



*Citation for published version:*

Walker, I, Garrard, I & Jowitt, F 2014, 'The influence of a bicycle commuter's appearance on drivers' overtaking proximities: an on-road test of bicyclist stereotypes, high-visibility clothing and safety aids in the United Kingdom', *Accident Analysis and Prevention*, vol. 64, pp. 69-77. <https://doi.org/10.1016/j.aap.2013.11.007>

*DOI:*

[10.1016/j.aap.2013.11.007](https://doi.org/10.1016/j.aap.2013.11.007)

*Publication date:*

2014

*Document Version*

Peer reviewed version

[Link to publication](#)

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**The influence of a bicycle commuter's appearance on drivers' overtaking proximities: An on-road test of bicyclist stereotypes, high-visibility clothing and safety aids in the United Kingdom**

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**Revised following peer review**

**Accepted for publication in *Accident Analysis and Prevention*. If you want to cite this paper in an academic publication, please check a literature database, or contact Ian Walker ([i.walker@bath.ac.uk](mailto:i.walker@bath.ac.uk)), to get the proper citation**

## ABSTRACT

This study looked at whether drivers overtaking a bicyclist changed the proximities of their passes in response to the level of experience and skill signalled by the bicyclist's appearance. Five outfits were tested, ranging from a stereotypical sport rider's outfit, portraying high experience and skill, to a vest with 'novice cyclist' printed on the back, portraying low experience. A high-visibility bicycling jacket was also used, as were two commercially available safety vests, one featuring a prominent mention of the word 'police' and a warning that the rider was video-recording their journey, and one modelled after a police officer's jacket but with a letter changed so it read 'POLITE'. An ultrasonic distance sensor recorded the space left by vehicles passing the bicyclist on a regular commuting route. 5690 data points fulfilled the criteria for the study and were included in the analyses. The only outfit associated with a significant change in mean passing proximities was the police/video-recording jacket. Contrary to predictions, drivers treated the sports outfit and the 'novice cyclist' outfit equivalently, suggesting they do not adjust overtaking proximity as a function of a rider's perceived experience. Notably, whilst some outfits seemed to discourage motorists from passing within 1 metre of the rider, approximately 1-2% of overtakes came within 50 cm no matter what outfit was worn. This suggests there is little riders can do, by altering their appearance, to prevent the very closest overtakes; it is suggested that infrastructural, educational or legal measures are more promising for preventing drivers from passing extremely close to bicyclists.

Keywords: bicyclists, bicycling, overtaking, proximity, stereotypes, experience, high-visibility

## **The influence of a bicycle commuter's appearance on drivers' overtaking proximities: An on-road test of bicyclist stereotypes, high-visibility clothing and safety aids in the United Kingdom**

Bicycling is a generally safe activity, providing increases in fitness and life expectancy thanks to the regular integrated exercise it provides (Andersen, Schnor, Schroll & Hein, 2000; British Medical Association, 1992; Tuxworth, Nevill, White & Jenkins, 1986; World Health Organization, 2013). However, avoidable collisions do occur when bicyclists must mix with motorists on the road. Although the most likely type of collision to befall a bicyclist involves being hit by a motorist who is turning their vehicle into or out of a junction (Stone & Broughton, 2003), collisions where bicyclists are struck by an overtaking motorist are disproportionately dangerous to riders – probably because, unlike at junctions, vehicles are often travelling at higher speeds (McCarthy & Gilbert, 1996; Pai, 2011; Stone & Broughton, 2003; Transport for London, 2005). In addition, even when overtaking drivers do not collide with riders, close-passing motor vehicles can create a subjective experience of being unsafe that is a disincentive to travel by bicycle (Guthrie, Davies & Gardner, 2001; Parkin, Wardman & Page, 2007). Given these two issues, the topic of what affects the space left by passing drivers, and what bicyclists, drivers or policy-makers might do about this, is an important field of study.

Walker (2007) used an ultrasonic distance sensor to measure the space left by motorists as they overtook a bicycle in two United Kingdom cities. That study showed effects of the bicyclist's lateral road position, helmet wearing and gender on the space left by passing drivers – drivers left less space when the bicyclist rode towards the centre of the lane or was wearing a helmet, and left more space when he wore a long wig so that he appeared to be a woman (an effect later replicated with real women by Florida Department of Transportation, 2011, and Chuang, Hsu, Lai, Doong & Jeng, 2013, in the United States and Taiwan respectively). Walker's study also showed that longer vehicles – buses and heavy goods vehicles – tended to get closer on average when passing the bicycle, a finding replicated by Parkin and Meyers (2010). Given this last finding, it is notable that Pai (2011) recently found long vehicles were particularly associated with bicycle overtaking collisions in United Kingdom police accident records, as did Kim, Kim, Ulfarsson and Porello (2007) with American data, suggesting indirectly that closer proximities measured on the road (Parkin & Meyers, 2010; Walker, 2007) might indeed translate into real collisions (Pai, 2011). Chuang et al.'s (2013) finding of decreased rider stability during a lengthy overtake even hints at one possible mechanism for this. Since Walker's study, there has been a certain amount of interest in the subject of how bicycle helmets affect bicyclists' and non-bicyclists' perceptions of risk

(Curnow, 2008; Fyhri, Bjornskau & Backer-Grondahl, 2012; Pucher & Buehler, 2008) and how close drivers will pass bicyclists on the road (Chapman & Noyce, 2012; Chuang et al., 2013; Love et al., 2012; Parkin and Meyers, 2010) – an issue which has even been expanded to drivers passing horse riders (Chapman & Musselwhite, 2011).

To explain the closer passing proximities seen when wearing a helmet, Walker (2007) referred to a study of bicyclist stereotypes from Basford, Reid, Lester, Thomson and Tolmie (2002), which found people often took helmets to be a sign of a bicyclist's experience and control. Quotes from their qualitative study included "Pictures of cyclists wearing helmets were generally considered to be more serious and sensible on the road than those without" (p. 9), "it was felt that people who had arranged appropriate and/or specialist cycling equipment and clothing were more likely to have also the experience and/or training to employ correct cycling behaviour" (p. 9) and "The 'proper kit' [for a responsible cyclist] was deemed to include wearing a helmet" (p. 9). Based on these claims, Walker hypothesized that motorists in his study might have taken the helmet as a sign of experience, control or skill, and accordingly felt able to pass closer when the rider was helmeted. It is this notion of perceived rider ability, as judged from a rider's appearance, that is explored further here.

This question of how drivers might use a bicyclist's appearance to judge their abilities fits nicely with two recent studies of stereotypes, which both suggest that many people recognize only a few broad and visually distinctive categories of rider. Gatersleben and Haddad (2010) gave participants a large set of attributes about bicyclists and asked them to rate the attributes for how characteristic they were of the typical bicyclist they encountered on the road. The attributes referred to bicyclists' appearances or behaviour ('wears Lycra', 'abides by the rules of the road'), motivations ('bicycles to keep fit'), demographics ('is male', 'is young') and personalities ('worries a lot'). Factor analysis of these responses, to examine which attributes were rated similarly by participants, revealed four fairly clear (Chronbach  $\alpha = .72 - .83$ ) stereotypes of bicyclists:

- (1) a 'responsible' bicyclist type, defined primarily by their courtesy to others, strong adherence to the rules of the road and traffic signals, and their use of lights and helmets;
- (2) a 'lifestyle' bicyclist type, who wears a helmet and Lycra, who belongs to a bicycling club and who rides an expensive bicycle for the adrenaline rush and to keep fit;
- (3) a 'commuter' bicyclist type who is probably a well-educated man cycling for utilitarian purposes whatever the weather; and
- (4) a 'hippy-go-lucky' bicyclist type who is likely to be a sociable woman who uses a bicycle with a basket on the front for shopping.

These are clearly broad stereotypes, but as Gatersleben and Haddad's methodology seems

sound, they likely reflect some reality of bicyclist types understood or recognized by road users in the United Kingdom – they are likely, in other words, to represent shared mental models, prototypes, or stereotypes of bicyclists. (Although given the factor structure for their ‘responsible’ bicyclist shows no significant loadings for motivational or demographic items, and therefore says nothing about who these people are or why they cycle, it is tempting to suggest that this reflects an idealized meek cyclist who will stay out of people’s way more than a class of people actually encountered in real settings!)

The idea that people understand broad stereotypes of bicyclists is further supported by Musselwhite et al.’s (2010) qualitative study of road safety discussions. Musselwhite et al.’s participants described three classes of bicyclist – professionals (such as couriers), commuters and leisure riders – although discussions about these classes showed some nuances: it was recognized, for example, that amongst the commuters there will be a difference between those who cycle all year round and ‘fair-weather’ bicyclists who might have less riding experience. Musselwhite et al. cited an earlier sociological study by Jensen (1999) which similarly grouped bicyclists into three categories, although this time based on their reasons for bicycling rather than other people’s perceptions: users of the heart, users of convenience and users of necessity. As Musselwhite et al. note, it might be possible to map Jensen’s groups onto the kind of stereotypes being described here, which is an interesting exercise as it reveals the extent to which there might be concordance between bicyclists’ motives and the motives recognized by observers. Jensen’s ‘users of the heart’ map very clearly onto Musselwhite’s leisure riders and Gatersleben and Haddad’s ‘lifestyle’ type – these are the people passionate about bicycling and who do it for pleasure in a serious manner; and her ‘users of convenience’ map onto Musselwhite’s and Gatersleben and Haddad’s ‘commuter’ categories quite clearly. However, Jensen’s final category – ‘users of necessity’, which involves people bicycling because they lack alternatives – are not really seen in either Musselwhite et al.’s or Gatersleben and Haddad’s studies. This potentially reveals an interesting mismatch between the reasons people really cycle and the reasons attributed to them by observers.

In summary, then, the literature shows that some shared ideas might exist about bicyclist stereotypes. Given that Walker (2007) previously showed that the simple visible cue of wearing a helmet, which is a component of some of these stereotypes, was associated with changes in motorists’ passing behaviour – and given studies such as Davies (2009), which showed the influence of stereotypes on people’s judgements in other traffic situations – the present study explored a range of bicyclist outfits with the aim of more clearly signalling different ‘types’ of rider. The intention was to see whether, as Walker (2007) predicted, this might affect the space left by passing drivers, with less space afforded to a bicyclist whose outfit made them look more

experienced or skilled. The underlying framework is one in which stereotypes are used as fast short-cuts to behavioural selection (McGarty, Yzerbyt & Spears, 2002), with drivers rapidly recognizing the bicyclist as belonging to one of relatively few categories, making inferences about their level of experience and likely behaviour based on this, and adjusting their overtaking manoeuvre accordingly. This is not to say motorists' perceptions will necessarily be *accurate* or their responses *appropriate* – in reality it is unlikely a rider's level of experience or control could ever be gauged accurately from their appearance, nor that all riders fall neatly into a small number of types – but rather is simply to suggest that overtaking behaviour will be modified to some extent based on the rider's appearance in a way that is consistent with shared beliefs.

## METHOD

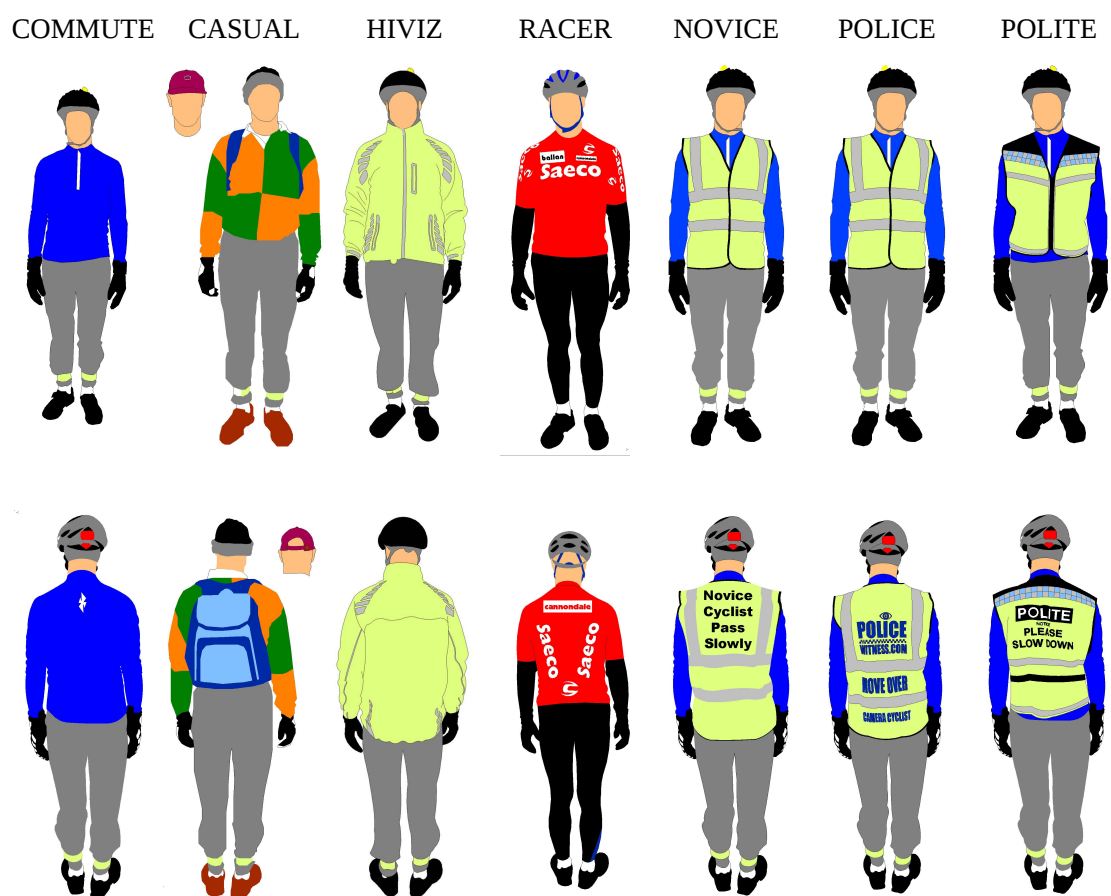
### Design

The study involved, for consistency, a single male bicyclist riding the same route over several months wearing various outfits, as illustrated in Figure 1, with instruments recording the proximities of each passing vehicle. As Figure 1 shows, the clearest manipulation of the rider's apparent experience is between the RACER outfit (intended to represent the Type 2/leisure rider identified by Gatersleben and Haddad, 2010, and Musselwhite et al., 2010) and the NOVICE outfit, which explicitly told other road users that the rider lacked experience. We predicted that RACER would receive less passing space on average than NOVICE. The COMMUTE, CASUAL and HIVIZ outfits were chosen to sit between these extremes, reflecting realistic outfits that might be seen on bicyclists, each somewhat like either Gatersleben and Haddad's Type 1 or Type 3 riders, or Musselwhite et al.'s commuter type. A somewhat similar manipulation was used by Florida Department of Transportation (2011), who found a moderate, but non-significant, tendency for motorists to pass closer when a bicyclist wore 'athletic' versus 'non-athletic' clothing (although no details were given of what exactly these outfits looked like). We took this approach further by using more outfits, by including an outfit which *literally* told drivers that the rider was inexperienced, and by quantifying the extent to which people thought that each outfit indicated the rider's experience.

One motivation for including HIVIZ was that Watts (1979) found little effect of a fluorescent vest on overtaking proximities, but that study was conducted over 30 years ago and it was not clear whether its findings would replicate today. As can be seen from the figure, all the outfits involved some sort of headgear, this being a helmet for all outfits except CASUAL, which used either a baseball cap or woollen hat, depending on the weather.

Also shown in Figure 1 are two additional outfits that were included in the study out of

curiosity, rather than specifically to test perceived experience, labelled here POLICE and POLITE. The POLICE outfit was the same as COMMUTE but with the addition of a vest that had been sold with a video camera marketed to bicyclists by a company called policewitness.com. As can be seen in Figure 1, this carried a message to approaching drivers saying ‘POLICEwitness.com – move over – camera cyclist’. We were interested to see whether this invocation of the term ‘police’, and the implied threat of evidence gathering, would affect drivers’ behaviour. The final condition used a commercially available vest which carried the message ‘POLITE notice – please slow down’. The intention of this vest, particularly with its characteristic blue and white checked bands, is clearly to invoke an image of the police, and we were interested to see what effect this would have.



	COMMUTE	CASUAL	HIVIZ	RACER	NOVICE	POLICE	POLITE
Experience	5.04 (1.26)	4.15 (1.25)	4.83 (1.37)	5.82 (1.20)	2.09 (1.12)	5.24 (1.48)	4.72 (1.38)
Skill	4.85 (1.21)	4.02 (1.20)	4.58 (1.27)	5.69 (1.20)	2.42 (1.07)	4.94 (1.46)	4.56 (1.40)
Wobble	3.11 (1.42)	3.81 (1.37)	3.49 (1.40)	2.62 (1.61)	5.25 (1.57)	3.10 (1.59)	3.44 (1.53)

**Figure 1 – The seven outfits used in this study, with 269 participants’ mean ratings out of 7 (and standard deviations) for how experienced, skilful and likely to wobble the riders appeared to be**



This study gathered data during one of the experimenters' regular commutes, thereby studying genuine driver behaviour on real roads. As such, it is important to note that, whilst care was taken to keep as many variables constant as possible, the study is not a laboratory experiment. There might be variation in factors such as road width, weather, etc. from one data point to another, as well as variations that cannot be known, such as driver characteristics. The study does not attempt to remove these sources of variance, and instead seeks to capture the range of overtaking proximities that might realistically be seen on a bicycle commute in the south-east of England during peak traffic hours and, critically, how this range of proximities might change with the rider's appearance. To work otherwise would involve studying drivers who are not naïve to the purpose of the study, and whose behaviour might therefore change to be unrepresentative of their behaviour in real settings (Walker, 2010).

### Equipment

A MaxBotix MB1200 XL-MaxSonar-EZ0 temperature-compensated ultrasonic distance sensor, which is accurate to within 1 cm, was used to record, at 10 Hz temporal resolution, the closest object to the right of the bicycle (this study took place in the United Kingdom, where traffic travels on the left and overtakes on the right). This sensor fed into an Arduino Uno prototyping computer running specially written software which recorded to an SD card, 10 times per second, the date and time, the proximity reading from the sensor, and a record of whether or not a button mounted on the bicycle's handlebars was pressed (see below). Researchers wishing to conduct a similar experiment can construct such a unit for approximately €100, and the plans and software needed to do this can be obtained from the authors, as can software automatically to extract the closest passing proximity for each vehicle.

The sensor, Arduino and batteries were housed in a small grey plastic box mounted on the bicycle's luggage rack, intended to be as inconspicuous as possible. The sensor and software were calibrated by holding targets at known distances and checking that the proximities recorded were correct – systematic discrepancies were adjusted in the software before data collection began. After data collection was complete, a constant was subtracted from all the readings so each measurement gave the distance between the passing vehicles and the outermost point of the bicycle's handlebars, rather than the sensor itself.

### Conditions

The outfits used in this study – viewed from behind by overtaking drivers – are illustrated in Figure 1. In more detail, they consisted of:

COMMUTE: Plain cycling jersey, plain trousers, reflective cycle clips, Bell commuting cycle helmet, cycle gloves.

CASUAL: Rugby shirt, plain trousers tucked into socks, woollen hat or baseball cap, plain gloves, small rucksack.

HIVIZ: Bright yellow reflective cycle commuting jacket, plain trousers, reflective cycle clips, Bell commuting cycle helmet, cycle gloves.

RACER: Colourful, skin-tight, Tour de France cycle jersey with sponsor logos, Lycra cycle shorts or tights, sleek race-fitting cycle helmet, cycle gloves.

NOVICE: Yellow reflective vest with words “Novice Cyclist, Pass Slowly”, plain trousers, reflective cycle clips, Bell commuting cycle helmet, cycle gloves.

POLICE: Yellow reflective vest with words “POLICEwitness.com – Move Over – Camera Cyclist”, plain trousers, reflective cycle clips, Bell commuting cycle helmet, cycle gloves.

POLITE: Yellow reflective vest with blue and white checked banding and the words “POLITE notice, Pass Slowly” looking similar to a police jacket, plain trousers, reflective cycle clips, Bell commuting cycle helmet, cycle gloves.

To check that people saw these outfits as indicating different levels of experience and skill, an online survey was carried out after the main study was finished, showing the drawings from Figure 1, one outfit at a time, to 269 participants recruited opportunistically through social media (Twitter) and snowball sampling. The sample was 67% male with a mean age of 41.17 (SD = 10.19); the general UK population of licensed drivers at that time was 55% male with a mean age of 47.8 (whatdotheyknow, 2013), which is slightly older and less male than our sample, but the sample nevertheless seems broadly comparable to the wider population. Participants were asked to rate, on 7-point Likert scales, how experienced, skilled and likely to wobble each rider appeared. Higher ratings indicated greater experience, skill or likelihood of wobbling. These data are shown in Figure 1, where it is clear that, as planned, RACER was judged more experienced ( $t_{263} = 38.12$ ,  $d = 3.26$ ,  $p < .001$ ), more skilled ( $t_{261} = 33.58$ ,  $d = 2.87$ ,  $p < .001$ ) and less likely to wobble ( $t_{261} = -18.68$ ,  $d = -1.69$ ,  $p < .001$ ) than NOVICE. The means of the other conditions sit between these two extremes.

### Procedure

One of the researchers (IG) collected the data on his usual 26 km (each way) commuting route between Cookham (Berkshire, United Kingdom) and Uxbridge (outer western London). The route included a range of road types, with 16% of its length through villages and small towns; 6% on narrow country lanes used heavily as a ‘rat run’ by commuting drivers; 44% on wider country roads, similarly used by motor commuters; 6% through quiet residential streets; 19% on busy main

roads; and 9% through a busy mixed industrial and housing estate. The journey was made at peak traffic hours of the morning and evening each day (typically beginning at around 0815 in the morning and 1730 in the evening) and the time of each ride was deliberately jittered by up to an hour from day to day in the hope of avoiding encountering the same motorists in the same places. The same bicycle, a Giant X1200 hybrid, was used for all rides – in part because its appearance was judged typical for a commuting bicycle.

On each day, the researcher chose one of seven shuffled cards at random to determine which outfit would be worn for the commute that day. As noted above, the aim was to work in vivo and record the range of overtakes a commuter in that part of the world might experience, rather than to carry out a laboratory study, but nevertheless various aspects of the ride were kept within realistic parameters as listed below. The data recording device included a button on the bicycle handlebars so the researcher could indicate which overtakes were suitable for analysis with a button-press as a vehicle passed. The button would insert a flag into the data file next to current readings and would not be pressed, thereby excluding an overtake from analysis, if the experimenter was riding unusually or if traffic conditions meant an overtake could be affected by extraneous factors. Specifically, the button would only be pressed if all the following criteria, decided in advance of the study, were met:

- The bicycle was travelling at between 16 and 28 kilometres per hour<sup>1</sup>
- The bicycle was riding in a consistent path at a distance from the kerb between 0.5 and 0.8 metres
- Visibility was good, with daylight, no rain and no fog
- The rider was sitting in the saddle, not standing on the pedals
- There were no nearby on-road complications such as parked cars or an intersection ahead.

The distance from each overtaking event used in the analysis was the lowest proximity reading within 1 second either side of the moment the button was pressed.

Data were collected between December 2012 and May 2013. There were a few occasions where technical difficulties or bad weather meant data were only collected on one leg of the return journey, which is why some conditions have data from odd numbers of rides. Data were analysed using R version 2.15.1 (R Core Team, 2012).

## RESULTS

A total of 5690 overtaking events were suitable for analysis (COMMUTE n = 857 from 11 rides,

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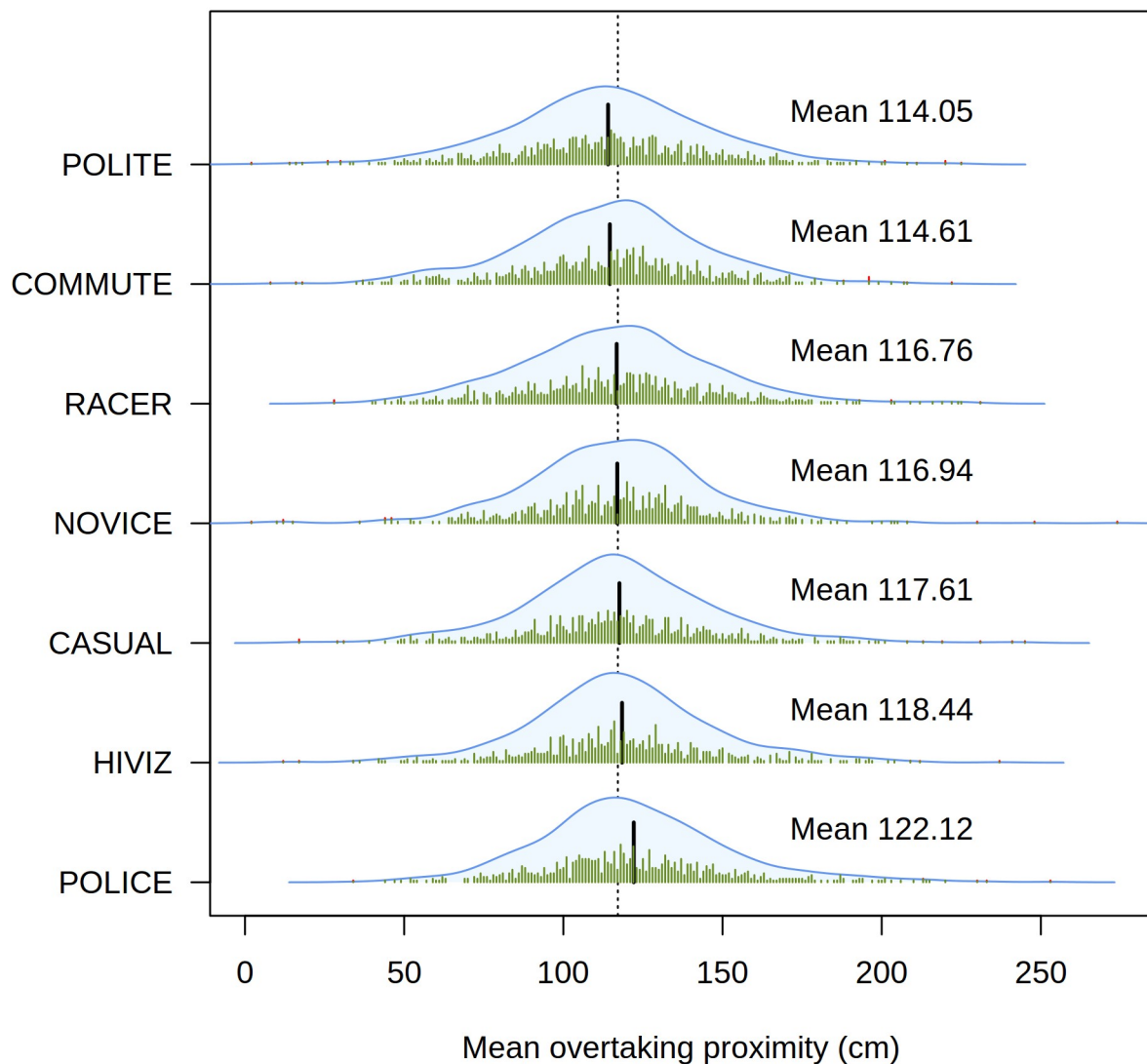
<sup>1</sup> Sixteen to 28 is relatively broad, but note that the range had to allow for realistic uphill and downhill riding. When not riding on hills speed was usually close to 20 kph.

CASUAL n = 779 from 9 rides, HIVIZ n = 737 from 9 rides, RACER n = 852 from 10 rides, NOVICE n = 807 from 8 rides, POLICE n = 790 from 10 rides, POLITE n = 868 from 10 rides). The overall mean proximity was 117.50 cm (SD = 30.00, range = 2 cm to 274 cm), which is lower than the 133 cm mean found by Walker (2007). Although we cannot be certain, it is likely this difference in part comes about because the 2007 study used almost exclusively urban streets, whereas the roads here were more mixed. It is also possible there are regional variations between the south-western cities used in the 2007 study and the outer-London areas studied here. However, we can be reasonably sure the difference was not an effect of concentrating on peak commuter hours in this study. We explain this by noting that Walker (2006) found that overtaking proximities increased linearly across the day, such that evening peak-time overtakes were substantially more distant than morning peak-time overtakes (see also Kim et al., 2007). This would suggest that focusing on peak times would not necessarily decrease mean passing proximities, provided both evening and morning peaks were included, as the tendency for morning overtakes to be close will be balanced by the tendency for evening overtakes to be more distant.

Incidentally, over 30 years earlier, Watts (1979) measured drivers overtaking bicyclists in the same area as we did in this study (Berkshire) and found a mean passing distance of 179 cm. It seems that drivers might have started passing closer to bicyclists over the past few decades. Speculatively, this could be a result of greater traffic volumes since the 1970s, or reduced levels of bicycling which mean that the average motorist is less likely to have experience of bicycling themselves, and so is less understanding of a bicyclist's needs.

### Effects of bicyclist outfits

The mean passing proximities for each condition, raw data points and kernel density plots to show the distribution of passing events, are presented in Figure 2.



**Figure 2 – mean overtaking proximities (black lines) and kernel density plots for each bicyclist outfit, with individual data points shown in rugs. The dotted vertical line is the overall mean for all data (117.50 cm)**

Analysis of variance showed the seven outfits were associated with significantly different passing distances, albeit with a small effect size ( $F_{6,5683} = 6.51$ ,  $MSE = 895$ ,  $p < .001$ ,  $f = .08$ )<sup>2</sup>. Pairwise  $t$ -tests corrected for multiple comparisons with Holm's (1979) method showed that the effect was carried by drivers affording more space to POLICE, as shown in Table 1, with comparable amounts of space left to each of the other outfits. Contrary to our predictions, there was

<sup>2</sup> The distributions shown in Figure 2 are somewhat platykurtic, but repeating the ANOVA with a log transform on the data changes the result very little ( $F_{6,5683} = 6.94$ ,  $p < .001$ ), suggesting this did not affect the analysis overmuch.

no evidence in Figure 2 or Table 1 of more space being given to NOVICE or less space being given to RACER.

**Table 1 – pairwise *t*-test *p*-values comparing passing distances for the seven outfits. *p*-values are corrected for multiple comparisons using Holm’s method**

	COMMUTE	CASUAL	HIVIZ	RACER	NOVICE	POLICE
CASUAL	.51					
HIVIZ	.16	1.0				
RACER	1.0	1.0	1.0			
NOVICE	1.0	1.0	1.0	1.0		
POLICE	< <b>.001</b>	<b>.05</b>	.22	<b>.005</b>	<b>.01</b>	
POLITE	1.0	.22	.05	.61	.53	< <b>.001</b>

*Note that of the two  $p = .05$  values, one is in bold because it was rounded up to .05 whereas the other is not bold as it was rounded down*

We looked to see whether there was any sign of very close overtakes being disproportionately common in any of the conditions, using the data shown in Table 2. Arbitrarily choosing 100 cm as the cut-off for a ‘close’ overtake<sup>3</sup> we found that the proportion of motorists getting close to the bicyclist varied across conditions ( $\chi^2_6 = 31.69, p < .001, w = .08$ ). The effect remained significant when the cut-off was reduced to 75 cm ( $\chi^2_6 = 26.43, p < .001, w = .07$ ), but not when the cut-off was reduced to 50 cm, to consider only the very closest passes ( $\chi^2_6 = 8.96, p = .18, w = .04$ ). This final analysis suggests that when the very closest passes are considered, around 1-2% of overtakes were extremely close to the bicyclist, regardless of how they dressed.

**Table 2 – Percentage of motorists passing ‘close’ to the bicyclists for three definitions of ‘close’**

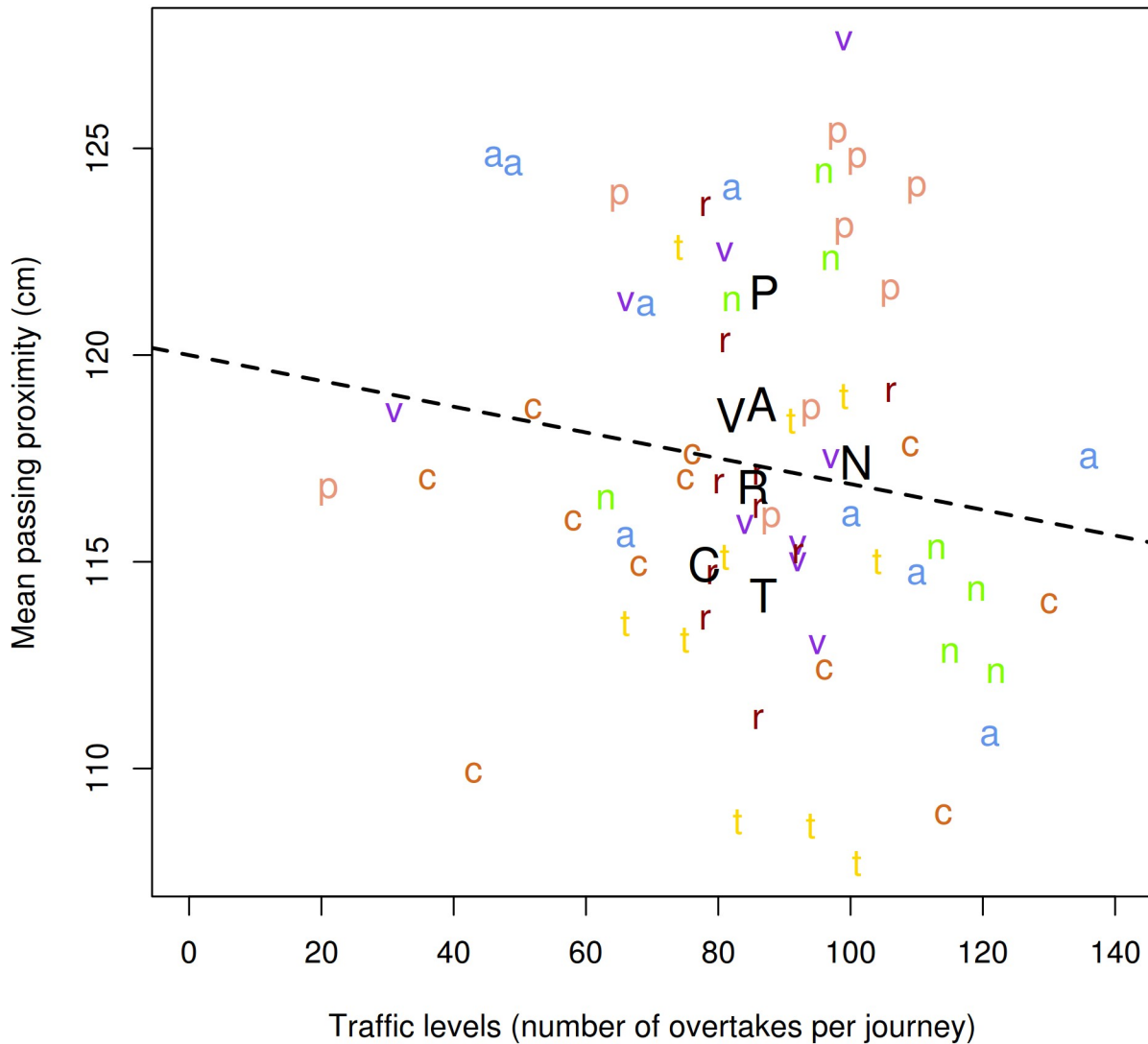
cut-off	COMMUTE	CASUAL	HIVIZ	RACER	NOVICE	POLICE	POLITE
< 100 cm	39.2%	33.0%	29.6%	37.1%	31.7%	24.5%	43.1%
< 75 cm	8.9%	6.7%	5.6%	8.2%	6.3%	4.1%	9.2%
< 50 cm	1.8%	1.2%	1.2%	1.4%	1.6%	0.5%	2.1%

### Influence of traffic volume

We were interested to see whether driver overtaking behaviour showed a relationship with traffic volumes, as indexed by the number of overtakes recorded on each journey. One journey was removed from this analysis owing to its being an extreme outlier (only 8 overtakes were recorded thanks to technical difficulties). The remaining 66 journeys are shown in Figure 3, from which it

<sup>3</sup> Although we describe this choice of 100 cm as arbitrary, we note that it approximates the ‘three feet’ laws found in certain American States (e.g., Love et al., 2012).

can be seen that, although there appears to be a slight downward trend in passing distances as traffic volumes increase, the pattern is not convincing and the correlation is accordingly not significant ( $r_{64} = -.16, p = .21$ ). Figure 3 also plots, with large capital letters, the centroid for each condition, showing how there appears to be no confound between traffic volume and condition, with traffic volumes largely comparable for each condition.



**Figure 3 – mean overtaking proximities on each journey as a function of traffic volumes, as estimated from the number of overtaking events on that journey ( $r = -.16, p = .21$ ). Each point represents one journey, with the letter indicating the outfit that was worn: c = COMMUTE, a = CASUAL, v = HIVIZ, r = RACER, n = NOVICE, p = POLICE, t = POLITE; large capital letters show the centroid for each condition**

### Patterns in successive overtakes

We addressed an additional question of interest, namely whether, when two or more drivers overtake the bicyclist in rapid succession, they influence one another's behaviour such that drivers behind the first might follow the vehicle in front rather than judge the manoeuvre themselves. In other words, is the overtaking proximity of a second or subsequent driver related to the proximity of the driver in front (showing they follow one another) or are their proximities independent? To the best of our knowledge, this issue has not been explored before, so any insights we can extract from these data are likely to be useful.

Any overtaking events that took place within 5 seconds of the previous event were identified, giving 1551 events<sup>4</sup>. Across the whole dataset, the mean distance left by a driver who was not following another was 117.03 cm (SD = 30.36) and the mean distance left by a driver who was within 5 seconds of the vehicle in front was 116.38 cm (SD = 28.72). This difference of 0.65 cm was not significant (95% CI = -2.43 to 1.13,  $t_{5133} = 0.71$ ,  $d = 0.02$ ,  $p = .48$ ). This lack of any difference between following and 'independent' drivers remained when each condition was considered separately: COMMUTE  $t_{725} = 0.07$ ,  $p = .94$ ; CASUAL  $t_{738} = 0.42$ ,  $p = .67$ ; HIVIZ  $t_{691} = 0.13$ ,  $p = .89$ ; RACER  $t_{846} = 1.52$ ,  $p = .13$ ; NOVICE  $t_{756} = 1.02$ ,  $p = .31$ ; POLICE  $t_{661} = 0.49$ ,  $p = .63$ ; POLITE  $t_{704} = 0.75$ ,  $p = .45$  – all  $p$ -values uncorrected.

Having seen no overall difference in proximity we then, for each overtaking event, calculated the difference in overtaking proximity from the event immediately before it in the dataset. If a driver's passing proximity were determined by that of the driver in front, the mean of this value should be close to zero. In fact, on average a driver who was close behind another driver passed the bicyclist 2.28 cm closer (SD = 36.28) than the driver in front, and a one-sample  $t$ -test showed this was significantly different to zero (95% CI = -0.47 to -4.09,  $t_{1543} = -2.47$ ,  $p = .01$ ). As such, a driver following close behind another tended to pass slightly closer to the bicyclist than the leading driver. In contrast, drivers who were not travelling behind other vehicles passed the bicycle 0.92 cm (SD = 41.49) further away than the preceding vehicle and this was not significantly different from zero (95% CI = -0.44 to 2.28,  $t_{3585} = 1.33$ ,  $p = .18$ ) – which is entirely to be expected

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4 We chose to treat close following as a binary variable, rather than use following distance as a continuous predictor in a regression analysis, because when one driver is following another with a gap of more than a few seconds, particularly when the gap is such that one driver is likely out of sight of the other as it frequently was in the data, there is no plausible mechanism by which the behaviour of the vehicle in front could affect a following driver's behaviour. Recall that this was an additional analysis to explore a question not previously studied; future studies might usefully explore the process of how drivers are influenced by the actions of other drivers they see – both in the short term (how an instantaneous behaviour such as passing a bicyclist is influenced by seeing other driver do the same) and in the long term (how informal driving practices [e.g., Björklund & Åberg, 2005] are transmitted through a population of motorists).



as the 'preceding vehicle' in this second analysis could be anything from 6 seconds to many minutes in front and so *should* have shown no relationship.

The findings from the analyses here, then, are that overall, drivers following close behind other drivers left similar amounts of space in absolute terms as drivers not following close to another, and this was the same regardless of what the bicyclist wore. However, at a more individual level, a given driver overtaking the bicyclist within 5 s of their 'leader' tended to get 2.28 cm closer on average than the driver immediately in front. The mechanism underpinning this is not clear at present.

### Power analysis

As this study found non-significant differences between most (but not all) of its outfit conditions, it is important to consider statistical power. A power calculation showed that, had all the groups been as small as the smallest here ( $n = 737$ ), the study could still have detected an ANOVA effect size as small as  $f = .05$  with power of .80. As such, we can safely conclude that the lack of significant differences between most of the outfits here was probably because motorists did not respond differentially to the bicyclist's various appearances, rather than because the study lacked power.

## DISCUSSION

This study, based on earlier research suggesting that people recognize different levels of experience in bicyclists, using cues that include helmets and clothing (Basford et al., 2002; Gatersleben & Haddad, 2010; Musselwhite et al., 2010), looked at whether a rider's appearance could influence drivers' overtaking proximities. We found that dressing a rider in outfits signalling different levels of experience and skill did not affect the mean amount of space left by passing motorists. The exception was a high-visibility vest whose back carried a prominent reference to the police and suggested the rider was video-recording the journey, which was allowed significantly more space by passing drivers.

A motive for this study was to test Walker's (2007) hypothesis that the reduced passing proximities seen when a bicyclist wore a helmet might have been caused because, as Basford et al. (2002) suggested, drivers take helmeted riders to be more experienced or in control. However, outfits like RACER and NOVICE, which suggested very different levels of experience (as shown in Figure 1), did not lead to changes in mean driver overtaking proximities or in the proportion of very close passes. It is therefore possible that (1) something other than perceived experience or control underpinned the reactions of drivers to the bicycle helmet in the 2007 study, (2) there are regional differences in driver attitudes or behaviour (the current study was in south-east England whereas the

previous was in the south-west), or (3) driver attitudes and behaviours have changed over the past few years such that motorists no longer respond to perceived experience as they did when Walker (2007) collected data. At present, we cannot say for certain which of these explanations is likely to be correct and further research could usefully address this question.

The finding that the POLICE condition led to significantly more space from passing motorists in this study is useful both because it confirms that the methodology was sensitive enough to detect responses to the outfits when these occurred, and because it shows there is at least one way that bicyclists might influence the proximity of passing motorists through what they wear. Speaking of which, it is interesting to note that, whilst the mean proximities did not change much as a function of the rider's outfit, there *were* substantial differences between outfits in the proportion of motorists' passes that came within 100 cm of the rider, as shown in Table 2 – with the greatest difference between POLICE (24.5%) and POLITE (43.1%). Whilst this does not necessarily mean a rider is more likely to be struck by a passing vehicle in one outfit rather than another, as differences were not significant in the 50 cm analysis, the finding could be useful for advising people how they might try to avoid some of the subjectively unpleasant close passes which can be a disincentive to bicycling in traffic (Guthrie, Davies & Gardner, 2001; Parkin, Wardman & Page, 2007).

However, having said this, we suggest, based on the data presented here, that it is unlikely bicyclist outfits could ever provide a sustainable solution to rider safety. Given that Table 2 shows that around 1-2% of overtakes were within 50 cm of the rider regardless of what he wore, it looks as though a small proportion<sup>5</sup> of motorists' passes will always be very close regardless of what a bicyclist wears. If this suggestion is correct, an important corollary is that the optimum solution to the closest overtakes, which must surely carry the greatest risk to the rider, will not lie with bicyclists: instead we might look to infrastructural (segregated cycleways), educational (improved driver training) or legal (strict liability laws, stronger policing of dangerous driving – Voelcker, 2007) interventions to prevent the most dangerous passes. These latter approaches would also offer a more sustainable, long-term solution to bicyclist safety than any approach which involves bicyclists manipulating drivers' judgements through what they wear, as the widespread adoption by bicyclists of any outfit which successfully influenced drivers would likely reduce its effect on driver behaviour as it became more familiar.

The question that naturally arises from the extra space given to POLICE is why drivers responded to this outfit more than the others. The vest, which had been supplied with a commercially available video camera, was included in the study because one of the experimenters

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<sup>5</sup> Although we describe this as a 'small' proportion, it should be noted that this could reflect 1-2% of many millions of overtaking events each day, such that even a small proportion will probably matter in real terms.

owned it and we were curious to see whether it would have any effect. Arguably it had two components that might have influenced driver behaviour: it might have made motorists think the rider was affiliated with the police thanks to the prominent emphasis given to that word on the back (see Figure 1); or perhaps its phrase ‘camera cyclist’ might have made motorists aware that their actions could be recorded. It is impossible to know for certain whether one or both of these components led to the behaviour seen here, and a proper experimental test would be difficult as it would be illegal for an experimenter to wear a vest that unambiguously identifies its wearer as a police officer. But it is striking that driver behaviour to POLICE was so different to POLITE given the key word differed by just one letter. Not only was passing much closer on average with POLITE, but subjectively the experimenter reported feeling much more at risk, and encountered overt acts of aggression from several drivers, when wearing POLITE. Critically, the difference between POLICE and POLITE ( $d = .26$ ) suggests that motorists were not simply making a quick and crude visual evaluation of the bicyclist, as otherwise we would expect these two outfits to be treated the same. A positive message that can therefore be taken from these data is that motorists seem able to read quite carefully what is written on the back of a bicyclist’s clothes, even if their subsequent behaviour is not necessarily what would be desired. Similarly, the fact drivers were apparently able to distinguish POLICE from POLITE and adjust their behaviour in response, especially in the context of earlier findings that drivers respond to a rider’s gender (Chuang et al., 2013; Florida Department of Transportation, 2011; Walker, 2007), might argue against any claims that dangerous overtakes are in some sense inevitable or the product of ‘carelessness’ – the data suggest drivers are quite able to adjust their behaviour based on relatively subtle changes in the situation.

We were also interested in this study to see the effects of the HIVIZ condition, given that such clothing is often recommended to bicyclists for its safety benefits. Watts (1979) found only a very small effect of a high-visibility vest on overtaking proximities in his study, and we similarly found no overtaking proximity advantage from wearing a high-visibility bicycling jacket, or most of the high-visibility vests, over casual clothing or an ordinary commuter cycling outfit. The finding that high-visibility clothing did not change overtaking proximity does not necessarily mean that such clothing has no value – it is intended primarily to make riders less likely to be overlooked, rather than influence the behaviour of people who have already seen them (Hoque, 1990). However, we must acknowledge a body of evidence that is emerging to suggest that high-visibility clothing might not be as good at increasing conspicuity as is often supposed (and, indeed, might lead to a false sense of security – Wood, Lacherez, Marszalak & King, 2009). Certainly, there is one study which supports its use: Thornley, Woodward, Langley, Ameratunga and Rodgers (2008) in New

Zealand found from a relatively large sample that time taken off work to recover from bicycle crashes was lower in users of high-visibility outfits. However, as that study included single-vehicle crashes in its data, where conspicuity is irrelevant, and as single-vehicle crashes are by far the most common type to befall bicyclists (Walker & Jones, 2005), the effects in that study can most likely be explained by the users of high-visibility outfits being the subset of more risk-averse bicyclists who ride more cautiously (an interpretation that would be supported by, for example, Bolen, Kresnow and Sacks, 1998, and Bolen, Sacks and Bland, 1999, whose American data strongly suggest users of bicycle safety equipment are risk-averse across multiple aspects of their lives).

Moreover, against the findings of Thornley et al. must be set several studies which suggest high-visibility outfits may be of more limited use. Gershon, Ben-Asher and Shinar (2012) showed with motorcyclists that the contrast between rider and background was more important than the colour of the rider's clothing per se, such that against light backgrounds, dark clothing increased conspicuity more than 'high visibility' items (see also Helman, Weare, Palmer & Fernandez-Medina, 2012). Outside the laboratory, the large-scale case-control MAIDS study of motorcyclist accidents (ACEM, 2009 – see particularly Table 8.13) found that dark clothing seemed to impair conspicuity more often than bright clothing enhanced it. With bicyclists specifically, Miller (2012), in a case-control study of high-visibility clothing, found no association between wearing high-visibility clothing and reduced crash risk (indeed, there was a small tendency for people with high-visibility outfits to experience more collisions than people without such aids, possibly suggesting a risk-compensation mechanism is at work). At present, then, the literature suggests that the safety benefits of so-called high-visibility clothing in daylight are likely smaller than is widely believed (although the night-time benefits of retroreflective clothing might be another matter).

Limitations of this study include not having data on the characteristics of the drivers themselves – it is possible there are systematic differences in passing behaviour associated with such variables as driver attitudes or experiences (particularly experiences with other transport modes such as bicycling or motorcycling). This could be a useful area for future study, although the risk of changing driver behaviour by informing them of the study's aims (Walker, 2010) means this could be a difficult area to study in practice. Thanks to our wanting to use a cheap, easily replicated data collection device, we also had no data on the type of vehicle used for each overtake. However, the relationship between vehicle type and passing proximity is already quite well understood (Chuang et al., 2013; Kim et al., 2007; Pai, 2011; Parkin & Meyers, 2010; Walker, 2007) and we did not want to explore this further, looking instead at the overall range of proximities on a typical commuting journey, including whatever was the typical mixture of vehicles seen on such a journey.

The study was also conducted in the United Kingdom, and it is not clear at this stage to what extent its findings would apply to other locales – although we note that, as described in the Introduction, gender effects found in the United Kingdom by Walker (2007) have been replicated in other countries (Florida Department of Transportation, 2011; Chuang et al., 2013). Speculatively, we might expect driver passing behaviour to become safer in countries with higher levels of bicycle use as, in a country where bicycling is more common, the typical driver is more likely to have experienced riding on the road and therefore is more likely to know how it feels to have cars pass closely (this relates to our earlier suggestion about why our mean passing distance might be different to that of Watts, 1979). Moreover, it is possible that differences between countries in infrastructure might lead to differences in passing behaviour. We note in particular the Dutch system of having no centre-line on many rural roads, as it seems drivers sometimes steer by reference to markings rather than the needs of other road users (e.g., Parkin & Meyers, 2010). At present, however, the extent to which the effects seen here are specific to the infrastructure and culture of the United Kingdom is moot, and international research would be welcomed to investigate this further.

It could also be suggested that as the researcher collecting data in this study was not blind to the purpose of the study or the condition under test on a given day, their behaviour might have changed and so influenced the motorists under study. Of course, it is always possible that this criticism is valid, as it is hardly possible to blind a bicyclist from the outfit they are wearing and it is conceivable (as one reviewer of this paper suggested) that the rider might have felt more visible or safer in some conditions. However, against such a suggestion we would note that the rider took considerable efforts to ride consistently throughout the study – he focused each day on maintaining his riding position, style and speed within relatively narrow limits, as described in the Method section, and we are confident that this was accomplished. With speed, position and riding style kept within narrow and consistent boundaries, it is not clear to us what else the rider might do, as a function of his outfit, to influence the behaviour of passing motorists. As such, although we agree that the rider was not blind to the condition and agree that this is not ideal, we cannot identify a reasonable mechanism by which this might have introduced systematic bias into the data<sup>6</sup>.

Finally, this study could measure only one aspect of driver reaction to the outfits – their passing proximity – but it is possible that other behaviours might have changed in response to the rider's appearance, such as passing speed, or the tendency to hold back and wait for clear overtaking possibilities. There is also a small possibility that differences in conspicuity between the outfits in Figure 1 could have had some effect. Again, these would be very useful areas for future

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<sup>6</sup> More anecdotally, we note that the rider-experimenter did not look at any data until the study was complete, and upon doing so was surprised by what the data showed, commenting that in many cases his subjective experience of driver behaviour in response to given outfits was not matched by the objective data.

study.

## CONCLUSIONS

The amount of space left by motorists as they overtook a bicycle was not related to the rider's apparent level of experience, as signalled by the outfit being worn. The only substantial change in drivers' behaviour was seen in response to a high-visibility vest which invoked the name of the police and suggested the rider was video-recording the journey, although at present it is not clear which of these components was responsible for the effect. Given that a small proportion (1-2%) of overtaking drivers passed within 50 cm of the rider no matter what was being worn, we suggest that there is little riders can do, by altering their appearance, to prevent the very closest overtakes. We suggest that the optimum solution to the very closest overtakes will not lie with bicyclists themselves, and instead we should look to changes in infrastructure, education or the law to prevent drivers getting dangerously close when overtaking bicyclists.

## AUTHOR NOTE

The authors have no affiliation with the manufacturers of any of the products used in this study, and received no specific funding for this project. They would like to thank Edward Varney for writing the software to extract passing measures from the raw data, Michael Garrard for his advice on improving the measurement device used here, and Charles Musselwhite for his helpful comments on a draft of this paper.

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