Hi-viz for cyclists, and other 'conspicuity' measures

1. Cycling UK's current position:

If wearing a fluorescent yellow jacket helps people feel safer when cycling and more willing to do it, then that is only to be welcomed.

It is, though, hard to prove whether hi-viz makes a significant impact on cyclists' safety, and there is very little evidence to support the argument that it does. Research suggests that hi-viz may help drivers spot cyclists more readily – but, it seems, spotting is one thing and driving safely around them another. One academic study, for example, found that whether a cyclist is wearing hi-viz or not makes very little difference to how closely motorists overtake them.

On the other hand, research suggests that retroreflective accessories designed to make you more conspicuous in the dark - especially ankle straps that move when you pedal - are probably worth the investment.

Notes:

i. A distinction is usually made between 'fluorescent' and 'retroflective' clothing (or other material).
   - A 'fluorescent' material will, technically speaking, produce light instantly when the atoms inside it absorb energy and become excited. In most (but not all) settings, they look bright in daytime. Fluorescent materials are not necessarily yellow.
   - A 'retroreflective' material bounces light back to its source. At night, therefore, it can appear to light up in the beam of headlights.

ii. This briefing is about hi-viz and contrast, not lights. We believe cyclists should behave legally and responsibly, which includes obeying lighting regulations.

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2. What research informs our current position?

Most of the studies mentioned below consider whether wearing 'hi-viz' of some kind makes cyclists more noticeable to drivers. By and large, it seems to be reflective accessories attached to limbs that move whilst riding *at night*, that make the most difference as far as *detecting* cyclists is concerned – because they move, and human beings are particularly sensitive to 'biomotion'.

Contrasting colours (i.e. colours that contrast with the background) seem to make a difference to drivers' detection of motorcycles – e.g. riding in a black outfit against nothing other than the sky. This may (or may not) be true for cycles as well.

It is important to note, however, that only two of the studies listed below (study (d) and the Danish study covered in section 3), look specifically at 'hi-viz' and *crash risk*, i.e. how much difference it makes to the chances of cyclists actually being involved collisions etc. These two studies, based on reported incidents, come to different conclusions. A further study (f), on the effect of the built environment, also looked at reported incidents and, in passing, commented on 'reflective' clothing, and recommended it.

One study (e) looked at the difference a cyclist's clothing makes to how closely a driver overtakes. The only jacket that made a significant difference was one featuring a prominent mention of the word 'police' and a warning that the rider was video-recording their journey. The author came to the conclusion that there is little a cyclist can do, in terms of clothing, to stop the "very closest overtakes".

We are aware of only one study (j) that investigated the effect of mandatory hi-viz wearing on overall casualty statistics. Having looked at road crash data from Italy (where hi-viz vests are compulsory at night), the author could only conclude that it had made no detectable difference

(but could not tell either how vigorously the police had enforced the law, or whether cyclists had complied with it).

Finally, a study on sticking reflective tape to the rear of a bike (m) concluded that it was a good idea.

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a. Cochrane review summary, by I Kwan and J Mapstone (2006).

This was a review of 42 randomised controlled trials (RCTs) looking at how effective visibility aids are for protecting pedestrians and cyclists. It considered both aids worn by cyclists and lights. The researchers could not find any studies on crash rates, so had to focus on *driver detection/recognition* only. (RCTs compare two similar groups of people who only differ on the issue being studied).

Extracts, as published:

"These studies showed that fluorescent materials in yellow, red and orange improved driver detection during the day; while lamps, flashing lights and retroreflective materials in red and yellow, particularly those with a 'biomotion' configuration (taking advantage of the motion from a pedestrian's limbs), improved pedestrian recognition at night. Although these visibility measures help drivers see pedestrians and cyclists, more research should be done to determine whether the increased visibility actually does prevent deaths and serious injuries."

"Visibility aids have the potential to increase visibility and enable drivers to detect pedestrians and cyclists earlier. Biomotion markings, which highlight the movement and form of the pedestrian, showed evidence of improving pedestrians' conspicuity at night. Public acceptability of various effective strategies which improve visibility would merit further development. However, the effect of visibility aids on pedestrian and cyclist safety remains unknown. A cluster randomised controlled trial involving large communities may provide an answer to this question. It would, however, be a challenging trial to conduct."

http://www.cochrane.org/CD003438/INJ_increasing-pedestrian-and-cyclist-visibility-to-prevent-deaths-and-injuries

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b. Cyclist visibility at night: perceptions of visibility do not necessarily match reality, by Joanne M Wood *et al*. Published in Journal of the Australasian College of Road Safety. (2010).

This study looked at how much difference a cyclist's clothing makes to whether drivers recognise them *at night*.

The test took place in a 'closed-road' driving environment, and involved observing 24 regular drivers who had good eyesight, 12 young (M=25.3 years) and 12 older (M = 72.5 years). They tested black clothing, a fluorescent vest, and a reflective vest *plus* ankle and knee reflectors. It was the difference between *fluorescent* clothing (i.e. bright) and *reflective* clothing (i.e. reflecting light) that mainly interested the researchers.

Extracts, as published:

"Visibility limitations make cycling at night particularly dangerous. We previously reported cyclists' perceptions of their own visibility at night and identified clothing configurations that made them feel visible. In this study we sought to determine whether these self-perceptions reflect actual visibility when wearing these clothing configurations. […] Drivers recognised more cyclists wearing the reflective vest plus reflectors (90%) than the reflective vest alone (50%), fluorescent

vest (15%) or black clothing (2%). Older drivers recognised the cyclists less often than younger drivers (51% vs 27%). The findings suggest that reflective ankle and knee markings are particularly valuable at night, while fluorescent clothing is not. Cyclists wearing fluorescent clothing may be at particular risk if they incorrectly believe themselves to be conspicuous to drivers at night."

http://eprints.qut.edu.au/38338/

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c. Bicyclists overestimate their own night-time conspicuity and underestimate the benefits of retroflective markers on moveable joints, by Joanne M Wood *et al*. Published in Accident Analysis & Prevention (2013).

A paper written by most of the same researchers as (b) above, and based on a similar (or perhaps the same) closed-road test at night (it was, possibly, written before (b) but published afterwards).

This time, it focuses on cyclists' perceptions of their visibility and how valid they are. Twenty-five cyclists took part, 13 of whom usually rode at least once a week, and 12 who rode once a month of less. They were asked to cycle on a test circuit and indicate when they were confident that an approaching driver would first recognise they were there. The cyclists wore black clothing alone or together with a fluorescent bicycling vest, or the fluorescent retroflective vest plus ankle and knee reflectors in "a modified 'biomotion' configuration". The bike's handlebars were fitted with a static, flashing or off light.

Abstract, as published:

"Participants judged that black clothing made them least visible, retroreflective strips on the legs in addition to a retroreflective vest made them most visible and that adding retroreflective materials to a fluorescent vest provides no conspicuity benefits. Flashing bicycle lights were associated with higher conspicuity than static lights. Additionally, occasional bicyclists judged themselves to be more visible than did frequent bicyclists. Overall, bicyclists overestimated their conspicuity compared to previously collected recognition distances and underestimated the conspicuity benefits of retroreflective markings on their ankles and knees. Participants mistakenly judged that a fluorescent vest that did not include retroreflective material would enhance their night-time conspicuity. These findings suggest that bicyclists have dangerous misconceptions concerning the magnitude of the night-time conspicuity problem and the potential value of conspicuity treatments."

https://eprints.qut.edu.au/57630/

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d. The use of conspicuity aids by cyclists and the risk of crashes involving other road users: a population based case-control study by Phil Miller, Nottingham Uni, UK. (2012).

This was a thesis based on a 'matched case-control' study involving 76 cyclists who had suffered a crash (recruited at emergency departments), and 272 matched cyclists who had not (recruited at public and private cycle parking sites). The 'consipicuity aids' of interest were low-cost, easy to use retroflective and fluorescent clothing and accessories (but not bicycle mounted reflectors).

The author adjusted for a range of confounding factors (e.g. age, gender, socio-economic deprivation, cycling experience, risk along the route they used, and personal crash history). In the light of his analysis, he raised some queries about his findings (e.g. the problems associated with accounting for 'route risk', and the possibility that cyclists wearing conspicuity aids could have overestimated the effect of them, over-compensated and consequently increased their net risk).

Extract, as published:

"The results of this study show a non-significant increase in the odds of a crash for users compared to non-users of conspicuity aids whilst cycling. This association was increased after adjustment for confounders but most models generated to adjust for confounding remained insignificant. No reduction in crash risk could be demonstrated. This is not consistent with the large body of evidence suggesting that conspicuity aids increase the distances from which wearers can be detected and recognised by drivers in a variety of settings."

"This study was designed to assess the effect of conspicuity aid use on the risk of crash for commuter and utility cyclists. A slightly greater proportion of cases than controls reported using conspicuity aids. There was therefore a raised odds ratio of collision crash involvement for those using conspicuity aids even after adjustment for a large number of important confounders. The study results do not demonstrate a protective effect as expected given previous work testing the effects of such aids on drivers' awareness of cyclists and pedestrians. This study demonstrates the importance of understanding why many cyclists remain at risk of collision crash resulting in injury despite the use of conspicuity aids."

http://eprints.nottingham.ac.uk/12855/

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e. 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 by Ian Walker, Uni of Bath. (Peer reviewed). (2013)

This study involved a single male bicyclist (the author) riding the same route over several months wearing various outfits, with instruments recording the proximities of each passing vehicle. It therefore studied genuine driver behaviour on real roads – the drivers being naïve to the purpose of the experiment.

The author says that it is important to note: "... 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."

Extracts, as published:

"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."

"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)."

http://opus.bath.ac.uk/37890/1/Walker_2013.pdf

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f. Built environment effects on cyclist injury severity in automobile-involved bicycle crashes by Peng Chen and Qing Shen published in Accident Analysis and Prevention. (2016)

From the USA, this is not a study of hi-viz per se, but a write-up of a modelling exercise to "estimate the effects of built environment factors on cyclist injury severity in automobile-involved bicycle crashes, as well as to accommodate possible spatial dependence among crash locations." It was based on collision profiles from Seattle's Department of Transportation. **The abstract says**:

"Our modeling outcomes show that: (1) injury severity is negatively associated with employment density; (2) severe injury or fatality is negatively associated with land use mixture; (3) lower likelihood of injuries is observed for bicyclists wearing reflective clothing; (4) improving street lighting can decrease the likelihood of cyclist injuries; (5) posted speed limit is positively associated with the probability of evident injury and severe injury or fatality; (6) older cyclists appear to be more vulnerable to severe injury or fatality; and (7) cyclists are more likely to be severely injured when large vehicles are involved in crashes. One implication drawn from this study is that cities should increase land use mixture and development density, optimally lower posted speed limits on streets with both bikes and motor vehicles, and improve street lighting to promote bicycle safety. In addition, cyclists should be encouraged to wear reflective clothing."

N.B. 'reflective' clothing is usually taken to mean something distinct from 'fluorescent' clothing (i.e. the sort that reflects light at night, rather the sort that looks bright in daytime). Whether this is the case here, it is hard to tell but, from the reference to street lighting, it seems reasonable to assume so.

http://www.sciencedirect.com/science/article/pii/S0001457515301184?via%3Dihub

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g. The conspicuity of pedestrians at night: a review by Tyrrell RA, Wood JM, Owens DA, Whetsel Borzendowski S, Stafford Sewall A., published by the journal of Clinical and Experimental Optometry, (2016)

A review, concluding that:

"Research has established that the conspicuity of pedestrians can be optimised by attaching retroreflective markings to the pedestrian's extremities. Doing so highlights the pedestrian's

'biological motion,' which facilitates the accurate perception of a person; however, retroreflective markings on the torso (for example, vests) are less effective. Importantly, behavioural evidence indicates that most road users - drivers and pedestrians alike - are not aware of the limitations of night vision. For example, drivers typically 'overdrive' the useful range of their headlight beams and under-use their high beam headlight setting. Further, pedestrians overestimate their own conspicuity at night and fail to appreciate the extent to which their own conspicuity depends on their clothing. The widespread misunderstanding of the challenges associated with night driving reflects a lack of awareness of the fundamental limitations of night vision."

http://onlinelibrary.wiley.com/doi/10.1111/cxo.12447/abstract;jsessionid=74FB5682A902B2F3CA740FEF98AD48EF.f03t02

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h. An Open-Road Study of the Daytime Conspicuity Benefits of Fluorescent Bicyclist Apparel by Drea K. Fekety, Darlene E. Edewaard, Ellen C. Szubski, Richard A. Tyrrell, DeWayne Moore (from the Proceedings of the Human Factors and Ergonomics Society Annual Meeting) (2017)

A paper from the USA by researchers who explored "the potential value of using fluorescent apparel strategically to make bicyclists more conspicuous to drivers during daylight hours." They note that (in the US at least), most crashes between motor vehicles and cyclists happen during daylight hours, and involve being struck from behind.

The research was based on a practical experiment on public roads, and examined the influence of four different clothing configurations on the distances at which participants recognised the cyclist wearing them.

Visually healthy observers, with an average age of 18.7 years, were asked to search for cyclists while a researcher drove them along a pre-determined route. They were told to press a button on a keypad each time they were confident they had recognised any person "on or with" a bicycle, who was "stopped or moving," and who was "in or near the roadway." The test cyclist wore one of four outfits, whilst pedalling on a stationary bicycle on a sidewalk to the right of the roadway while facing away from the approaching vehicle.

Pressing the button triggered a timer on a laptop operated by an experimenter in the back seat, who stopped the clock once the vehicle had passed a test cyclist. The time that elapsed was used to calculate 'response distances', and the participants were also interviewed and debriefed on the way back.

The researchers considered the degree to which response distances varied among the four clothing configurations to be statistically significant. Mainly, they found that "a fluorescent yellow jersey did not significantly improve the cyclist's conspicuity relative to a black jersey. However when the cyclist paired the fluorescent jersey with fluorescent yellow leggings, participants responded from a distance 3.3x farther than an identical outfit with black leggings."

The authors also state:

"The finding that fluorescent yellow leggings can provide a dramatic enhancement to bicyclist conspicuity is, we believe, a consequence of highlighting the bicyclist's pedaling motion. The rhythmic up-down movements of a cyclist's lower legs uniquely specify a pedaling motion that is visually distinct from, for example, a pedestrian walking or jogging. Further, considerable research has identified that highlighting a cyclist's biological motion can provide powerful conspicuity

enhancements. Thus fluorescent leggings can offer a powerful and low-tech tool for enhancing bicyclists' daytime conspicuity."

As such, the findings are clearly consistent with some of the research mentioned above.

A possible criticism of the experiment, though, is the fact that the research subjects knew that they were looking out for cyclists, although the authors do say that their instructions were delivered in such a way as to limit "expectancy that they would encounter a planted/scripted researcher on a bicycle during their trip". This could mean, though, that the test was more about how cyclists' clothing affects the ability of drivers who are looking out for cyclists to be confident that what they have noticed is a cyclist, i.e. is not the same as testing whether clothing makes a difference to the likelihood of a driver having their eye caught by a cyclist in a situation where they may or may not be paying attention.

http://journals.sagepub.com/doi/pdf/10.1177/1541931213601954

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j. The effect of an Italian nationwide mandatory visibility aids law for cyclists by Gabriele Prati (2018). Published in the Journal of Transport and Health

This was, according to the author, the first study on the impact on bicycle safety of legislation imposing "bicycling visibility aids" (by law, cyclists in Italy must wear a reflective vest when riding at night - sunset to sunrise - and in tunnels.

Having looked at official monthly data on road crashes from 2001–2015, the author concluded that: "… the implementation of legislation imposing high-visibility clothing for cyclist did not influence the number of bicycles involved in road crashes as well as its proportion in the total vehicles involved in road crashes. The introduction of the legislation did not produce immediate effects, nor did it have any effects over time."

Gaps in information about how the law was introduced, the degree of enforcement by the police since, and whether cyclists have changed their behaviour, however, made it impossible for the author to consider the findings in the wider context (i.e. is it because the police have not enforced the law and/or because cyclists are ignoring it?).

The abstract says:
"Results revealed that the implementation of legislation imposing high-visibility clothing for cyclist did not influence the number of bicycles involved in road crashes as well as its proportion in the total vehicles involved in road crashes. The introduction of the legislation did not produce immediate effects, nor did it have any effects over time. Lack of knowledge on how the law was introduced, the degree of enforcement by the police, and behavioral changes in response to the law makes it difficult to attribute the lack of effect on bicycle crashes."

https://www.sciencedirect.com/science/article/pii/S2214140518300045

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k. More on 'biomotion'

According to Wikipedia:

"**Biological motion** is the visual system's ability to perceive object movement by connecting a few small, individual stimuli. Humans use biological motion to identify familiar activities and gestures, which is useful for social interaction.[1] Biological motion processing is a highly routine instance of

more general perceptual and attentional processes that construct global form information from constituent parts.[2] Currently, research is being done to uncover the brain structures which allow for biological motion processing."

- https://en.wikipedia.org/wiki/Biological_motion
- See also a YouTube film demonstration from 1971: https://www.youtube.com/watch?v=1F5ICP9SYLU

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Reflective tape

m. Reflective Tape Applied to Bicycle Frame and Conspicuity Enhancement at Night by Marco Costa, Leonardo Bonetti, Manuela Bellelli, Claudio Lantieri, Valeria Vignali, Andrea Simone, published in Human Factors: the journal of the Human Factors and Ergonomics Society (2016)

This is a paper from Italy on the results of four studies to assess "bicyclist conspicuity enhancement at night by the application of reflective tape (ECE/ONU 104) to the bicycle rear frame and to pedal cranks."

The experimenters stuck reflective tape onto a bicycle's rear frame, and first compared detection distance in four conditions: control, rear red reflector, high visibility jacket, and reflective tape. In the second experiment, they studied the same conditions with night street lighting on and off. In the third, they evaluated detection and recognition distances in rainy conditions. In the fourth, they assessed visibility with the tape stuck to pedal cranks.

Reporting on the results, the authors say:

"In the first study, the application of reflective markings resulted in a detection distance of 168.28 m. In the second study, the detection distance with reflective markings was 229.74 m with public street light on and 256.41 m with public street light off. In rainy conditions, detection distance using the reflective markings was 146.47 m. Reflective tape applied to pedal cracks resulted in a detection distance of 168.60 m."

Their conclusion was that:

"Reflective tape applied to the rear bicycle frame can considerably increase bicyclist conspicuity and safety at night.

Accordingly, they highly recommended reflective tape as a complement to front and rear lights for night-riding.

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Contrasting colours

It looks as if research into contrasting colours (i.e. colours that contrast with the background), is largely focused on motorcyclists. Findings seem to suggest that wearing a colour that contrasts with the background – e.g. a black outfit against a nothing other than a bright sky – does make it easier for drivers to detect them. This could be true of cyclists too, but as these studies did not involve them, this evidence cannot be used to assume categorically that it is.

n. **Low Conspicuity of Motorcycles for Car Drivers: Dominant Role of Bottom-Up Control of Visual Attention or Deficit of Top-Down Control? By Joceline Rogé, Evgueni Douissembekov, Fabrice Vienne, published in Human Factors: The Journal of the Human Factors and Ergonomics Society. (2011)**

A study from France evaluating whether the low visibility of motorcycles is the result of their "low cognitive conspicuity and/or their low sensory conspicuity for car drivers." It was inspired by the fact that, "in several cases of collision between a car and a motorcycle, the car driver failed to detect the motorcyclist in time to avoid the collision."

The low cognitive conspicuity hypothesis was carried out in a car-driving simulator. The subjects were 42 car drivers (32.02 years old) including 21 motorcyclist motorists and 21 non–motorcyclist motorists, and involved a motorcycle detection task.

To test the low sensory conspicuity hypothesis, the authors studied the effect of the colour contrast between motorcycles and the road surface on the ability of car drivers to detect motorcycles when they appear from different parts of the road.

Reporting on the results, the authors say:

"A high level of color contrast enhanced the visibility of motorcycles when they appeared in front of the participants. Moreover, when motorcyclists appeared from behind the participants, the motorcyclist motorists detected oncoming motorcycles at a greater distance than did the non–motorcyclist motorists. Motorcyclist motorists carry out more saccades and rapidly capture information (on their rearview mirrors and on the road in front of them)."

http://journals.sagepub.com/doi/abs/10.1177/0018720811427033

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p. **Attention and search conspicuity of motorcycles as a function of their visual context by Gershon P, Ben-Asher N, Shinar D, published in Accident; Analysis and Prevention. (2012)**

A study from the Ben-Gurion University of the Negev, Beer Sheva, Israel. It involved two experiments: the first evaluated "the influence of PTW [powered two wheeler] attention conspicuity on the ability of un-alerted viewers to detect it; the second evaluated "the PTWs search conspicuity to alerted viewers." The independent variables in both included driving scenarios (urban and inter-urban), PTW rider's outfit (black, white, and reflective) and PTW distance from the viewer.

The 66 participants in experiment 1 were each presented with a series of pictures and asked to report all the vehicle types present in each picture. The 64 participants of experiment 2 incorporated the same pictures as experiment 1, but the participants were instructed to search the pictures for a PTW and to report its presence or absence as soon as they reach a decision.

In experiment 1, (i.e. with 'un-alerted' viewers), the detection of a motorbike depended on the interaction between its distance from the viewer, the driving scenario and the rider's outfit. The researchers found that on urban roads, where the background surrounding the motorbike was more complex and multi-coloured, the rider's reflective and white outfits increased its attention conspicuity compared to the black outfits. On the other hand, on inter-urban roads, where the background was solely a bright sky, "the black outfit provided an advantage for the PTW detectability."

In experiment 2 (i.e. with 'alerted viewers'), the average motorbike detection rate was "very high", and the "average reaction time to identify the presence of a PTW was the shortest in the inter-urban environment." As in experiment 1, in urban environments the reflective and white clothing made it easier for views to detect a motorbike, while in the inter-urban environment, the black outfit presented an advantage.

The authors conclude:

"The conspicuity of a PTW can be increased by using an appropriate rider's outfit that distinguishes him/her from the background scenery. Thus, PTW riders can actively increase their conspicuity by taking into account the driving route (crowded urban/inter urban), eventually increasing the probability of being detected by the other road users. In addition, increasing the alertness and expectancy of drivers to the presence of PTWs can increase their search conspicuity."

https://www.ncbi.nlm.nih.gov/pubmed/22062342

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3. The research from Denmark (2017)

The effect of a yellow bicycle jacket on cyclist accidents by Harry Lahrmann *et al*. Aalborg Uni, Denmark, published in Safety Science. (August 2017).

This paper's main conclusion is that: *"This randomised controlled study delivered strong evidence that cyclists are protected against multiparty accidents when wearing a bright-coloured jacket."*

Cycling UK looked at its results in depth because they received wide media attention, but conflicted with much of the research we cite above.

a. The study basics:

- This was a year-long randomised control study (Nov 2012 – Oct 2013), and took place in Denmark.
- It involved 6,793 volunteer cyclists, recruited from across Denmark via newspapers, direct email, radio and TV, and recommendations from those who signed up. They had to be at least 18, and ride their bikes at least 3x a week in the summer. The mean age was 46.
- The volunteers were randomly assigned to either the test group (with jackets) or control group (no jackets). The test and control group shared similar characteristics.
- The trial was *'non-blinded'*, i.e. participants knew what the study was about, and whether they were in the test or control group.
- 3,420 agreed to wear yellow reflective jackets (test group) every time they rode for a year; 3,391 wore their 'regular bicycle garments' (control group).
- The jacket was fluorescent yellow, with reflective strips.
- The volunteers were regular cyclists, summer and winter, and their typical destination was work/education. They used their bikes almost every day (in general, that is, i.e. not necessarily during the trial).
- Incidents were *self-reported*, a method chosen because of the high degree of under-reporting of 'personal injury accidents' (PIAs) in Denmark.

- To reduce the possibility that participants would forget about any incidents, they were asked to send in fill in monthly questionnaires (which followed the format used in Danish police records). The forms asked for details of date, location, weather, accident type etc.
- Members of the test group were also asked, in a separate email sent randomly each month, if they wore their jacket the last time they rode.
- For the incident to 'qualify', at least *one* of the following criteria (the 'inclusion criteria') had to be met:
  - the cyclist had to be in physical contact with a counterpart
  - toppled and/or injured as a consequence of the counterpart's behaviour (including damage to the cyclist's belongings, even if no physical contact had occurred)
  - toppled/injured whilst riding without the involvement of others
- Only incidents that happened on public roads were included (thus excluding MTB incidents in forests).

KEY:

- HVZ = those wearing the hi-viz jackets
- NJK = those not wearing the hi-viz jackets
- PIA = personal injury accidents (the authors use the word 'accident' throughout).

b. Results:

- Between them, the two groups reported 833 incidents. Using a quality assurance process, which tested (it seems) the reports against the inclusion criteria (see above), these were whittled down to 694.
- Of these, HVZ reported 274; the NJK reported 420.
- Of these, 302 (44%) were assessed to be 'more severe than bruising', and only these were included in further analyses.

- More 'single' PIAs (i.e. where no one but the cyclist was involved) were reported than 'multiparty' PIAs (i.e. which involved a counterpart): 176 (58%) single; 126 (42%) multiparty. The researchers were surprised by this because they did not expect a hi-viz jacket to make any difference to the number of single PIAs reported by each group. As a result, they suspected 'response bias'.
- *Without compensating for this bias,* the researchers calculated that the 'accident rate per month' (AR) for all PIAs was 47% lower for HVZ than for NJK; and 55% lower for incidents involving cyclists and motor vehicles.
- *When they had corrected for the above bias* using a known formula, the researchers reduced the 47% to 38% (i.e. for all PIAs, multiparty + single).

- The average usage rate of the supplied jacket was 77%, but this varied widely over the year: only 5% failed to wear their jacket in Nov 2012, but this figure rose to 33% in July (probably because of the heat). The researchers included any incidents these participants reported anyway under a principle called 'intention-to-treat'.
- Five months into the trial from April 2013, the researchers gave the HVZ the option of telling them whether they wore 'other yellow/brightly coloured clothing when cycling' (presumably instead of the jacket). This ranged from 5% in April, and 18% in both July and August.

- It seems that NJK cycled slightly more frequently in the winter than HVZ.

- More NJK people answered all of the 12 questionnaires (85.3%), than HVZ people (75.8%).

- To calculate the 'accident rate per month' (AR), the researchers divided the number of PIAs by the total number of 'person months' cycled by the participants. In total (it seems), HVZ reported on 37,526 'person months'; and NJK reported on 38,489. From this, they calculated the

ARR (accident rate ratio). (For their summer and winter estimates, they adjusted the month count accordingly).

- The researchers subtracted any months when they did not hear from a participant. Also, if someone terminated their participation, they subtracted all the months after that.

- Cycle mileage was not accounted for.

c. Queries about this study:

❖ Bias from the researchers and the funders?

- The study's hypothesis was: *"... that the use of high-visibility clothing on the upper body of a cyclist would improve cyclists' visibility and consequently lead to a reduction in the number of multiparty PIAs."*

- The trial was funded by the non-for-profit Danish Foundation TrygFonden, who work to improve safety in range of settings (e.g. roads, water, fire, first aid etc). TrygFonden:
  - were responsible for the design, production and distribution of the jackets to the participants
  - strongly advocate hi-viz and ordinarily supply jackets to cyclists, according its website
  - is owned and funded by the membership organisation TryghedsGruppen, which is in turn funded by dividends from insurance premiums raised by Tryg, an insurance company it owns. Tryg calls itself one of the largest non-life insurance companies in the Nordic region, with 3 million customers.

- When the authors present their AR and ARR calculations, corrected and uncorrected, for multiparty PIAs, they offer figures for most of the data they collected from the questionnaires, but not that on *'contact with police, emergency room and insurance company'*.

Although we are talking about very few incidents here (as, indeed we are with all of the PIAs – see below), the figures not only suggest a higher proportion of HVZ multi-party PIAs were reported by the police and to insurance companies, but that the victims were more likely than NJK seek treatment from the emergency services (rather than just a doctor alone):

MULTIPARTY PERSONAL INJURY ACCIDENTS				
	HVZ		NJK	
	Number	%	Number	%
PIAs in total	43	*100.0*	83	*100.0*
Reported by police	6	*14.0*	8	*9.6*
Reported to insurance companies	16	*37.2*	25	*30.1*
Treatment at emergency room/hospital	13	*30.2*	16	*19.3*
Treatment only by own doctor	1	*2.3*	3	*3.6*
Treatment at emergency room and own doctor	6	*14.0*	4	*4.8*

Moreover, using the same methods as the researchers for calculating the AR and ARR per month, it would appear that HVZ were actually over 1.5x more likely than the NJK to seek treatment at an emergency room *and* their own doctor. They were the sort of incidents, it seems, that they could not underplay or gloss over.

- From April 2013 (i.e. five months into the trial), the researchers gave the HVZ the option of telling them whether they wore *'other yellow/brightly coloured clothing when cycling'* (presumably instead of the jacket). This ranged from 5% in April, and 18% in both July and August. The researchers do not, however, say if they asked the NJK the same question. We therefore have no idea what kind of *'regular bicycle garments'* they wore. They too could have been yellow or bright at times, a factor that could have skewed the result.

- *At the end of the study,* the researchers asked their volunteers to which degree they believed that a *"bright-coloured bicycle jacket/vest can increase your safety in traffic in general?"* 81% in the HVZ and 66% in the NJK answered 'very high' or 'high'. The authors suggest that *"the difference between the two groups may be the result of positive experiences in the test group*

after wearing the jacket for one year". It is not clear, however, why NJK reported much less faith in wearing a bright jacket. This raises questions about whether their experience of not wearing one impacted negatively on their faith in its protective properties.

❖ Bias from the participants?

- This was a *non-blind* study. This means that the participants knew they were testing the safety effect of a hi-viz jacket. The authors themselves note this several times as a possible weakness, e.g.:

"… any difference between the test and control groups indicates a potential reporting bias between the groups, which may occur because the study is non-blinded, and the participants know whether they belong to the test or control group".
"… the risk reduction for the individual cyclist is likely to be even greater than 47% as indicated by the safety effect among participants with high jacket use (60%). […]. Some may argue that this effect seems unrealistically high. This may reflect a weakness in the study design: the fact that it was non-blinded and the use of self-reported accidents, which may result in response bias."
"This study as well as the study of the effect of bicycle lights (Madsen et al., 2013) suggest a bias in the two groups' reporting which could be prompted by the fact that the experiment was non-blinded."
"The internal validity of the trial is affected by the fact that the study is non-blinded."

- To take part in the study, volunteers had to be willing to wear a hi-viz jacket for at least a year. It is much more likely that cyclists well-disposed towards it would prepared to do this than those who are not.
- A possible incentive for the people who were randomly assigned to the NJK group to keep going with the trial was the prospect of *"… receiving a yellow bicycle jacket after the completion of the study".* In other words, they probably rather wanted one.

❖ Possible impact of participant bias

- **Underreporting of PIAs by HVZ**

The authors say: *"… it is possible that the test group [HVZ] reported slightly fewer PIAs than they should because they wanted to prove the safety effect of the bicycle jacket. This source of bias is well-known both in psychology (Nichols and Maner, 2008; Orne, 1962) and in medical research (Rothman et al., 2008)."*

To explain this, the authors suggest that the effect of "increased visibility" amongst HVZ is compensated for by: i) risk adaptation (i.e. that wearing hi-viz makes cyclists adopt a more risky riding behaviour because they feel safer in their jackets); and in the light of ii) British research suggesting that drivers pass more closely to cyclists wearing helmets. As a result, they say: *"… the reporting bias, if any, would result in a lower number of reported PIAs, whereas the risk adaptation would result in a higher number of PIAs, causing the two effects to cancel each other out."*

Precisely why the authors believe these two effects cancel each other out is not clear. Moreover, even if the theory does have some validity, neither effect is quantified. As they do not share their workings or elaborate very much on this theory, it is difficult to see past the authors' reference to risk adaptation, the possibility that HVZ really did adopt a more risky riding style as a result of it and could well have suffered more PIAs than they actually reported – an unmitigated sign of response bias, in other words.

i. **Risk adaptation**: the authors' claim that risk adaptation played a part in this study is, in any case, questionable. Are cyclists really likely to take significantly more risks with their personal safety when they are knowingly involved in testing a jacket whose safety properties they are well-disposed to prove? Are they not more likely to take greater care? Risk adaptation is surely much more likely in people who have bought a jacket for personal reasons because they believe it makes them safer, i.e. people who are not trying to prove anything by it.

Elsewhere, in fact, that the authors argue that all of their volunteers could well have been more likely than the general population to be *risk averse*. This, they speculate, is because they had signed up to use a jacket expected to improve their road safety and were therefore potentially more concerned about safety than most. They then suggest that "safety concerned cyclists" (i.e. like their volunteers) will have a *"presumably defensive"* cycling style. This line of thought allows the authors to contend that the jacket could have *"... a higher effect for the average cyclist, compared to the effect on the group in this study"* (i.e. because, the average cyclist in the external world may be less risk averse than the people recruited for the trial).

So, what of their earlier argument that risk adaptation might cancel out response bias? And, if they do subscribe to risk adaptation after all - a known phenomenon often used to caution *against* putting too much faith in protective accessories like hi-viz and helmets - should it not make the authors a little more cautious about recommending hi-viz to the general population?

Or do they simply think that it makes little difference because, in their view, wearing a hi-viz jacket saves people from the adverse effects of wearing a hi-viz jacket? It is, they say: *"... likely that risk adaptation compensates for the effect of the increased visibility, i.e. cyclists become less careful when they feel more protected (Adams, 1985; Sagberg et al., 1997)." (!)*

ii. **British close pass study:** the study the authors cite here is about helmets, not hi-viz. As it happens, its author Ian Walker also looked at the effect on overtaking distances of different outfits including a hi-viz jacket (see 2d above). His results suggested that: *"... there is little riders can do, by altering their appearance, to prevent the very closest overtakes."*

❖ **The question of 'Single PIAs'**

Obviously, when cyclists crash by themselves, whether they are wearing hi-viz or not is most probably irrelevant. This is something that the authors note, saying that they did not expect jacket-wearing to influence the number of 'single PIAs' reported by each group.

Oddly, there *was* a noticeable difference: the NJK reported more 'single' PIAs than the HVZ (96 v 80).

The authors admit that such a difference *'"indicates a potential reporting bias between the two groups, which may occur because the study is non-blinded, and the participants know whether they belong to the test or control group."* They adjusted their calculations in the light of this, using a known formula (without this correction, the AR for PIAs amongst the test group was estimated to be 47% lower than that of the control group; after this correction, this was reduced to 38%).

The authors do not note, however, what could well be another possible sign of reporting bias, this time in the discrepancies in the *proportion* of single PIAs versus multiparty PIAs reported by each group.

The proportion of single PIAs reported by HVZ was actually *higher* than that reported amongst the NJK group, most significantly for the following:

- In total (65% v 54%)
- In wintertime (74% v 61%)
- In daylight (58% v 45%)

The authors say that neither of the following findings reached statistical significance, but that, amongst HVZ alone:

- A higher proportion of those who reported a high jacket use logged single PIAs than those who reported a low jacket use (72% v 59%)
- Also, those who stated they wore the jacket during the incident was higher than those who said they did not (69% v 56%)

Does this imply that HVZ were more sensitive to single PIAs than NJK? Could this be because they were so convinced of the protective value of hi-viz in terms of driver detection, that they were overly interested in incidents where driver detection was irrelevant (and/or, for that matter, overly disinterested in incidents where driver detection might play a role). Was the opposite the case

NJK, but for the same pro-hiz motivations? Certainly, as discussed above, it looks as if NJKs were recording more trivial incidents on their questionnaires than HVZ.

Does not all the above point to the inherent weakness of non-blind studies and how challenging it is to assess the impact of participant bias?

❖ Calculating risk: months v mileage

The authors decided to calculate the effect of a hi-viz jacket in terms of 'accidents per person a month'. They admit, however:

"Apart from the jacket use, the mileage driven is an important factor affecting the number of accidents. It is generally expected that the higher the mileage (i.e. exposure), the higher the accident number. Although a recording of the mileage could provide insight into this correlation, the study did not record the participants' cycling mileage in the monthly questionnaires."

Arguably, casualties per mile (or trip) is the best measure of risk because it makes exposure far more quantifiable than frequency (especially rather vaguely reported frequency).

Firstly, although the participants agreed to cycle 3x a month, nowhere do the authors confirm that this is what most of them did. It is not unreasonable to assume, however, that some of them did not comply with their undertaking. We do know at least that a fair proportion of them did not cycle at all some months, e.g. 23% of HVZ in February 2013. Therefore, a month of cycling could mean anything from nothing, to 60+ cycling forays. (We assume the authors deducted non-cycling months from the total, but they do not confirm this – all they say is that they deducted months they did not hear from someone, and months after a volunteer's decision to quit the study).

The authors acknowledge that mileage data would have been useful to collect, but decided against it:

"The decision to exclude this was taken partly because the uncertainty related to this estimation would be too large to provide useful information, partly as a result of the RCT design, which split participants into two similar groups, thus reducing the influence of mileage on the safety effect recorded. If mileage is to be recorded, devices such as bicycle computers are preferred in order to ensure better estimates than can be obtained via self-reporting."

Maybe collecting mileage data is problematic, and maybe varying mileage is a confounding factor cancelled out by randomisation, but casualties per mile is still arguably a better measure than risk per month when there is no way of investigating what a month of cycling actually means in terms of exposure.

❖ In perspective:

One thing this study seems to confirm, however, is how low-risk cycling seems to be (at least in Denmark):

It collected data from 6,700 cyclists who were expected to cycle at least three times a week (although some did not manage this).

In 76,015 'person months' worth of data on personal injury accidents (PIAs), only 126 multiparty and 176 single party were filed. This means that three fifths of the very small number of incidents reported altogether (58%) did not involve another vehicle, but the cyclist alone. This suggests that hi-viz/driver detection is not relevant in a good many PIAs involving cyclists (again, at least in Denmark).

Of the 126 multiparty PIAs, 27 occurred while the participant was wearing a hi-vis jacket *or* 'another bright-coloured garment', and 99 incidents where they were not (83 in the control group and 16 in the test group who had not worn their supplied jacket for some reason). That equates to 0.0017 PIAs altogether a month.

Of these, only:

- 14 were reported to the police (= 0.00018 a month)
- 41 were reported to insurance companies (= 0.00054 a month)
- 29 were treated at emergency room/hospital (= 0.00038 a month)
- 4 were treated by own doctor (= 0.000051 a month)
- 10 were treated at emergency room and own doctor (= 0.00013 a month)

This suggests that cycling is not all that hazardous, and personal conspicuity aids such as hi-viz jackets are not a crucial road safety issue.

❖ **And, finally, the authors' own caveats:**

- *"… the effect will most likely decrease if an increasing number of cyclists start using a bright-coloured bicycle jacket because the jacket will not attract as much attention when more cyclists use it."*
- *"… other road users' risk may increase when attention is directed to cyclists with bright-coloured jackets at the expense of other cyclists'.*

http://www.sciencedirect.com/science/article/pii/S0925753517313528

Cherry Allan
Last revised 16/05/2018