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Drivers overtaking bicyclists: Objective data on the effects of riding position, helmet use, vehicle type and apparent gender

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Abstract

A naturalistic experiment used an instrumented bicycle to gather proximity data from overtaking motorists. The relationship between rider position and overtaking proximity was the opposite to that generally believed, such that the further the rider was from the edge of the road, the closer vehicles passed. Additionally, wearing a bicycle helmet led to traffic getting significantly closer when overtaking. Professional drivers of large vehicles were particularly likely to leave narrow safety margins. Finally, when the (male) experimenter wore a long wig, so that he appeared female from behind, drivers left more space when passing. Overall, the results demonstrate that motorists exhibit behavioural sensitivity to aspects of a bicyclist's appearance during an encounter. In the light of previous research on drivers' attitudes to bicyclists, we suggest drivers approaching a bicyclist use physical appearance to judge the specific likelihood of the rider behaving predictably and alter their overtaking accordingly. However, the extent to which a bicyclist's moment-to-moment behaviour can be inferred from their appearance is questionable, and so the tendency for drivers to alter their passing proximity based on this appearance probably has implications for accident probability.

Keywords: Bicycles; Pedal cycles; Overtaking; Bicycle helmets; Gender; Naturalistic experiment

1. Introduction

Collisions as motorists overtake bicyclists seem to be disproportionately dangerous. In a British study of almost 5000 bicyclists, this type of collision accounted for less than 4% of the accidents that bicyclists reported having experienced, yet it comprised almost 13% of the officially recorded bicycle accidents in the same region for the same time period, showing that these collisions, when they do happen, are particularly likely to draw police attention (Walker and Jones, 2005). Similarly, Transport for London (2005) found collisions during motorists' overtaking manoeuvres were the single greatest cause of bicyclist fatalities in their recent survey. The high level of severity in incidents between pedal cyclists and drivers travelling in the same direction presumably derives from velocities being greater than in junction accidents, where vehicles have slowed to manoeuvre.

However, serious as bicyclist overtaking collisions are, very little is known about their causes because research to date has understandably tended to focus on the more frequent junction-based collision (e.g., Hills, 1980; Höger et al., 2005; Moray, 1990; Räsänen and Summala, 1998; Walker, 2005a,b). As described below, we do have some post hoc information on the general circumstances of overtaking accidents from analyses of police reports, and one experiment has used a driving simulator to explore events in the run-up to overtaking. However, at present practically nothing is known about what happens when overtaking manoeuvres take place. This paper therefore presents behavioural data to address several unanswered questions relating to drivers' overtaking behaviours around bicyclists.

1.1. Analyses of official accident reports

Large-scale accident data surveys have been carried out in the United States by Cross and Fisher (1977), in New Zealand by Atkinson and Hurst (1983), and in the United Kingdom by Stone and Broughton (2003). Their findings have tended to be relatively consistent, providing us with a useful picture of how bicyclists' accidents happen. They confirm that collisions from cars moving in the same direction as bicyclists are particularly likely to lead to serious injury (Stone and Broughton, 2003),

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although this is often the result of shunts from behind, as well as collisions during passing itself. They also draw a distinction between same-direction collisions which involve bicyclist behaviour, as when a rider moves out into a motorist's path, and same-direction collisions which do not involve bicyclist behaviour, as when a rider who is travelling straight ahead is struck by a driver getting too close whilst passing (Cross and Fisher, 1977).

Recently, we noted consistent age and gender differences in this latter form of overtaking accident and argued that drivers' overtaking manoeuvres must therefore vary in safety as a function of a bicyclist's appearance and riding style (Murphy Jones and Walker, submitted for publication). Accordingly, the approach of the present study was to manipulate a bicyclist's visible behavioural characteristics and look for correlated changes in driver overtaking behaviour.

1.2. Overtaking manoeuvres and their relationship with rider and vehicle characteristics

> "The more room you take up, the more space cars leave for you! Broadly speaking, cars will leave you as much room as you leave yourself so keep out from the edge of the road about the same distance you want cars to keep out from you." (Martin, 1998)

As this remark nicely illustrates, veteran bicyclists frequently report the experience of receiving more overtaking leeway from motorists when riding away from the edge of the road. Accordingly, the practice of riding relatively medially is often used – and recommended to novices – as prophylaxis against overtaking collisions (e.g., Ballantine, 2000; Department for Transport, 1999; Franklin, 1997; Walker and Jones, 2005). However, there are no behavioural data to tell us whether it is really true that the space drivers give bicyclists increases as the bicyclists' distance from the road edge increases. One study used a virtual reality environment to show that drivers exhibited more changes of speed as they approached a bicyclist riding in the centre of a lane rather than at the edge, a behaviour the authors took to indicate lower levels of driver 'confidence' around the more central bicyclist (Basford et al., 2002). But as well as being simulated – and considering only two extreme riding positions – that study looked at the run-up to the passing manoeuvre rather than the manoeuvre itself, and so does not tell us about the relationship between riding position and drivers' safety margins as bicyclists are actually overtaken.

Their simulator data notwithstanding, the study by Basford et al. (2002) was primarily an exploration of drivers' attitudes to bicyclists, and one of the many interesting findings to emerge was that drivers frequently believe bicyclists wearing helmets are more serious, sensible and predictable road-users than bicyclists without helmets. Basford et al.'s data therefore show that the decision to wear a helmet affects drivers' perceptions of bicyclists in a way that could plausibly lead to behavioural changes, such as a greater propensity to overtake with narrow safety margins. However, although this certainly seems to tally with bicyclists' anecdotal reports, there are again no behavioural data to tell us whether it is really the case or not. Helmet use in the United Kingdom showed an increasing trend over the 1990s until almost 22% of all cyclists on major roads were observed wearing a helmet in 1999 (Towner et al., 2002). Therefore, the idea that helmet use might change drivers' behaviour in a way that could affect bicyclists' safety is one that definitely requires attention.

Vehicle type is a third putative factor in overtaking risk. Our recent large-scale survey of bicyclists found that some vehicles – most notably buses – seemed over-represented in bicyclists' self-reports of collisions during overtaking manoeuvres (Walker and Jones, 2005), a finding supported by a subsequent analysis of police accident data (Murphy Jones and Walker, submitted for publication). If it were found that certain vehicle types consistently overtook bicyclists more dangerously than average, particularly if the vehicles were those associated with professional drivers, such as buses, then this would be valuable information for targeting educational interventions towards the drivers, warning them that they are getting closer to bicyclists than they might think and urging them to leave additional room.

This study therefore had two main purposes. First, it sought to measure the specific effects of the three issues identified above (rider positioning, helmet wearing and vehicle type) which, based on previous work, might plausibly influence driver overtaking behaviour but on which we have no empirical data at present. Second, it asked a more general theoretical question about the extent to which motorists exhibit behavioural sensitivity to the vulnerability of other road users. Appropriate behaviour in potentially dangerous situations relies upon an accurate perception of risk (Trimpop, 1994). This is particularly the case in traffic, where each encounter can vary dramatically in its potential for harm. However, the extent to which motorists actually demonstrate any sensitivity to other road users' vulnerability is unknown. Any relationship between the experimental manipulations used here and changes in driver behaviour will provide a useful guide to the extent to which motorists, in the few seconds it takes for an on-road encounter to unfold, assess the vulnerability of another road-user and adjust their behaviour in light of this assessment.

The only really feasible way to collect reliable data on the topics of interest here was to work in vivo, in order that drivers' natural behaviour was recorded, unaffected by factors such as a laboratory setting or the knowledge they were being observed. It was also necessary to collect a large amount of data in order that influences specific to each event and location averaged out to allow the effects of the experimental manipulations clearly to be seen. The leeway given by an individual motorist in a particular overtaking incident will have a vast range of influences. Given this complexity, the factors studied here were only ever going to account for a relatively small amount of variance in drivers' overtaking leeways. Nevertheless, it is still useful to quantify the effects of these factors over the noise. If the variables considered here reliably account for even a small proportion of variance in overtaking behaviour then, given that there are many millions of bicycle overtaking events around the world every day, any improvement in our understanding of how overtaking collisions occur has the scope to help prevent some of them taking place.

Only one previous study has measured overtaking proximities in vivo, done as part of an effort to relate the subjective experience of using roads to objective measures of their conditions (Guthrie et al., 2001). However, as well as using a relatively basic method for measuring overtaking proximities, relying on height in a video frame as an index of passing distance, that study did not seek to explain variations in overtaking proximities and so the present experiment is, to the best of our knowledge, the first to do this.

The author, who collected the data, is male. However, people with whom the project was discussed often asked the same thing: what would happen if the rider were instead female? This is an important question. Given that women and men tend to be involved in different types of accident when cycling (Walker and Jones, 2005; Murphy Jones and Walker, submitted for publication), and given the aforementioned idea that drivers vary their overtaking behaviour as a function of other road-users' perceived vulnerability and behavioural predictability, there are grounds for believing that there might be differences in how women and men are treated by overtaking motorists. Just as drivers thought helmet-wearing bicyclists were more sensible and predictable, and so were hypothesized to overtake such riders with narrower safety margins (Basford et al., 2002), women might consistently be seen as less likely to behave erratically than men, or vice-versa, with corresponding effects on overtaking proximities. A set of additional data was therefore collected at the end of the study with the short-haired male rider either looking normal or wearing a long feminine wig, in order that he appeared to be a woman to drivers approaching from behind, thus allowing a direct analysis of whether there were any effects of a bicyclist's apparent gender on drivers' overtaking leeways.

2. Method

2.1. Materials

A Trek hybrid bicycle was fitted with a Massa M-5000/95 temperature-compensated ultrasonic distance sensor with its centre 0.77 m from the ground, facing perpendicularly to the direction of travel and feeding into a laptop computer running MultiLab software via a MultiLog Pro data-logger sampling from the sensor at 50 Hz. The computer simultaneously received input from a video camera mounted on the handlebars. A laser pointed to the ground on the rider's left and could be adjusted to mark various distances from the bicycle's centreline, thus allowing the rider to maintain relatively fixed paths from the edge of the useable roadway. The equipment was concealed from passing motorists by a pair of ordinary panniers and, in the case of the camera, the rider's body. A white Giro helmet was worn for part of the study.

2.2. Procedure

The author rode 320 km at various times of day between 07:00 and 18:00 in May and June 2006 within the English cities of Salisbury and Bristol wearing everyday clothing of shirt and trousers. The choice of clothing – along with the type of bicycle, the use of panniers and the rider's age (32) – would be consistent with the overall appearance of a commuter/utility bicyclist; this struck the middle-ground in terms of apparent rider 'seriousness', between a racy "professional" rider on the one hand and a young "stunt cyclist" on the other (Basford et al., 2002).

A broad variety of roads was included, including radial routes, city-centre streets and suburban roads, with journeys comprising mixtures of roads typically to be found on utility trips. Originally the intention had been also to measure the association between lane width and overtaking behaviour, as narrow lanes might reasonably encourage closer overtaking if drivers seek to avoid crossing the centre-line (Goodridge, 2006). However, it quickly became apparent that this was not practical when collecting data with high ecological validity since lane width varies constantly, particularly as a function of parked cars, traffic islands, etc. We therefore chose instead to look at effects of absolute positioning rather than relative positioning, averaging out any lane-width effects by collecting observations over many sites. We believe this decision also provided more practically useful data since understanding the effects of absolute road position (i.e., position relative to the edge) on overtaking behaviour is better for bicyclists, who can judge where they are in relation to a road's edge with more ease than where they are in relation to a road's whole width. Future work in more contrived environments might look at how our findings on absolute position translate to relative position, and we return to issues of traffic lanes in Section 4.

Maintaining a speed of 17–20 kph wherever possible, the author rode at a fixed distance from the edge of the useable road (i.e., the physical edge, or the outermost edge of parked cars where these were present), and every few kilometres this distance, and the presence or absence of the bicycle helmet, was altered. The distance from the kerb was either 0.25, 0.50, 0.75, 1.00, or 1.25 m. Afterwards, the video record was analysed to record the description and minimum proximity of each overtaking vehicle, as well as the rider's position and helmet state at the time. Proximity data were calculated from the rightmost point of the bicycle, in order that a measure of 0 m equated to the point at which a collision would occur (Table 1).

On roads with two parallel lanes for traffic travelling in the same direction, events were only counted when a vehicle definitely overtook; motorists who were simply travelling in the other lane were ignored. Overtaking events were also discounted if the bicyclist was manoeuvring at the time or if the motorist's path might have been influenced by something other than the presence of the bicyclist, for example, the need to pass parked cars ahead. As such the dataset contained only overtaking events in which motorists were definitely overtaking the bicyclist with no obvious external influences on their behaviour.

Table 1
Number of overtaking events per condition

	Distance from road edge (m)					
	0.25	0.50	0.75	1.00	1.25	Total
Helmet	426	270	153	197	160	1206
No helmet	244	275	186	272	172	1149
Total	670	545	339	469	332	2355

For the subsidiary gender analysis, 281 additional overtaking events were recorded by riding up and down a 1.25 km stretch of radial road in Salisbury over two days at a fixed distance of 0.75 m from the road edge. The same set of clothes was worn throughout, chosen to appear appropriate for either gender when seen from behind. After each journey up and down the road, a long feminine wig was either donned or doffed as necessary and the journey immediately began again. This tight control, with the bicyclist, the riding style, the riding speed, the clothes, the riding position and the street all held constant, meant that the experimenter's behaviour and appearance were comparable across all the trials with the only difference being that he looked more like a woman to some of the drivers approaching from behind and more like a man to others.[1]

3. Results

The overtaking events in the dataset had minimum passing proximities ranging from 3.54 m to somewhat less than 0 m.[2] As would be expected given the greater scope for distances to vary above the mean than below, there was positive skew in the distribution which was successfully corrected to normal throughout the analyses with square-root transformation. All other assumptions of the analyses were met.

Thirty-five observations (1.5% of the sample) were dropped from the dataset after being identified as extreme outliers in SPSS exploration, leaving data from 2320 overtaking events; a priori analysis with G*Power (Buchner et al., 1997) had identified 2259 as the number necessary reliably to identify a 'small' effect size of $f = 0.1$ in this design with $\alpha = .05$ and $\beta = .02$. An initial analysis suggested no particular differences between the two cities and so all data were analysed together. Moreover, during data processing a check was made on situations where several vehicles overtook the bicycle in close sequence, and there was no tendency for the vehicles in these sequences all to pass at similar distances; the proximity of each overtaking event was independent of those around it.

3.1. *Effects of riding position and helmet*

The mean overtaking proximities, as a function of riding position and helmet-use, are displayed in Fig. 1. It can clearly be seen, contrary to the general belief described in Section 1.2, that riding further out from the edge of the road was associated with a reduction in drivers' overtaking leeways rather than an increase. An analysis of variance (ANOVA) on these data found significant main effects of Riding Position ($F_{4,2313} = 42.39$, MSE = 0.02, $p < .001$) and Helmet ($F_{1,2313} = 8.71$, MSE = 0.02, $p = .003$) but no interaction between the two ($F_{4,2313} = 1.15$, MSE = 0.02, $p = .33$). The helmet effect was caused by proximities generally being lower with a helmet than without. The overall effect size for this ANOVA was $R^2 = .08$. That the two factors of riding position and helmet use account for as much as 8% of the variance in such a complex, multidimensional phenomenon as driver overtaking is rather impressive.

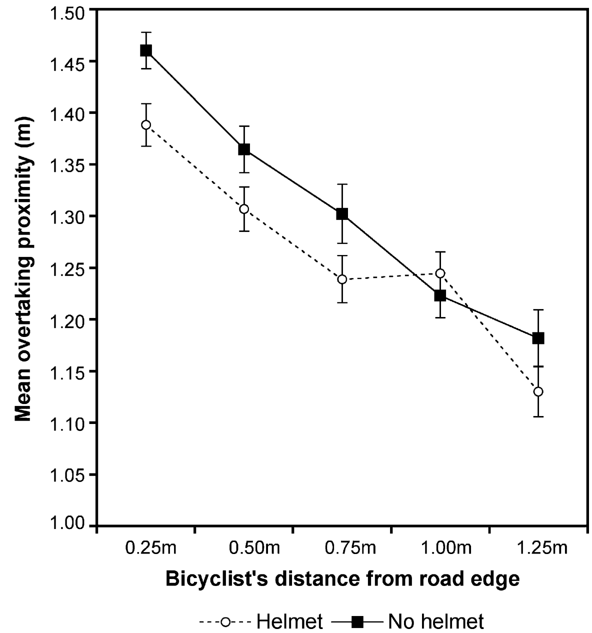

Fig. 1. Mean overtaking proximities as a function of the bicyclist's riding position and helmet-wearing. Bars indicate standard errors of the mean. (○): Helmet; (■) no helmet.

The above ANOVA notwithstanding, there is a more meaningful way to analyse the data obtained in this study which acknowledges the fact that the distribution of overtaking proximities was Gaussian, i.e., most overtaking events were at medium distances. Because our primary aim here is accident analysis, it is not the average bulk of events at medium proximities that really concerns us; rather we are interested in the events where overtaking proximities were particularly close, as it is these that are likely to lead to collisions. Another analysis was therefore carried out to see whether riding position and helmet use were associated with the likelihood of observing particularly low overtaking proximities.

The dataset was divided at Tukey's Hinges and a comparison made between the top and bottom quartile, i.e., between the set of overtaking events with the smallest leeways and the set with the greatest leeways. For the sake of exposition we will refer to these as 'near' and 'far', respectively. Incidentally, please note that whereas the data below are calculated with the bottom quartile and the top quartile, we also repeated the analysis with the bottom quartile and the next-to-bottom quartile, to ensure that we were not getting distorted findings by comparing the very nearest events with the very furthest. This produced results comparable to the analysis below, confirming that the effects we show here are primarily caused by characteristics of the nearest events rather than of the furthest.

[1] We are aware that the relationship between gender and hairstyle is imperfect. However, in the country where this study was carried out the hairstyle represented by the wig would be strongly associated with a woman rather than a man, and the fact that effects emerged demonstrates that the manipulation worked.

[2] The author was struck twice by overtaking vehicles, once by a bus and once by a heavy goods vehicle—the latter inflicting minor injury. On both occasions a helmet was being worn. As proximity data were unreliable for these events they were removed from the data set. However, it is interesting to note their occurrence in light of the vehicle type analysis presented below.

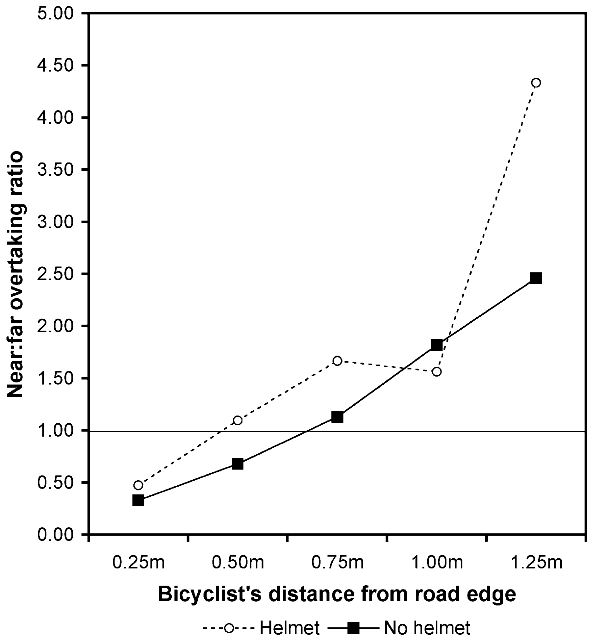

Fig. 2. Ratio of particularly close to particularly distant overtaking events as a function of the bicyclist's riding position and helmet-wearing. The horizontal line marks the division between conditions where overtaking was predominantly safe (below the line) and conditions where overtaking was predominantly dangerous (above the line). (◯): Helmet; (■): no helmet.

For each of the ten conditions, the near:far ratio was calculated. A score less than 1 meant a condition was more likely to be associated with far events than near events, and a score greater than 1 meant a condition was more likely to be associated with near events than far events. In simple terms, then: the higher the ratio, the more dangerous that condition was.

These ratios are displayed in Fig. 2, showing that as riding position shifts from the road edge towards the road centre, the likelihood of experiencing near overtaking events rather than far overtaking events increases, in line with the findings of the above ANOVA. Also in line with the ANOVA, near overtaking events were more likely to be experienced than far overtaking events when a helmet was being worn, and this effect became more pronounced as riding position moved away from the road edge, reaching a peak for the 1.25 m condition in which there were 4.33 times as many near events as far events when a helmet was worn. This helmet effect was not seen in the 1 m riding position, in which overtaking was no more likely to be near than far when a helmet was worn.

Stepwise binary logistic regression was carried out on these data to predict group membership (near events or far events) from helmet use and riding position and any interaction between the two. Helmet use and riding position correctly categorized 65.2% of events into one of the two groups ($p < .001$, Nagelkerke pseuo-$R^2 = .16$). Both helmet use (odds ratio = 1.41, 95% CI = 1.10–1.80, $p = .007$) and riding position (odds ratio = 7.08, 95% CI = 4.97–10.09, $p < .001$) were significant predictors of an event's group membership whereas the interaction between the two factors was non-significant and so not included in the overall model reported above (odds ratio = 0.76, 95% CI = 0.37–1.54, $p = .44$). Given that the dependent variable had been coded as 1 = near and 0 = far, the odds ratio for the helmet effect indicates that putting the helmet on increased the odds of overtaking events being near rather than far by a factor of just over 1.4. Similarly, the riding position odds ratio indicates that increasing the distance from the road edge by 1 m increased the odds of overtaking events being near rather than far by a factor of over seven.

3.2. Vehicle characteristics

The overtaking vehicles were classified as (1) ordinary cars, (2) light goods vehicles and minibuses, (3) sports utility vehicles and pickup trucks, (4) buses, (5) heavy good vehicles and (6) taxis. (Powered two-wheelers were another category but are omitted here as there were too few for meaningful analysis.) The mean overtaking proximities for each category are shown in Fig. 3.

An ANOVA on these data revealed a significant effect of vehicle type on overtaking proximity ($F_{5,2284} = 10.31$, MSE = 0.02, $p < .001$). Tukey's HSD tests showed that buses and heavy-goods vehicles passed significantly closer than ordinary cars (both $p < .001$), light-goods vehicles (both $p < .001$), and sports-utility vehicles (both $p < .001$). No other comparisons were significant. Overall, the key finding here is a clear suggestion that professional drivers of large vehicles pass bicyclists closer on average than the drivers of private 'domestic' vehicles.

Similarly, a binary logistic regression predicting near v. far group membership from vehicle type found that overall, vehicle type predicted only 56.6% of overtaking events into the correct category with Nagelkerke pseudo-$R^2 = .05$. However, these figures belie an asymmetry, as whilst the model was poor at predicting near overtaking events from vehicle type (28.8%

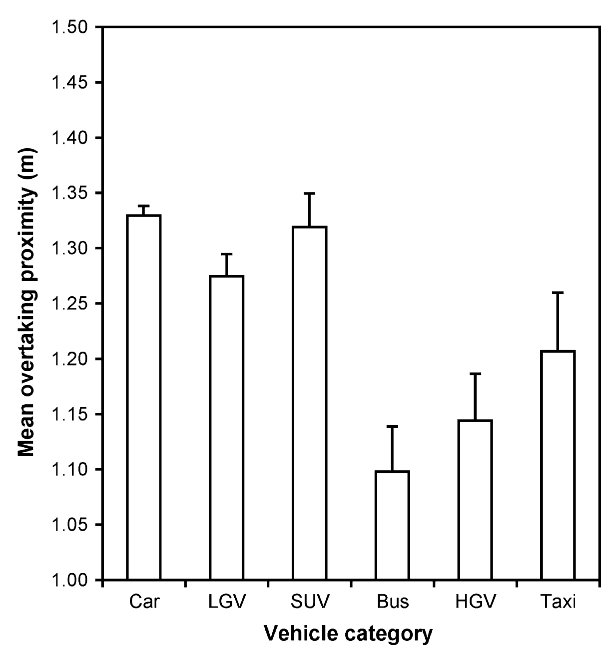

Fig. 3. Mean overtaking proximities as a function of overtaking vehicle type. Bars indicate standard errors of the mean. LGV: light-goods vehicle/minibus; SUV: sports utility vehicle/pickup truck; HGV: heavy-goods vehicle.

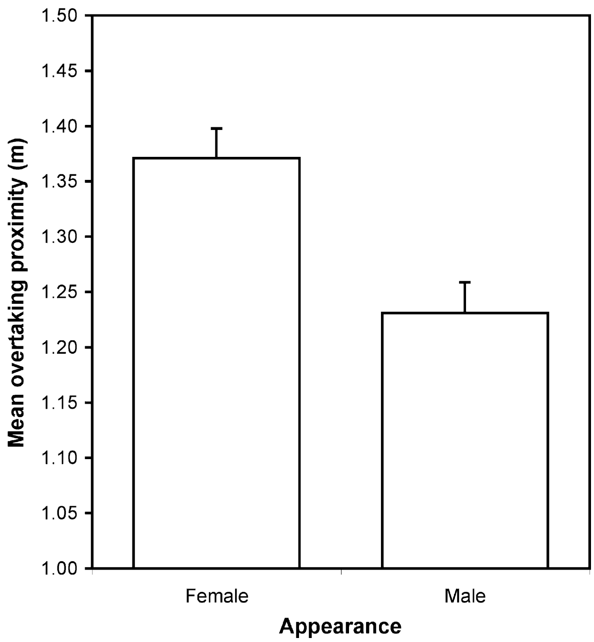

Fig. 4. Mean overtaking proximities as a function of the bicyclist's apparent gender to approaching motorists. Bars indicate standard errors of the mean.

correct) it was rather good at predicting far overtaking events (84.1% correct). The categories 'ordinary car' and 'sports utility vehicle/pickup' were significantly associated with reductions in the 'near' event category (car: odds ratio = 0.28, 95% CI = 0.11–0.71, $p = .007$; sports utility vehicle: odds ratio = 0.28, 95% CI = 0.10–0.79, $p = .02$), showing even more clearly than the ANOVA that 'domestic' vehicles were less likely to give particularly narrow berths to the bicyclist than commercial vehicles.

Finally, given that Hurst (1998) anecdotally suggested an association between car colour and overtaking behaviour, another ANOVA was carried out on the car and sports-utility data. This found no evidence at all of any relationship between Colour and overtaking proximity ($F_{6,1818} = 0.24$, MSE = 0.02, $p = .96$).

3.3. Effects of apparent gender

Mean overtaking proximities are presented in Fig. 4 as a function of the rider's apparent gender. On average motorists left considerably more space when passing the rider when he gave the impression of being female. A two-tailed independent-samples t-test confirmed that the effect was significant ($t_{279} = 3.71$, $p < .001$, $d = 0.44$). The difference in means is over 14 cm, with a borderline medium effect size. Clearly, donning the wig to appear more female to approaching motorists had a definite and substantial effect on overtaking proximities: drivers left more space for what they thought was a woman.

4. Discussion

Drivers' proximities when overtaking bicyclists are highly variable, but practically nothing was known about what influences them. This study used an instrumented bicycle to measure a large sample of overtaking events in real on-road environments. It asked whether the margins for error left by overtaking drivers showed any systematic variation as a function of the rider's position on the road, whether the rider wore a helmet, the type of overtaking vehicle, or the rider's apparent gender. We now consider the findings in turn.

4.1. Effects of riding position

The further out into the road the experimenter cycled, the less space he received from overtaking vehicles. We therefore offer the following principle: *to a first approximation, a driver follows the same path when overtaking a bicycle no matter where the bicycle is*. This illustrates how the further out a rider travels, the less space will be between them and a passing vehicle on average. This finding is contrary to what many experienced bicyclists believe (including the author prior to this study). That the data so clearly proved this belief wrong is, as well as anything else, an excellent illustration of the need for objective research over subjective experience when seeking to understand traffic behaviour.

Unfortunately, we cannot simply conclude from this finding that bicyclists are safer riding close to the edge of the road. First, this puts more obstacles in the rider's path – drainage grates, road debris and car doors – thus introducing another set of dangers which would likely offset the advantages gained from increasing the distance from passing vehicles. It also removes the option of moving away should a vehicle begin to get too close. Second, we know that being at the edge of a road is a particular problem at junctions, as motorists' search patterns tend to focus on more medial areas where motor vehicles are found (e.g., Hills, 1980; Räsänen and Summala, 1998). The best advice might therefore be for bicyclists to ride at a medium distance where grates and debris are unlikely to be encountered (perhaps around 0.5–0.75 m from the edge), moving further towards the lane centre when approaching junctions.

So why is the relationship between riding position and drivers' overtaking proximity so different from riders' subjective experiences, as illustrated in Section 1.2? Looking at the data collected here, we can discount hypotheses based around selective remembering of particularly generous overtaking events when riding towards the road's centre, or particularly close events when near the road edge, as these were not seen. (Incidentally, this also dismisses any idea that riding close to the road edge might encourage drivers to 'take a chance' and squeeze through narrow gaps.)

Instead, the most likely origin of the idea that riding further out leads to greater passing leeways can perhaps be inferred from Fig. 1 where, although the space between passing vehicles and the rider dropped as the rider's distance from the kerb increased, it did not drop as much as 25 cm for each 25 cm shift in rider position. This means that on average, as the rider moved further towards the centre of the road, the *absolute* position of overtaking motorists indeed shifted outwards – a 1 m shift in riding position led to a 73 cm shift in driving position – even though *relative to the rider* they came closer. This seems the most likely cause of the misperception common amongst bicyclists.

4.2. Effects of helmet use

There was a reliable difference in overtaking proximities as a function of whether the rider wore a helmet or not. This is perhaps best seen in Fig. 2, which shows a rider is more likely to experience particularly tight passing events when wearing a helmet, and that this effect increases as riding position moves from the edge of the road towards the centre. The exception to this is the 1 m point where the helmet effect was absent. At present, we have no explanation for this anomaly, although it seems possible it is related to the fact that on many roads, the 1 m position would be the first to require car drivers to cross the central dividing line when overtaking.

There are two possible explanations for the finding drivers generally passed closer to a helmeted bicyclist. It could be an example of risk compensation (e.g., Horswill and Coster, 2002; Trimpop, 1994), such that the perceived safety increase from the helmet leads to an increase in risk-taking.[3] Alternatively, closer overtaking could be the result of drivers believing helmeted riders to be more serious and experienced and so less likely to act erratically (Basford et al., 2002). In the first explanation drivers' behaviour changes because of the perceived *consequences* of a collision whereas in the second explanation behaviour changes because of the perceived *likelihood* of a collision.

At present, we lack the data definitively to chose between these accounts, and indeed, although it does seem unlikely that most motorists would see any form of collision with a bicyclist as acceptable (as the risk compensation account implies they must), both mechanisms could plausibly play a role in influencing drivers' perceptions (we return to this issue in Section 4.4). What the two putative explanations have in common is that it is drivers' *beliefs* about bicyclists which affect overtaking behaviour – beliefs about helmet efficacy on the one hand and about the relationship between helmet-wearing and behavioural predictability on the other – and in both cases these beliefs are of questionable validity. Without wishing to descend into the controversial issue of bicycle helmet efficacy in collisions with motor vehicles (e.g., Curnow, 2005; Hagel and Pless, 2006; Towner et al., 2002), if drivers are passing closer to helmeted bicyclists because they believe the bicyclists are protected, this belief is at best questionable, as evidenced inter alia by the high death rates in overtaking collisions (Section 1).

If, on the other hand, drivers believe helmeted bicyclists are less likely to do something unexpected during overtaking, there *is* some justification for this. American surveys found a trend towards regular bicyclists wearing helmets more than casual riders (Rodgers, 2000), and that people who wear helmets are generally more likely to be interested in acting safely (Bolen et al., 1998; see also Farris et al., 1997; Walker, 2006). Findings from Spain tend also to concur (Lardelli-Claret et al., 2003). However, if the drivers in this study had beliefs about helmeted riders being more experienced or predictable, these will almost invariably be the result of informal observation at best, or 'common sense' at worst, rather than knowledge of this academic literature, and so are not firm bases for guiding behaviours which affect the safety of others. Indeed, even if helmet use were firmly correlated with riding experience, using that knowledge to overtake closer to a bicyclist with a helmet is effectively to act as if their extra riding experience somehow makes the bicyclist less likely to encounter a pothole, a careless pedestrian or a piece of debris requiring avoidance. As such, even under the most generous interpretations, the association between helmet wearing and the actual increase in the ability safely to pass close to a rider when overtaking is tenuous.

In sum, then, whether drivers seeing helmets are making assumptions about the consequences or the likelihood of collisions, these assumptions are of questionable validity. Drivers might profitably be warned about the unreliability of the assumptions they are making.

4.3. Effects of vehicle type

The data showed that drivers of buses and heavy goods vehicles passed the rider much closer than other drivers, and indeed the author was struck by both classes during the experiment. This accords with the high number of bus overtaking incidents reported in the OxCam Survey (Walker and Jones, 2005) and the effect cannot simply be a product of driving for professional reasons, as light goods vehicles left significantly more room. The most likely explanation arises from vehicle characteristics. Owing to their length and poor acceleration, buses and heavy goods vehicles take much longer to pass a bicyclist than shorter vehicles (our data show that a standard bus typically takes around 4 s to overtake, in contrast to 0.5–1.0 s for a car). This means that to pass safely, a driver must encroach onto the oncoming traffic lane for a long period (even with a bicyclist riding towards the road edge, thanks to the width of these vehicles). We suggest it is an inculcated reluctance to remain out-of-lane, coupled with a lack of lengthy gaps in oncoming traffic and vehicle design issues which put bicyclists out of sight long before overtaking is complete, that often cause drivers of long vehicles to pull back across before it is safe to do so, hence creating the close proximities and frequent conflicts (e.g., Walker and Jones, 2005). We therefore recommend drivers of long vehicles receive extra information about the dangers of overtaking bicyclists during their training, and regular reminders thereafter. With a degree of Realpolitik, we suggest it may also behove bicyclists to acknowledge the overtaking limitations of such long vehicles in urban environments and assist their overtaking efforts where practicable.

4.4. Effects of apparent gender

When wearing a long feminine wig, the author appeared plausibly female to motorists approaching from behind. Without

[3] This is a somewhat different form of risk compensation to the usual use of the term in traffic psychology, as here the implication would have to be that the driver seeing a helmeted rider trades an increased risk of a crash (because of the narrower overtaking proximity) and an increased risk of hurting the rider in places other than the head for the decreased risk of a head injury. There are certainly anecdotal reports of drivers expressing the belief they can pass closer to a helmeted rider because the helmet means it effectively 'doesn't matter' if there is a collision, but no empirical data to suggest that this form of risk compensation is really taking place. We are grateful to the anonymous reviewer who raised this point.

the wig, he was fairly obviously male. In a tightly controlled procedure this manipulation produced substantial differences in overtaking leeways such that drivers gave more space to what appeared to be a woman.

What is the source of this gender effect? First, and most simply, it could simply be a product of female cyclists being more unusual on Britain's roads than male cyclists (Department for Transport, 2003). It may also be a product of politeness, or a form of risk-compensation strategy based on women being seen as more frail. However, there is also another intriguing possibility. In Section 4.2 we suggested the helmet effect could have arisen because of perceived rider predictability. It is therefore possible that a related mechanism might also explain the gender effect, with the implication being that motorists in general feel female bicyclists are less predictable than male riders and thus leave more space when passing.

Accordingly, as with the idea that helmets indicate experience, there is some evidence to suggest that male bicyclists *are* on average a little more experienced than female riders (Walker and Jones, 2005). However, as with the helmet issue, few drivers in this experiment could have been aware of this finding and most were far more likely basing their analyses on stereotypes. Moreover, even if there is some relationship between gender and experience, this is a long way from saying that a given rider's experience level can reliably be predicted from their hair! Again, if this explanation proves to be correct, motorists might profitably be warned not to make assumptions about a bicyclist's likely behaviour based on appearances.

4.5. Motorist sensitivity

Our data strongly support the general idea raised in the Introduction, that motorists show considerable levels of behavioural sensitivity to the appearance of a vulnerable road user. When encountering a bicyclist, motorists cannot simply be invoking some form of default bicyclist passing behaviour; rather, the way a given bicyclist is passed is effectively tailored to the perceived needs of that rider. That the bases on which this tailoring is currently carried out are probably suspect does not negate the fact it happens, and this provides an encouraging foundation for any attempts to change driver behaviour around vulnerable road users. As drivers have demonstrated that they alter their behaviour in relatively specific ways, specific interventions based on the needs of particular subgroups of non-drivers can be developed with a good likelihood of success. For example, drivers of large vehicles could explicitly be shown how long it takes them to overtake a cyclist, and reminded that the cyclist is alongside longer than they might think (e.g., 'That cyclist is next to you for more than five seconds as you pass'). All drivers could profitably be given messages urging them not to interpret signs such as helmets as indicating experience or otherwise.

One factor which we believe now needs urgent attention is the role of on-road cycle lanes in affecting overtaking proximities. There are claims that such lanes, by firmly delimiting the regions of road assigned to motorists and bicyclists, encourage motorists to pass riders closer than they would otherwise do (e.g., Owens, 2005). We could not assess this in the present study as suitably controlled stretches of road were not found. However, it would be very useful for future research to explore the effects of cycle lanes on overtaking proximities, and whether these vary as a function of cycle lane width.

Another factor which could profitably be explored in future is bicyclists' perceptions of motorists' overtaking behaviours. If we are to promote safer overtaking to motorists, it would be useful to know what leeways bicyclists feel comfortable with, and whether there are individual differences in these. It would also be useful better to understand the phenomenology of bicyclists being overtaken too closely, as this may well impact upon efforts to promote bicycle use, particularly in cities (Lingwood, personal communication).

5. Conclusions

Overtaking motorists pass closer to a bicyclist when the rider wears a helmet, rides away from the edge of the road, is male, or when the vehicle concerned is a bus or heavy goods vehicle. Based on previous work on drivers' perceptions of bicyclists, we have suggested that many of these effects are the result of motorists making assumptions about bicyclists' behaviours based on a brief visual assessment of their likely experience levels. We argue that these assessments can only ever provide a poor guide to the likelihood of a collision occurring and would encourage efforts to warn motorists of the assumptions they are making and the fallibility of these.

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