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The effect of a yellow bicycle jacket on cyclist accidents

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ABSTRACT

This study is the first randomised controlled trial (RCT) of the safety effect of high-visibility bicycle clothing. The hypothesis was that the number of cyclist accidents can be reduced by increasing the visibility of the cyclists. The study design was an RCT with 6793 volunteer cyclists – 3402 test cyclists (with a yellow jacket) and 3391 control cyclists (without the jacket). The safety effect of the jacket was analysed by comparing the number of self-reported accidents for the two groups. The accident rate (AR) (accidents per person month) for personal injury accidents (PIAs) for the test group was 47% lower than that of the control group. For accidents involving cyclists and motor vehicles, it was 55% lower. The study was non-blinded, and the number of reported single accidents was significantly lower in the test group than in the control group. This is likely a result of a response bias, since the bicycle jacket was not expected to affect the number of single accidents. To compensate for this bias, a separate analysis was carried out. This analysis reduced the effect of the jacket from 47% to 38%.

1. Introduction

Cycling is regarded a healthy and environmentally friendly means of transport (Hosking et al., 2011). However, cyclists are an exposed road user group. In 2010, nearly 2000 cyclists were killed in traffic accidents in the EU, corresponding to 7% of all traffic fatalities (Candappa et al., 2012). In Denmark, the risk of cyclist accidents is significantly higher than for other road user groups (Hansen and Jensen, 2012), and the risk is most likely even far greater than reflected by the official Danish accident statistics. Research suggests a degree of under-reporting of bicycle personal injury accidents (PIAs) in Denmark of up to 86% for severely injured and 94% for slightly injured in the official Danish accident statistics (Janstrup et al., 2016). Similarly, de Geus et al. (2012) and Heesch et al. (2011) found that accident rates among cyclists and the degree of under-reporting are both high.

A review study from The Cochrane Library (Kwan and Mapstone, 2009) studied randomised controlled trials (RCT) to assess the effects of increasing pedestrian and cyclist visibility. The study found 42 studies comparing the visibility with and without visibility aids. These studies showed that fluorescent materials improved drivers' detection during the day, while lamps, flashing lights and retroreflective materials improved the detection at night. The review found no studies that measured the effect of increased visibility on the number of accidents. Wood et al. (2013) also found that fluorescent and retroreflective materials improved cyclists' visibility. Tin Tin et al. (2013) shared the same hypothesis, but could not confirm this.

Several studies have assessed the effect of conspicuity aids for cyclists on the accident rate (AR) (Chen and Shen, 2016; Hagel et al., 2014; Heesch et al., 2011; Hoffmann et al., 2010; Lacherez et al., 2013; Madsen et al., 2013; Miller, 2012; Teschke et al., 2012; Thornley et al., 2008; Tin Tin et al., 2014, 2013; Wood et al., 2009). Most of these studies found no significant results and were not RCT studies. Madsen et al. (2013), however, conducted an RCT to assess the effect of running lights for cyclists and used self-reported accidents to estimate the effect. They found that the number of accidents decreased by 61%. In a study of 9 years of cycling accidents in Seattle, Chen and Shen (2016) observed a lower likelihood of injuries for bicyclists wearing reflective clothing.

Herslund and Jørgensen (2003) suggested that increasing the visibility of cyclists could reduce the number of 'looked but failed to see'-accidents between motorised vehicles and cyclists. This view was supported by a Finnish study of vehicle-bicycle accidents which concluded that accidents occur because motorists notice the cyclist too late (Räsänen and Summala, 1998).

82% of all Danish multiparty accidents involving cyclists occur in daylight (The Danish Road Directorate, 2017). Thus, it is important to find measures that can reduce the number of cyclist accidents in daylight, for instance the use of fluorescent materials which could improve

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Fig. 1. The bicycle jacket.

the detection by drivers as shown by Kwan and Mapstone (2009). The objective of this study was to assess the potential of achieving a reduction in accident occurrence by increasing cyclists' visibility using a yellow bicycle jacket (Fig. 1). The hypothesis of this study 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. Furthermore, it was hypothesised that the safety effect would be higher in winter than in summer, and higher in daylight and twilight than in the night time.

2. Method

2.1. Study design

The effect of the jacket was tested in an RCT with self-reporting of accidents. This reporting method was chosen because as mentioned above, the degree of underreporting of personal injury bicycle accidents in Denmark is very high. Participants were randomly assigned to a test and a control group. The test group participants agreed to the condition of wearing the reflective bicycle jacket every time they would ride their bicycles during the study period, i.e. for one full year. During that same year, the control group would wear their regular bicycle garments.

2.2. Participants

Participants were recruited from across Denmark via newspapers, direct email contact and radio and TV interviews. Furthermore, people who had signed up could recommend others to participate, and the former then participated in a lottery to win a prize. A detailed description of the recruitment for the study and the practical execution is available in Hansen et al. (2014).

In total, 11,202 cyclists signed up for the study. Only cyclists who would ride their bicycle at least three times a week in the summer and who were at least 18 years old when signing up were recruited. 366 registrations were rejected because they failed to meet the criteria, see Fig. 2. The cyclists were stratified on the jacket size (S-XXXL) since the jackets were produced in advance and therefore limited in amount. Thus, not all cyclists who signed up were selected to participate.

8042 participants were randomly assigned to the test and control groups. Of these, 6793 participants confirmed their participation (test group, n = 3402, control group, n = 3391). The test group participants received the yellow bicycle jacket to wear during the study period, while the control group used their regular bicycle garments with the prospect of receiving a yellow bicycle jacket after the completion of the study.

The demographic characteristics of the participants and the overall Danish population are shown in Table 1. The mean age of the participants was 46 years, i.e. approx. 2.5 years below that of the average Danish population. They used their bicycles almost every day both summer and winter, and their typical destination was work/education. Although they frequently rode their bicycles, 80% of the participant households had at least one car, compared to only 60% of the Danish population in general. The test and control groups shared similar characteristics. However, the study participants in the two groups differed by one year in age and slightly in the frequency of their daily use

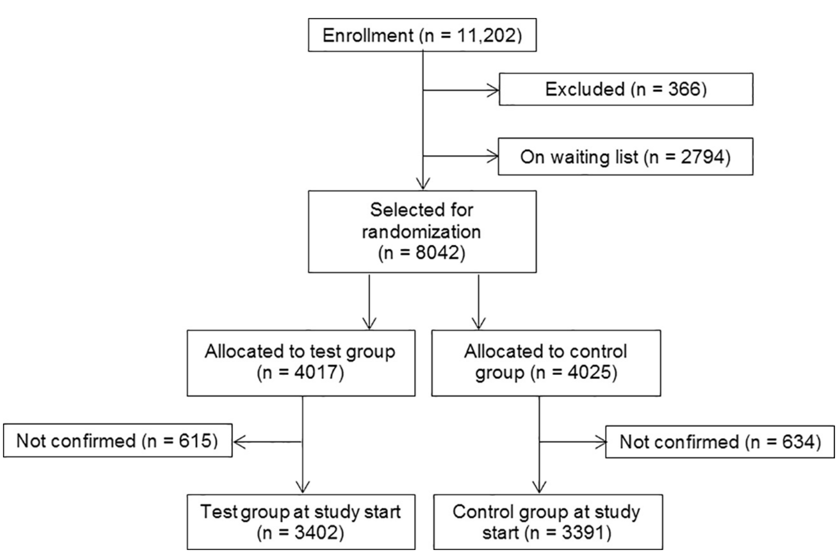

Fig. 2. Flowchart for recruitment.

Table 1
Participant characteristics.

Characteristics	Test group (n = 3402)	Control group (n = 3391)	p[a]	Danish population ≥ 18 years (Statistics Denmark, 2016)
Gender				
Women	42.8%	43.7%	0.48	50.8%
Men	57.2%	56.3%		49.2%
Age				
Mean	46.2 years	45.4 years	0.003	48.7 years
Car ownership				
No car in the household	17.8%	19.9%	0.11	40.3%
1 car in the household	63.6%	62.0%		45.1%
2 cars in the household	17.7%	17.0%		12.9%
> 2 cars in the household	0.9%	1.1%		1.4%
Use of bicycle – winter				
Daily	51.5%	52.3%	0.05	
3–4 times a week	38.0%	38.1%		
1–2 times a week	9.8%	9.0%		
Approx. every two weeks	0.5%	0.5%		
Monthly	0.1%	0.1%		
Rarely	0.3%	0.0%		
Use of bicycle – summer				
Daily	73.3%	74.2%	0.42	
3–4 times a week	26.7%	25.8%		
Most frequent destination				
To/from work/education	72.6%	73.3%	0.76	
To/from shopping	3.7%	3.6%		
To/from leisure activities	4.2%	3.8%		
To/from visiting family/friends	0.6%	0.5%		
Bicycle rides for the experience/exercise	17.9%	17.4%		
Business trips (e.g. delivering goods)	0.2%	0.3%		
Other	0.8%	1.1%		

[a] Comparison of test and control groups by chi-square tests except by *t*-test for age.

of a bicycle during winter time, when the control group cycled more frequently than the test group.

2.3. Questionnaires

2.3.1. Recruiting questionnaire

When signing up for the study, participants completed a web-based questionnaire containing demographic information: subject characteristics (gender, age), car ownership (yes/no), bicycle riding frequency (intervals) and jacket size needed.

2.3.2. Accident questionnaire procedure

The project was conducted between 1 November 2012 and 31 October 2013. On the first day of each month, all participants received an e-mail with a link to a web-based questionnaire (Lahrmann and Madsen, 2014). In the e-mail, they were asked whether or not they had been involved in an accident on their bicycle during the previous month. In the case of a positive response, they were guided through a questionnaire to fill out accident details corresponding to the details in the Danish police records (for more information cf. Section 2.4).

2.3.3. Questionnaire about the use of the jacket

Once a month, on a random day, the test group received another web-based questionnaire in which they were asked whether they had worn the bicycle jacket the last time they rode their bicycle. The goal of this questionnaire was to monitor the usage rate of the jacket. (Lahrmann and Madsen, 2014)

2.4. Variables in the accident questionnaire

The accident questionnaire stated that a cycling accident could be an accident in which the participant had hit another road user, i.e. multiparty accidents, but also a single accident with no other road users involved. Participants were also asked to report accidents in which they were not injured. Later on, all reported accidents were reviewed by the researchers, and only accidents in which the participant was cycling and which occurred in Denmark on a public road were included. This was to exclude mountain bike accidents in the forest, for instance. Furthermore, at least one of the following criteria must be met:

- The cyclist had been in physical contact with a counterpart.
- As a consequence of the counterpart's behaviour, the cyclist had been toppled and/or injured. This criterion also included damage to the cyclist's belongings, even though no physical contact between the road users had occurred.
- The cyclist had been toppled and/or injured during the bicycle ride without the involvement of other road users.

In addition, the participants were asked to report several factors regarding the accident, such as date and time of day of the accident, accident location (e.g. intersection), accident type (e.g. rear-end collision), counterpart (e.g. bicyclist), state of the road (e.g. wet), lighting conditions (e.g. dark), weather (e.g. snowing), any personal injury (e.g. scratches), whether the accident was reported to the police and/or the cyclist's or the counterpart's insurance company, whether the accident had required a visit to the hospital emergency room or to a doctor. Participants were also asked to give a prose description of the accident. Finally, they were asked to access Google Maps (www.maps.google.com) and to locate the accident on the map and copy the coordinates from the accident location into the questionnaire.

2.5. Statistical analysis

The effect of the bicycle jacket was evaluated through comparisons of ARs (accidents per person month) in the test and control groups according to the principle of intention-to-treat (Rothman et al., 2008). This principle compares all participants in the randomised groups, even if some participants in the test group did not wear the jacket, and prevents confounding bias (Rothman et al., 2008). Since ARs were estimated, the relevant measure of association was the accident rate ratio (ARR), i.e. ratios of ARs in the test and control groups, which takes into account any differences in the number of months participants are

Table 2
Use of bicycle jacket on a random day (test group, n = 3402).

Month	Used the jacket [%]	Wore other yellow/brightly coloured clothing when cycling[b] [%]	Cycled without yellow jacket [%]	Did not cycle this month [%]	No answer [%]
Nov. 2012	84	–	5	4	7
Dec. 2012	73	–	6	16	4
Jan. 2013	70	–	10	14	5
Feb. 2013	59	–	12	23	6
Mar. 2013	60	–	17	16	7
Apr. 2013	62	5	15	11	7
May 2013	50	13	24	6	7
Jun. 2013	39	17	30	6	8
Jul. 2013	25	18	33	15	9
Aug. 2013	34	18	31	9	8
Sep. 2013	47	12	23	9	9
Oct. 2013	50	7	20	12	11

[b] The option to specify other yellow/bright-coloured clothing was not included until April.

involved. Months during which we did not receive any emails from a participant were subtracted from the total of 12 months per person. If a participant requested to terminate participation, the following months were not included for that participant. Because bicycle accidents are relatively rare, ARRs can be interpreted as odds ratios and risk ratios, i.e. we may speak about the odds of bicycle accidents being higher in the control group – thus facilitating comparisons with other studies (Hels et al., 2011; Kirkwood and Sterne, 2003). All statistical analyses were based on counts of PIAs. The significance level was set at 0.05.

The bicycle jacket is expected to influence the number of multiparty PIAs, whereas the number of single PIAs is not likely to be affected by jacket wearing. Therefore, 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. We adjusted for potential report bias as suggested by Madsen et al. (2013) by correcting the risk of multiparty PIAs in the control group, using a correction factor equal to the estimated ARR for single PIAs as a general correctional factor

$$C_{j,C,corr} = ARR_{single,j,C}.$$

The index j refers to type of accident (e.g. winter accidents) and the index C means "Control group". Specifically,

$$C_{j,C,corr} = \frac{80\ single\ PIAs/37{,}526\ person\ months}{96\ single\ PIAs/38{,}489\ person\ months} = 0.85$$

with data from Tables 3 and 4.

This correctional factor was multiplied by the reported number of PIAs in the control group, thus reducing the number of PIAs in the control group caused by the likely underreporting of PIAs in the treatment group (Madsen et al., 2013). The corrected ARs for the control group were estimated in the following way:

$$AR_{multiparty,j,C,corr} = AR_{multiparty,j,C} \times C_{j,C,corr}$$

In practice, the corrected analysis was based on an estimate of a corrected ARR given by the relative difference between the multiparty ARR and the single ARR:

$$CorrARR_{multiparty,j} = \frac{AR_{multiparty,j,T}}{AR_{multiparty,j,C,corr}} = \frac{ARR_{multiparty,j,T}}{ARR_{single,j,C}}$$

As the ARRs are likely to be skewed, the standard errors are usually estimated through a transformation to the logarithmic scale. The standard error of the corrected ARR of multiparty PIAs on the logarithmic scale was given by:

$$SE(ln(CorrARR_{multiparty,j})) = \sqrt{SE(ln(ARR_{multiparty,j,T}))^2 + SE(ln(ARR_{single,j,C}))^2}$$

And the formula of the 95% confidence interval on the logarithmic scale:

$$ln(CorrARR_{multiparty,j}) \pm 1.96SE(ln(CorrARR_{multiparty,j}))$$

The 95% limits were then back-transformed. In practice, the standard error on a logarithmic scale can be estimated in the following way:

$$SE(ln(CorrARR_{i,j})) = \sqrt{\frac{1}{X_{i,j,T}} + \frac{1}{X_{i,j,C}}}$$

where X denotes the number of PIAs, i is either "multiparty" or "single" and T denotes the test group and C the control group.

3. Results

3.1. Jacket use

The average usage rate of the bicycle jacket or other types of yellow/bright-coloured clothing over the year (percentage of days wearing jacket out of all survey days) was 77% for the participants who rode their bicycle in that particular month. However, a large variation was seen in the usage rate during the 12 months of the study. The highest usage rate was in the first month of the study (November) and the lowest was in July (Table 2).

3.2. Response rate of accident questionnaires

The majority of all participants answered all twelve questionnaires. The response rate was higher in the control group than in the test group (test: 75.8%, control: 85.3%) (Table 3). Only a few participants discontinued their involvement in the study by email or telephone or by not answering any of the questionnaires (test: 3%, control: 1.9%).

3.3. Accidents

From 1 November 2012 to 31 October 2013, the participants reported 833 accidents. In the quality assurance process, 139 accidents were excluded, resulting in a final number of accidents of 694. Of these, 274 accidents were reported by the test group, and 420 were reported by the control group. Participants' residences as well as accident locations were spread across the country (Fig. 3).

On the basis of the participants' accident descriptions, it was assessed whether the accidents were single or multiparty accidents. Furthermore, the severity of the accident was assessed. A total of 302 accidents (44%) were assessed to be PIAs which were more severe than bruising, and only these were included in the further analyses. PIAs of the test group occurring at times when the participants were not wearing the yellow jacket were included in the accident number according to the principle of intention-to-treat.

In all types of PIAs, except those in which cyclists suffering accidents were treated both at the hospital emergency room and by their

Table 3
Responses to the accident questionnaire.

	Test group (n = 3402)	Control group (n = 3391)
People resigning from the study during the year	27 (0.7%)	10 (0.3%)
People never answering an accident questionnaire	78 (2.3%)	54 (1.6%)
People answering between 1 and 11 accident questionnaires	746 (21.9%)	446 (13.2%)
People answering all 12 accident questionnaires	2578 (75.8%)	2891 (85.3%)
Answered accident questionnaires	37,526	38,489

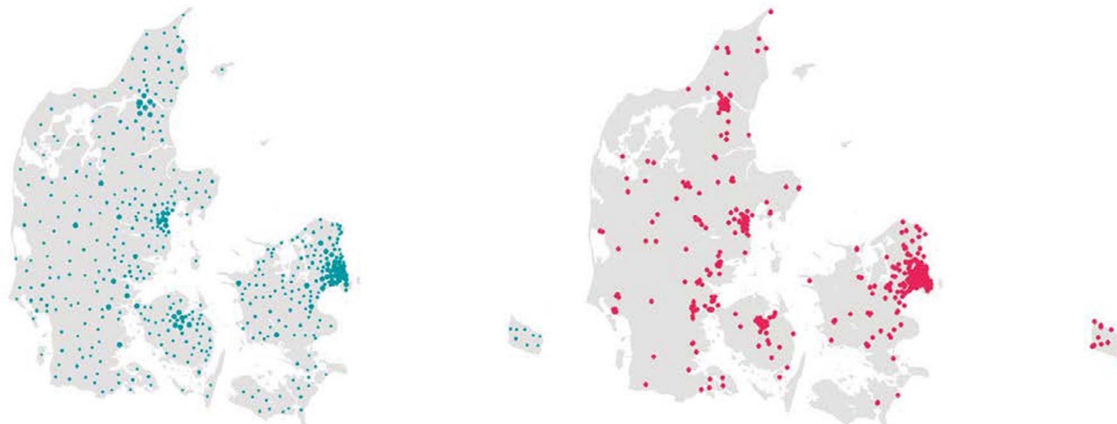

Fig. 3. The 6793 participants' places of residence (left) and the 694 reported accidents (right).

Table 4
Characteristics of PIAs shown by the number of PIAs (n = 302) and the proportion of multiparty and single PIAs, respectively, for each characteristic. Low and high use of the bicycle jacket represents the 50% of the participants with the lowest and highest usage rate, respectively.

Accident characteristics	Test group		Control group	
	Multiparty PIAs	Single PIAs	Multiparty PIAs	Single PIAs
PIAs in total	43 (35%)	80 (65%)	83 (46%)	96 (54%)
Season				
Winter	17 (26%)	49 (74%)	39 (39%)	62 (61%)
Summer	26 (46%)	31 (54%)	44 (56%)	34 (44%)
Lighting conditions				
Daylight	33 (42%)	45 (58%)	67 (55%)	55 (45%)
Twilight	5 (33%)	10 (67%)	6 (29%)	15 (71%)
Dark	5 (17%)	25 (83%)	10 (28%)	26 (72%)
Usage rate of bicycle jacket				
Low use of bicycle jacket	26 (41%)	37 (59%)	–	–
High use of bicycle jacket	17 (28%)	43 (72%)	–	–
Usage of bicycle jacket at accident				
Wore the bicycle jacket or another bright-coloured garment	27 (31%)	60 (69%)	–	–
Did not wear the bicycle jacket	16 (44%)	20 (56%)	–	–
Counterpart				
Light counterpart (cyclist, pedestrian)	23	–	37	–
Motorised counterpart (moped, MC, car, van, truck/bus)	20	–	46	–
Contact with police, emergency room and insurance company				
Reported by police	6 (86%)	1 (14%)	8 (100%)	0 (0%)
Reported to insurance companies	16 (62%)	10 (38%)	25 (61%)	16 (39%)
Treatment at emergency room/hospital	13 (42%)	18 (58%)	16 (43%)	21 (57%)
Treatment only by own doctor	1 (33%)	2 (67%)	3 (33%)	6 (67%)
Treatment at emergency room and own doctor	6 (86%)	1 (14%)	4 (44%)	5 (56%)

own doctors, the number of multiparty PIAs was higher in the control group than in the test group (Table 4). Single PIAs showed a similar pattern, i.e. larger numbers of single PIAs were seen in the control group than in the test group. In particular, the overall proportion of single PIAs was greater for the test group (65%) than for the control group (54%) ($p = 0.06$). The same pattern was found during winter time, showing a higher proportion of single PIAs for the test group (74%) compared to the control group (61%) ($p = 0.10$). In daylight, an almost significantly higher percentage of single PIAs was seen in the test group (58%) compared to the control group (45%) ($p = 0.11$). 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.

3.4. Safety effect of the bicycle jacket

Table 5 shows the safety effect of the bicycle jacket. Overall, the bicycle jacket reduced the number of multiparty PIAs by 47% (ARR-1.00 = 0.53–1.00 = −0.47) (Table 5). For motorised counterparts, the safety effect was 55%. The safety effect was higher in winter (56%) than in summer (39%), higher in daylight (51%) than for the overall effect (47%), and higher for participants with high jacket use (60%) than for those with low use (33%) (Table 5). When corrected for response bias, the effects were reduced (Table 6). For instance, the effect on multiparty PIAs was reduced from 47% to 38%.

4. Discussion

4.1. Safety effect of the bicycle jacket

This study found that the overall accident rate ratios for multiparty PIAs were 47% lower for test cyclists than for the control group cyclists. This effect is of the same magnitude as the effect of the permanent running light (41%) (Madsen et al., 2013). The hypothesis was that the

Table 5
ARs, ARRs and 95% confidence intervals for ARRs. The closer ARR is to 1.00, the lower the effect of the treatment. An ARR below 1.00 indicates a decrease in the number of accidents in the test group. All ARRs marked with * were statistically significant.

Multiparty PIAs	AR * 10^3		ARR	95% CI (ARR)
	Test group	Control group		
All	1.15	2.16	0.53*	[0.37; 0.77]
Winter	0.89	2.02	0.44*	[0.25; 0.78]
Summer	1.40	2.29	0.61*	[0.38; 0.99]
Daylight	0.85	1.74	0.49*	[0.32; 0.75]
Twilight	0.13	0.16	0.85	[0.26; 2.80]
Night time	0.13	0.26	0.51	[0.18; 1.50]
Light counterpart	0.61	0.96	0.64	[0.38; 1.07]
Motorised counterpart	0.53	1.20	0.45*	[0.26; 0.75]
Low jacket use[a]	1.45	2.16	0.67	[0.43; 1.05]
High jacket use[a]	0.86	2.16	0.40*	[0.24; 0.68]

[a] The participants were divided into two groups: low jacket use for participants with jacket use below the median jacket use and high jacket use for those with jacket use above the median jacket use.

Table 6
Corrected ARs, ARRs and 95% confidence intervals for ARRs. The closer ARR is to 1.00, the lower the effect of the treatment. An ARR below 1.00 indicates a decrease in the number of accidents in the test group. All ARRs marked with * were statistically significant.

Multiparty PIAs	AR * 10^3		ARR	95% CI (ARR)
	Test group	Control group (adjusted)		
All	1.15	1.84	0.62*	[0.39; 1.00]
Winter	0.89	1.73	0.52*	[0.27; 0.98]
Summer	1.40	1.96	0.72	[0.41; 1.26]
Daylight	0.85	1.49	0.57*	[0.34; 0.96]
Twilight	0.13	0.13	1.00	[0.29; 3.40]
Night time	0.13	0.22	0.60	[0.20; 1.83]
Light counterpart	0.61	0.82	0.75	[0.41; 1.36]
Motorised counterpart	0.53	1.02	0.52*	[0.29; 0.95]
Low jacket use[a]	1.45	1.84	0.79	[0.46; 1.34]
High jacket use[a]	0.86	1.84	0.47*	[0.26; 0.86]

[a] The participants were divided into two groups: low jacket use for participants with jacket use below the median jacket use and high jacket use for those with jacket use above the median jacket use.

effect would be greater in daylight than in the dark, but the results cannot confirm this hypothesis (daylight: 51%, dark: 49%) (Table 5). The hypothesis was based on the assumption that due to the jacket's small areas of reflective material (Fig. 1), the jacket's fluorescent yellow colour would provide more protection in the daytime than in the dark. Our findings suggest, however, that even a small amount of reflective material on the garment appears to provide some protection. The effect in twilight is based on only few accidents, and thus no conclusions about the effect could be drawn.

The effect of the jacket was larger during winter than during summer, which is in accordance with the hypothesis. This can be related to the fact that daylight is weak during winter in Denmark, due to the country's geographical location. Furthermore, bicycles usually do not have their lights turned on during the day, and the cyclists therefore easily blend into the surroundings unless they wear fluorescent clothing to stand out. This means that higher jacket usage rate during winter is an important factor for the large effect during winter. It should be noted that although fluorescent clothing also increases the probability of being seen in the summer, the usage of the jacket was lower in summer. To this might be added that in summer more bright colours (from clothing, green leaves, etc.) usually compete for attention. The effect of wearing the bicycle jacket was also larger when the counterparty was a motorised vehicle. The explanation may be that the view of drivers is generally more limited compared to that of pedestrians and cyclists, and that the former move at a higher speed.

In the present study, an average of 77% wore the jacket, and the risk reduction for the individual cyclist who wears their jacket whenever cycling is likely to be even greater than 47% as indicated by the safety effect among participants with high jacket use (60%) (Table 5). 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 (Furnham, 1986). It seems that the majority of the test group cyclists believed that the bicycle jacket decreased their accident risk. At the end of the study period, both the test and the control group cyclists were asked, *'To which degree do you believe that a bright-coloured bicycle jacket/vest can increase your safety in traffic in general?'*. 81% in the test group and 66% in the control group answered *very high* or *high* (Thedchanamoorthy et al., 2014). The difference between the two groups may be the result of positive experiences in the test group after wearing the jacket for one year. Consequently, it is possible that the test group 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).

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 (Adams, 1985; Sagberg et al., 1997). The test group might have adopted a more risky riding behaviour because they felt more safe wearing the jacket (Koornstra, 2009). Another aspect of risk adaptation is whether there are differences in car drivers' behaviour towards cyclists with and without visible safety equipment. A British study has shown that overtaking motorists pass closer to bicyclists wearing a helmet than bicyclists not wearing a helmet (Walker, 2007). If this was also the case in this study, it may have influenced the size of the safety effect. The effects mentioned point in different directions: 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. Moreover, the effects on the number of PIAs in the test group are so large and robust that this is unlikely to compromise the main result from the study: the yellow bicycle jacket decreases the number of PIAs in the test group.

4.2. Study design and execution

Most traffic safety evaluation studies are conducted as before-after studies, but this design does not allow for controlling for confounding factors that may bias the estimated effect (Elvik, 1993, 1996). In this study, an RCT was conducted, since this design in itself corrects for confounding factors (Hauer, 1997). Randomisation assigns each participant randomly to either the test group or the control group. This implies that all possible confounders are distributed equally between the two groups, and the design thus allows for the only difference between the two groups being the variable considered, in this case the participants' multiparty bicycle PIAs. In this study, however, a large number of participants (15.5%) did not confirm their participation after the randomisation (Fig. 2), which may have resulted in a bias. One effect was that the study participants in the test group were one year older than the participants in the control group. Despite being statistically significant (Table 1), it is unlikely that the small difference has played any major role for the conclusion of the study. Furthermore, drop-out numbers were similar in the two groups (test: 615, control: 634). Therefore, the safety effect found in this study can be assumed to result from the bicycle jacket use rather than from other factors that tend to influence the results in traditional before-after studies, such as demographic characteristics and changes in behaviour, infrastructure and general safety level over time.

This study used self-reporting of accidents for data collection – a method whose validity may be questioned. Lajunen and Özkan (2011) conclude that official statistics as well as self-reporting are both subject to systematic and random errors and are therefore to some degree biased. They underline that the benefit of self-reporting is that even minor incidents are reported, but also that in self-reporting respondents may forget an accident. In our study, accidents are reported monthly, which reduced the recall period to less than one month. None of the studies described by Lajunen and Özkan (2011) used such a short reporting period.

Self-reported accidents can also be affected by effects of social desirability. The agreement between self-reported accident data and other data sources can be low (Wåhlberg, 2009, 2010; Wåhlberg et al., 2010). Wåhlberg thus recommends the inclusion of a so-called "lie scale" to correct the inconsistencies. Despite the risk of bias in self-reported accidents, these may be the best available data source, due to the large underreporting of accidents in the official records which applies to bicycle accidents in particular (Broughton et al., 2010; Bull and Roberts, 1973; Elvik and Mysen, 1999; Janstrup et al., 2016). Therefore, self-reported accidents have previously been used in cycling accident studies in order to adjust for the under-reporting of accidents (de Geus et al., 2012; Madsen et al., 2013). In this study, the participants' responses indicate that only 5% (15/302 = 0.05) of cyclists' PIAs were reported to the police and that 32% (96/302 = 0.32) went to a hospital emergency room, their doctor or both to be treated for their injuries (Table 4). The consequence is that cycling safety issues are reflected fully in neither police nor medical records and thus are not adequately dealt with in road safety work.

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. Thus, test group participants seem to under-report PIAs, whereas participants in the control group seem to over-report PIAs. Similar effects are known from both marketing and psychology and are often referred to as demand characteristics (Nichols and Maner, 2008; Orne, 1962) or response bias (Furnham, 1986). There seems to be a response bias in our data which results in 96 single PIAs in the control group and only 80 in the test group. This difference was unexpected, as the bicycle jacket is supposed to have no effect on single PIAs. Madsen et al. (2013) suggested a correction method to adjust for this bias, and this correction method was applied in this study.

One implication of the use of self-reporting of accidents is the need to ensure that all participants share a common understanding of the definition of an accident and thus report only the desired types of accidents, leaving none of them out. To reduce this source of error, we asked the participants to report all accidents they had been involved in when cycling. The study team decided subsequently if the accident did in fact comply with the inclusion criteria. This procedure caused the number of accidents to be reduced by 139 from 833 to 694, and a higher consistency was achieved as regards accidents included. Furthermore, a high response rate is required when using self-reported accidents in order to achieve representative results. The response rate of the monthly accident questionnaires in this study was high; 75.8% in the test group and 85.3% in the control group answered all 12 questionnaires (Table 3). A similar response rate (86%) was found by Madsen et al. (2013). The missing responses may reflect months with no accidents, but they may also suggest that some accidents were omitted in the self-reporting. Since the rate of participants answering all questionnaires was lower in the test group, it cannot be ruled out that this has created a bias and that the actual number of accidents was higher than expected in the test group. With the correction based on the difference in single PIAs, this potential bias is compensated for. It should be noted, however, that in both studies the participants were very dedicated and probably not representative of the population in general. It is likely that the response rate would be lower if using self-reporting of accidents elsewhere.

A key prerequisite for obtaining a safety effect with the jacket is that participants actually wore the jacket when cycling. In the study, the usage was at its maximum at the start of the study in November, and then decreased over the summer period, followed by a rise during autumn (Table 2). Some decrease in usage rate was expected, since participants in such studies tend to have the largest commitment at the beginning of the study (Yanay and Yanay, 2008). In addition, although the jacket was only a shell jacket, the participants expressed that it was too warm to wear in the summer (Thedchanamoorthy et al., 2014). However, the average usage rate of 77% seems high and can probably be explained by the participants' commitment to the study.

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. 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.

4.3. Reliability and validity of results

The study was conducted as an RCT with 6793 participants. The number of participants needed in each group to obtain statistically significant results was based on the rate of self-reported accidents among cyclists in previous studies (Lohmann-Hansen et al., 2001; Madsen et al., 2013) and on an estimated safety effect of the jacket. As previously described the present study had a very high involvement from the participants. Thus, 81% of participants responded to all 12 accident questionnaires. Therefore, the reliability of the trial is most likely very high. The internal validity of the trial is affected by the fact that the study is non-blinded. The number of single PIAs is lower in the test group than in the control group, seemingly causing the study to be affected by response bias. However, this bias was adjusted by scaling down the effect of the ratio between the numbers of single PIAs in the test group and the numbers of single PIAs in the control group. Although we cannot document that the response bias seen in the reporting of single PIAs also applies to multiparty PIAs, it is likely to have influenced the reported number of PIAs. If the presumed under-reporting of multiparty PIAs was higher than that for single PIAs, the actual safety effect is overestimated, even in the corrected analysis. In this case, the safety effect may be lower than 47%. It seems unlikely, however, that the under-reporting is higher for multiparty PIAs than for single PIAs. On the other hand, if the response bias is lower for multiparty PIAs, the estimation of the effect of the jacket as reflected by the corrected analysis is conservative. The actual effect will then most likely lie between the corrected and uncorrected estimates, i.e. between 38% and 47%.

The average age of participants was approx. 2.5 years below that of the Danish population in general, and their car ownership rate was higher; 80% of the participants had at least one car in their household, compared to 60% in the Danish population (Table 1). These figures and the fact that the participants were volunteers who had signed up to use a bicycle jacket which was expected to improve their road safety suggests that participants were concerned about safety, potentially to a higher degree than the population in general. But what will be the impact of this on the effect of a bicycle jacket? The assessment is that the effect of a bicycle jacket worn by a safety concerned cyclist with a presumably defensive cycling style will be less than the effect on a risk-seeking cyclist, because a risk-conscious cyclist is more likely than a risk-seeking cyclist to give way even if the counterparty is the one to give way. This influence of the external validity may point to a higher effect for the average cyclist, compared to the effect on the group in this study.

The external validity of the experiment is challenged by the fact that the effect is assumed to change if the environment changes. For instance, 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. In this study, the participants were spread across the country (Fig. 3), and the likelihood of being in a group with multiple bicycle jackets is small. This also means that the found effect represents an average of the effect in big cities, small cities and rural areas, although some variation between these areas is expected. The external validity is also influenced by the fact that other road users' risk may increase when attention is directed to cyclists with bright-coloured jackets at the expense of other cyclists. These considerations are not specific to bright-coloured jackets but are generally valid. Overall, the assessment of the external validity is that the effect will most likely decrease as jacket use increases, but not to a degree that may compromise a general positive effect of a yellow jacket.

5. Conclusions

This randomised controlled study delivered strong evidence that cyclists are protected against multiparty accidents when wearing a bright-coloured jacket. Other studies have also indicated that higher visibility of cyclists significantly reduces their number of PIAs. This study involved as many as 6793 cyclists and estimated a statistically significant reduction of 47% of multiparty PIAs.

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