet, primarily among cyclists who fell off their bicycle and were not in a collision with a motor vehicle or train (Bil et al. 2018).

It is not possible to ascertain the number of fatal head injuries in cyclists that might have been prevented by helmet use. First, there is no information in these administrative datasets on whether or not a helmet was being worn. Secondly, 75% of deaths due to head injury in cyclists (77% in drivers, 60% in pedestrians) had a non-specific ICD-10 code (S019, S029, S069, S079, S099), which prevents consideration of whether there were any grounds for believing that a helmet could have prevented that injury. It should also be noted that many studies refer to ‘cyclists’ and do not distinguish those cycling for travel from those engaging in off-road or BMX biking, for which the risks of injury and the effects of helmets are probably different. Finally, there were no data available for this study on use of a helmet nor of a seatbelt. In England, almost all drivers wear a seatbelt most or all of the time; this will have reduced their head injury rate in the event of a collision. While a large proportion of cyclists in England wear a helmet most of the time, those who choose to wear or not wear a helmet probably differ systematically; there is no information on which group has the higher risk of being involved in a fall or collision.

### Perceptions of danger

The rates and numbers of head injury fatalities clearly show a discrepancy between public perception of the dangers of cycling and the reality. Media coverage on cycle fatalities is disproportionate both to the absolute risk and relative to other road travel fatalities (MacMillan 2016), which may exacerbate the existing known difficulties in understanding risks and rates (Reyna and Brainerd 2008).

Rates of fatal head injury among cyclists remain very similar to that of walking; cycling is far from the leading cause of travel-related fatal head injury. Focussing on road safety for cyclists understates the danger to pedestrians. If the focus is to reduce travel-related fatal head injuries, pedestrians would be the group on which to focus most effort.

### Road danger reduction

Although devastating for those involved, the number of cyclists suffering a fatal head injury is very low. If campaigns are successful in reducing the perceived risk of harm and more people start to cycle, more people could become injured and therefore it would become a greater public health issue. However, this is debatable as there appears to be a pattern of safety in numbers with walking and cycling: the more pedestrians and cyclists there are, the safer walking and cycling is. This could be due to drivers becoming more aware of cyclists and a greater political will to improve conditions for cyclists, or to the conditions that lead to greater numbers of pedestrians and cyclists being those that reduce road danger (J.S. Mindell 2017).

The best way to reduce fatal and non-fatal injuries is to reduce road danger (Hine and Tight 2017), rather than reducing exposure (less walking and cycling) or mitigating the consequences of collisions or falls. The trend towards transport planning that puts pedestrians then cyclists at the top of the road user hierarchy (Department for Transport 2004) should help, particularly with improved junction design and better training of drivers of large vehicles, as well as improved vehicle design to increase the drivers' ability to see cyclists (Talbot et al. 2017). 74% of all cycle collisions in London occurred at junctions (Talbot et al. 2014). England is fortunate compared with many high and low income countries in having pavements [sidewalks] on most roads streets, except in rural areas, but better pavement quality and maintenance is required to reduce the number of pedestrian falls.

## 4.5 Conclusions

The answer to the question 'Are head injuries to cyclists an important cause of death in road travel fatalities?' is 'it depends'. If the intention is reduce the number of fatal head injuries, the focus should be on pedestrians and drivers, who account for five and four times as many deaths respectively from head injuries as cyclists. Overall, fatality rates from head injuries are no more important in cyclists than in pedestrians, depending on whether time or distance is used as the denominator. If the focus is to reduce the fatality rate from head injury – or indeed from any other type of road travel injury – then road danger reduction for all road users should be the goal.

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