Hi-vis for cyclists and other 'conspicuity' measures

This briefing explains Cycling UK's current view on 'hi-vis' (high visibility clothing) and looks at the research that backs it up.

It does not consider lights and reflectors, although some of the studies listed investigate these too.

Contents

1. Cycling UK's current position

If wearing hi-vis helps people feel safer when cycling and more willing to do it, that is only to be welcomed.

It is, though, hard to prove whether hi-vis makes any significant impact on cyclists' safety, and there is very little convincing evidence to support the argument that it does.

Research suggests that hi-vis may help drivers spot cyclists more readily, but it appears that spotting is one thing and driving safely around them another. One academic study, for example, found that whether a cyclist is wearing hi-vis 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 anything that moves when you pedal (e.g. ankle straps) – are probably worth the investment.

Overall, Cycling UK believes that improving cyclists' safety is best served not by making hi-vis clothing compulsory, but by improving driving behaviour, lowering speeds, reducing traffic volume, and providing high-quality facilities. We also believe that all road users, including cyclists, should behave legally and responsibly, which includes obeying lighting regulations.

2. The research informing our current position: summary

Broadly speaking, the studies listed in section 3 fall into two categories. They either:

- Use staged live or simulator experiments to find out whether wearing 'hi-vis' of some kind makes cyclists more detectable / detectable more quickly and/or further away to drivers; OR
- Analyse crash data (or questionnaires, surveys or interviews about crashes and near misses) to see whether hi-vis affects the incidence of collisions in real life.

It is worth bearing this distinction in mind: analysing the results of experiments investigating driver detection is not the same as analysing actual crash (or near miss) data.

This briefing also lists studies relating to the conspicuity of other vulnerable road users (horse riders, motorcyclists and pedestrians) because of their pertinence to cyclists.

As with most research, almost all of it has its strengths, limitations and weaknesses, the conclusions do not necessarily agree and some of the results are neither conclusive nor convincing.

Note: a distinction is usually made between 'fluorescent' and 'retroreflective' clothing or trims:

- Technically speaking, 'fluorescent' material produces light instantly when the atoms inside it absorb energy and become excited. In most (but by no means all) settings, they look bright in daytime. Fluorescent materials are not necessarily yellow.
- 'Retroreflective' material bounces light back to its source. At night, therefore, it can appear to light up in the beam of headlights.

Hi-vis and detecting cyclists

At night, reflective accessories attached to limbs seem to make the most difference as far as detection is concerned. This is probably because they move, and human beings are particularly sensitive to 'biomotion'.[1] (Studies a, b, c & p).

One live experiment also found that fluorescent yellow leggings, paired with a fluorescent top, made a difference to cyclists' conspicuity in daytime. A fluorescent jersey alone proved little better than a black jersey. Again, pedalling motion probably accounts for this. (Study i).

A few of the studies also emphasise the value of retroreflective as opposed to fluorescent clothing at night (Studies b, c).

Contrasting colours (i.e. colours that contrast with the background) seem to help make motorcyclists more detectable – e.g. riding in a black outfit against nothing other than

[1] According to Wikipedia: "Biological motion is motion that comes from actions of a biological organism. Humans and animals are able to understand those actions through experience, identification, and higher level neural processing. Humans use biological motion to identify and understand familiar actions, which is involved in the neural processes for empathy, communication, and understanding other's intentions." https://en.wikipedia.org/wiki/Biological_motion . See also a YouTube film demonstration from 1971: https://www.youtube.com/watch?v=1F5ICP9SYLU

the sky. Contrast may also have a role to play for horse riders. This may (or may not) be true for cyclists as well. (Studies m & n).

Finally, a study on sticking reflective tape to the rear of a bike concluded that it was a good idea for night-time riding. (Study l).

Hi-vis and crash risk/close overtaking

Other studies look specifically at 'hi-vis' and crash risk, i.e. whether crash / near miss rates differ between cyclists who wear hi-vis and those who do not. The results are inconsistent and sometimes counterintuitive.

Analysis of a UK study "... found no evidence that cyclists using conspicuity aids were at reduced risk of a collision crash compared to non-users after adjustment for confounding, but there was some evidence of an increase in risk." (Studies d i & ii).

Another UK study investigated the difference a cyclist's clothing makes to how closely drivers overtake them. The only jacket that made a significant difference was one that prominently featured the word 'police' and a warning that the rider was video-recording their journey. The author concluded that there is little a cyclist can do, in terms of clothing, to stop the "very closest overtakes". (Study e).

Conversely, researchers from Denmark concluded that hi-vis jackets reduce the risk of 'personal injury accidents'. This was based on self-reports from recruited cyclists, about half of whom were asked to wear hi-vis jackets, and half not. It was, though, a 'non-blind' experiment, meaning that the results were at risk of 'response bias' because the subjects knew whether they were in the test or control group and what they were testing (i.e. some could have been invested in proving the protective value of hi-vis jackets). This, along with other weaknesses of the research, is discussed in some detail later. (Study j).

A study from Canada, based on interviews with injured cyclists, returned some rather peculiar findings: while white or light upper body clothing decreased the odds of a cyclist being involved in collision with a motor vehicle in daylight, red/orange/yellow upper body clothing and tail lights increased the odds in the dark. What's more, the authors' 'crude estimates' suggested that reflective clothing also increased the odds of a crash at night, compared to 'black, fluorescent clothing, headlights and tail lights'. The authors also found that using 'multiple visibility aids' is associated with reduced odds of severe injury. (Study g).

A further study on the effect of the built environment, also looked at reported incidents and, in passing, commented on 'reflective' clothing, and recommended it. (Study h).

Mandatory hi-vis

There seems to be only one study that investigated the effect of mandatory hi-vis wearing on overall casualty statistics. Having looked at road crash data from Italy (where hi-vis vests are compulsory at night), the author could only conclude that it had made no detectable difference (but could not tell at the time either how vigorously the police had enforced the law, or whether cyclists had complied with it). (Study k).

Cyclists' perception and attitudes

Some studies conclude that cyclists (and pedestrians) overestimate how visible they are at night. (Studies b, c & t). Some also conclude that cyclists under-rate and under-use

certain types of visibility aid, particularly at night. (Studies: c – retroflective markings on ankles and knees; f – visibility aids, lights & clothing).

Others suggest that cyclists put too much faith in 'bright' clothing as a whole, or certain items in particular (studies: b – fluorescent clothing at night (which isn't designed to reflect light back from headlights in the dark); d – conspicuity aids in general; e. hi-vis clothing at peak commuting times).

Other measures highlighted in the studies (improving driver behaviour, lowering speeds, cycle training and infrastructure)

Unsurprisingly, study n also found that "… increasing the alertness and expectancy of drivers to the presence of PTWs [powered two-wheelers] can increase their search conspicuity."

Likewise, researchers looking into conspicuity for horse riders, noted that experiments that ask drivers to actively search for a vulnerable road user register much higher detection rates and distances than experiments that simply ask drivers to report on anything that grabs their attention. (Study o).

This suggests that the driver training and testing system, along with public road safety campaigns, must stress the importance of always looking properly. After all, 'Driver/Rider failed to look properly' is the 'contributory factor' most often ticked by police attending the scene of a traffic crash (GB)[2]. With cyclists and pedestrians disproportionately represented in road casualty statistics, it is especially crucial for drivers to stay on the alert for vulnerable road users, irrespective of their outfits.

Findings that conspicuity aids appeared to somewhat increase cyclists' odds of a collision led the researchers to state: "Conspicuity aids may not be effective in reducing collision crash risk for cyclists in highly-motorised environments when used in the absence of other bicycle crash prevention measures such as increased segregation or lower motor vehicle speeds." (Study dii).

The horse riding study mentioned above also recommended lower speeds on roads where horse riding activity is relatively high.

Another study (m) found that, while driving, 'motorcyclist motorists' were best at detecting motorcyclists, implying in turn that drivers' awareness of cyclists improves if they cycle too (other research confirms this, in fact[3]). Integrating cycle training with the driver training and testing process would be one of the most effective ways of ensuring this happens.

---

[2] See DfT's Reported Road Casualties Great Britain, Table RAS 50050.
https://www.gov.uk/government/collections/road-accidents-and-safety-statistics

[3] Rogé, Joceline (et al.). Mechanisms underlying cognitive conspicuity in the detection of cyclists by car drivers. Published in Accident Analysis & Prevention. July 2017.
https://www.sciencedirect.com/science/article/abs/pii/S0001457517301343#

3. The research in detail

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 accessories that cyclists wear and lights fixed on bikes. The researchers could not find any studies on crash rates at the time, 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.”

“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

oOo

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.

Their findings suggest that, at night, a reflective vest plus reflectors, is better than a reflective vest alone, a fluorescent vest or black clothing. The authors also cite the value of ankle and knee markings.

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/

oOo

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 or 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/

oOo

d. (i) 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 (this is the phenomenon known as 'risk compensation' or 'risk adaptation')).

Extracts, 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/

and:

d (ii) Use of conspicuity aids by cyclists and risk of crashes involving other road users: Population based case-control study by Phil Miller, Denise Kendrick, Carol Coupland, Frank Coffey. Published in Journal of Transport & Health (2017).

This is clearly based on the same study as (i), but published in a peer-reviewed journal.

Extracts, as published:

"…. The unadjusted OR [odds ratio] for a collision crash when using any conspicuity aid vs none was 1.2 (95% CI 0.7 to 2.2) and 2.4 (95% CI 1.1 to 5.6) after adjustment for age, gender, index of multiple deprivation score, route risk score and previous bicycle crash."

"Conclusion

This study found no evidence that cyclists using conspicuity aids were at reduced risk of a collision crash compared to non-users after adjustment for confounding, but there was some evidence of an increase in risk. Bias and residual confounding from differing route selection and cycling behaviours in users of conspicuity aids are possible explanations for these findings. Conspicuity aids may not be effective in reducing collision crash risk for cyclists in highly-motorised environments when used in the absence of other bicycle crash prevention measures such as increased segregation or lower motor vehicle speeds."

https://www.sciencedirect.com/science/article/pii/S2214140516303796

oOo

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 (blind) 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

oOo

f. Visibility-related characteristics of crashes involving bicyclists and motor vehicles – Responses from an online questionnaire study by Philippe Lacherez, Joanne M. Wood, Ralph P. Marszalek, Mark J. King, published in Transportation Research Part F: Traffic Psychology and Behaviour, Volume 20 (2013)

This paper analyses the results of an online survey of cyclists involved in crashes with motor vehicles. Respondents were asked what kind of visibility aids (VAs – lights and clothing) they were wearing at the time of the crash (along with questions about the perceived cause of the collision, weather and visibility). 184 cyclists were surveyed, mostly from Australia.

The authors say in their abstract:

"Over a third of the crashes occurred in low light levels (dawn, dusk or night-time), which is disproportionate given that only a small proportion of bicyclists typically ride at these times. Importantly, 19% of these bicyclists reported not using bicycle lights at the time of the crash, and only 34% were wearing reflective clothing. Only two participants (of 184)

nominated bicyclist visibility as the cause of the crash: 61% attributed the crash to driver inattention. These findings demonstrate that crash-involved bicyclists tend to under-rate and under-utilise visibility aids as a means of improving their safety."

https://www.sciencedirect.com/science/article/abs/pii/S1369847813000508

oOo

g. The relationship between visibility aid use and motor vehicle related injuries among bicyclists presenting to emergency departments by B.E.Hagel, N.T.R.Romanow, N.Morgunov, T.Embree, A.B.Couperthwaite, D.Voaklander, B.H.Rowe published in Accident Analysis & Prevention, Vol 65 (2014)

This is a write-up of a study to determine whether visibility aids (VA) reduce the risk of a cyclist experiencing a collision with a motor vehicle (MV). The authors considered such things as reflectors, lights and various types of clothing.

The researchers looked at cyclists struck by a MV and assessed at emergency departments in Calgary and Edmonton, Alberta Canada, May 2008 – October 2010 (there were 278 cases all told, out of 2,403 injured cyclists). Controls were bicyclists with non-MV injuries. Participants were interviewed about their personal and injury characteristics, including use of VAs.

Having adjusted for a variety of factors (e.g. age, sex, type of cycling, speed and upper body clothing colour), the authors concluded that (to quote):

"Visibility aid prevalence is low among injured bicyclists."

"In daylight, white or light upper body clothing decreased the odds of a bicyclist–motor vehicle crash.

"In the dark, red/orange/yellow upper body clothing and tail lights increased the odds of a bicyclist–motor vehicle crash.

"Using multiple visibility aids is associated with reduced odds of severe injury in bicyclists."

Despite the fact that reflective clothing is designed for use at night and fluorescent clothing for the day, the authors' 'crude estimates' indicated that during dark conditions, "reflective clothing or other items, red/orange/yellow front upper body clothing compared with black, fluorescent clothing, headlights and tail lights were estimated to increase the odds of a MV collision."

https://www.sciencedirect.com/science/article/abs/pii/S0001457513005113?via%3Dihub

oOo

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

From the USA, this is not a study of hi-vis 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."

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

oOo

i. 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), 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 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 as a whole, 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

oOo

j. 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 conclusion, which stirred much media interest at the time, is that: "This randomised controlled study delivered strong evidence that cyclists are protected against multiparty accidents when wearing a bright-coloured jacket."

The authors deduced this by analysing reports from 6,793 volunteer, regular cyclists recruited across Denmark, who were randomly assigned either to a test group (with jackets = HVZ) or control group (no jackets = NJK). (My highlighting).

The test and control group shared similar characteristics, the typical destination was work/education and the study lasted from 1 November 2012 to 31 October 2013.

The jacket was fluorescent yellow, with reflective strips.

The researchers collected monthly reports from their participants on both single 'personal injury accidents' (PIAs, where only the cyclist was involved) and on multi-party PIAs (involving a motor vehicle).

The incidents had to be on public roads and meet at least one of the following criteria:

- 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.

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 – NJK cycled slightly more person months than HVZ (around 38,500 to 37,500). From this, they worked out the accident rate ratio (ARR).

This led the researchers to state that:

- The AR for all PIAs (single and multi-party) was 47% lower for people wearing hi-vis jackets than those not wearing jackets; and 55% lower for incidents involving cyclists and motor vehicles.
- They had identified a 'response bias' (see below) and adjusted for it. This reduced the 47% to 38%.

Note: this study's hypothesis was clearly pro-hi-vis: "... 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." Also, the trial was funded by an organisation who strongly advocates hi-vis and ordinarily supply jackets to cyclists, according to its website at the time).

The following weaknesses and limitations are also worth noting:

- Although this was a large, year-long study, representing over 76,000 'person months', the sample of PIAs that met the researchers' criteria was very small - just 302:

Test group		Control group	
Multiparty PIAs	Single PIAs	Multiparty PIAs	Single PIAs
43 (35%)	80 (65%)	83 (46%)	96 (54%)

(Apart from anything else, this implies that cycling in Denmark is not unduly risky!).

- This was a 'non-blind' study. As a result, it could well have suffered from 'response bias' because the participants knew whether they were in a test or control group and what they were testing. As such, the authors admit that "... 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…". In fact, they point to the weaknesses of a non-blind trial several times (e.g. "The internal validity of the trial is affected by the fact that the study is non-blinded.")

- The authors speculate: "It is likely that risk adaptation compensates for the effect of the increased visibility, i.e. cyclists become less careful when they feel more protected." They suggest that this helps cancel out the participants' response bias (along with the finding, from a British study, that drivers pass helmeted cyclists more closely). (Looked at another way, this seems tantamount to claiming that wearing a hi-vis jacket saves people from the adverse effects of wearing a hi-vis jacket; and that these added hazards simply gave HVZ yet more incidents not to report).
- Yet the authors argue elsewhere that all their volunteers could well have been more likely than the general population to be risk averse because they had signed up to use a jacket expected to improve their road safety (NJK were promised a free jacket at the end of the trial). This line of thought allows them 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. (Although it could equally well be argued that anyone who buys themselves a hi-vis jacket is as likely to be as risk adverse – or have been encouraged to become as risk adverse – as someone who signs up for a hi-vis jacket trial; and that recommending hi-vis to the wider, less risk adverse population (if it is indeed less risk adverse) could lead to more people 'risk adapting' and putting themselves in greater jeopardy. 'Risk adaptation' is, after all, a known phenomenon often used to caution against putting too much faith in other protective accessories such as helmets).
- The authors did not account for cycle mileage, despite acknowledging that: "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."
- Although the participants agreed to cycle 3x a month, nowhere do the authors confirm that this is what most of them did. Nonetheless, they base their calculations on whole months in which a participant cycled, so do not factor in how many trips they did (another good way of determining exposure). (Note that NJK cycled a little more than HVZ, at least in terms of months).
- There were no months when 100% of HVZ riders wore their jackets "on a random day": this ranged from 84% in November 2012, to 25% in July 2013. To get round this, the researchers asked all HVZ riders to specify whether they wore other yellow/bright clothing instead from April 2013, but did not give the control group this option. It is not impossible, therefore that some NJK riders were sometimes 'brightly' clothed too. (Whether they were wearing their jacket/bright clothing or not, all qualifying HVZ PIAs were always logged against HVZ).
- In numeric terms, HVZ reported significantly fewer single PIAs than NJK (no motor vehicle involved). The authors say: "the bicycle jacket was not expected to affect the number of single accidents" and put this anomaly down to 'response bias'. The authors therefore adjusted for this.

- Oddly, though, they say that the proportion of single PIAs was higher amongst HVZ than for NJK (65% v 54%). What's more, they state: "Among respondents who reported a high jacket use, the proportion of single PIAs was higher (72%) than among respondents with low jacket use (59%). Finally, among those who stated that they wore the jacket during the accident, the proportion of single PIAs was higher (69%) compared to the proportion among those who reported that they did not (56%). However, the two latter comparisons did not reach statistical significance." 'Risk adaptation' is a possible explanation for this (see above), as is response bias (perhaps because HVZ, keen to prove the value of jackets, might have been tempted to downplay multi-party incidents and (overly) willing to report those where driver detection was irrelevant).
- Although the authors do not highlight this, their figures suggest that HVZ's incidents tended to be more serious than NJK: not only was a higher proportion of HVZ multi-party PIAs "reported by [sic] the police" and to insurance companies, but the victims were more likely to seek treatment from the emergency services, rather than just a doctor alone. Clearly, these were incidents they couldn't gloss over:

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*

- Finally, the authors finish with a couple of caveats of their own:

"… 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

oOo

k. 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 to which the police enforced it, and whether cyclists had 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:

"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

oOo

I. 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: journal of the Human Factors & 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.

https://www.ncbi.nlm.nih.gov/pubmed/27923887

oOo

m. 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 (average of 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

oOo

n. 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)

This is a study from the Ben-Gurion University of the Negev, 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

o. Conspicuity of horses and riders on roads by Weekley J, Helman S & Wann J. TRL report PPR845. (2017).

This report was prepared for the British Horse Society and based on a review of existing literature. The authors found only three relevant studies on horse riding.

Two were questionnaire-based (i.e. relying on self-reporting), which led them to conclude: "...two elements that may be worth considering in providing a possible safety advantage when riding on the road network; these are the addition of lights to any equipment worn and the selection of horses of broken colour." (Horses of broken colour - piebald or skewbald - experienced significantly fewer near misses than horses of block colour).

The third study gives the results of an experiment in which drivers were shown images of horse riders wearing dark, fluorescent or black/white tabards and asked to indicate when they saw them. Of this, the authors conclude:

"The results showed no statistically significant difference between response times for the fluorescent tabard and the black/white tabard, however there was a significant difference between the times for the black/white tabard and the dark colour, and between the fluorescent tabard and the dark colour, with the dark tabard being associated with longer response times (i.e. slower detection).

"This third study indicates that drivers may have a quicker response time when presented with a horse-rider combination wearing either a fluorescent or broken-colour tabard than with a dark colour tabard (or none)."

They caution, however, that:

"These findings would not necessarily be replicated in a live environment, nor would the drivers' behaviours necessarily change as a result of the quicker identification; however

it is possible that such clothing may allow a driver additional time in which to perceive the hazard and respond."

With so few conspicuity studies of horse riders, the report looks at evidence on other vulnerable road users too. As a result, its recommendations emphasise biomotion and contrast:

"Riders should use bright and reflective safety clothing wherever feasible. Again ideally this should cover as much of the rider and horse as possible, prioritising covering width extent above height, although also on the legs to introduce 'biological motion' cues. There is no firm evidence to say one colour is more visible than any other across multiple environments; riders should consider the dominant colours in their riding environment (e.g. coloured foliage and crops, backgrounds associated with sunsets) and choose a colour which will provide contrast accordingly."

They also recommend LED lights in clothing and speed limit reduction and enforcement on roads with significant horse / rider activity.

Importantly, the authors note that experiments do not necessarily replicate real-life (see above); and that detection rates and distances in experiments are affected by whether drivers are asked to search actively or report on anything that grabs their attention.

The latter kind of experiment which is, arguably, closer to real life conditions, demonstrates much lower 'safety margins'. Hence they caution "...it is not likely that drivers are always actively searching for pedestrians, or indeed for any other vulnerable road user group." This implies that driver training is crucial.

https://trl.co.uk/publications/conspicuity-of-horses-and-riders-on-roads

oOo

p. High visibility safety apparel and nighttime conspicuity of pedestrians in work zones , Journal of Safety Research (2004)

q. Conspicuity of high-visibility safety apparel during civil twilight, University of Michigan (2006)

r. The roles of garment design and scene complexity in the daytime conspicuity of high-visibility safety apparel, Journal of Safety Research (2008)

By James R Sayer & Mary Lynn Mefford (University of Michigan)

These studies focussed on road construction and maintenance workers and the effect of personal safety garments of various kinds. The first trial simulated conditions on a closed track, while the other two were carried out in more naturalistic conditions on public roads. In all cases, drivers were asked to search actively for a pedestrian (something that they may not be doing in real life).

The authors found that retroreflective trim improves conspicuity at night, particularly if it is located on the sleeves, most likely because it emphasises biomotion. Arm motion, however, did not affect conspicuity in daylight or twilight.

They also concluded that the complexity of the surrounding scene significantly affected detection distances: "The more background information a driver has to search through,

the longer it is likely to take the driver to locate a pedestrian -- even when wearing a high-visibility garment."

https://www.sciencedirect.com/science/article/abs/pii/S0022437504000908?via%3Dihub
https://trid.trb.org/view/889965
https://www.sciencedirect.com/science/article/abs/pii/S0022437508000443?via%3Dihub

oOo

s. Seeing pedestrians at night: visual clutter does not mask biological motion by Richard A Tyrrell , Joanne M Wood, Alex Chaparro, Trent P Carberry, Byoung-Sun Chu, Ralph P Marszalek, published in Accident Analysis & Prevention (2009)

As the title suggests, these researchers found that, at least on a closed road at night, "... even in the presence of visual clutter pedestrians wearing biological motion configurations are recognized more often and at greater distances than when they wear a reflective vest."

https://www.sciencedirect.com/science/article/abs/pii/S0001457509000281?via%3Dihub

oOo

t. 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

Cherry Allan. Last revised March 2021