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Safety in numbers for cyclists—conclusions from a multidisciplinary study of seasonal change in interplay and conflicts

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ABSTRACT

In many European countries, it is a political goal that future growth in local travel should be absorbed by sustainable transport modes. Concerns that increased walking and cycling produce more accidents have been countered by the "safety in numbers" (SiN) argument. According to SiN, the more walkers/cyclists there are in a population, the lower their risk. SiN has been demonstrated in cross sectional and longitudinal studies, but the mechanisms behind the effect have yet to be proven.

Previous studies have mostly relied on register data. The current study, carried out in 2013 and 2014 tests the existence of this effect in a more controlled manner. This is achieved through the use of three data sets: (1) roadside survey data with cyclists, pedestrians and car drivers from Oslo carried out at three time points in the cycling season (2) a panel study covering the same time period, and (3) video observations at four different locations in Oslo. By exploiting the natural seasonal variation in cycling frequency, and by using a repeated measures design we can further control for other factors suggested to lie behind the SiN mechanism, such as differences in infrastructure and traffic culture.

The results suggest that bicyclists experience a short term Safety in Numbers effect through the season. Each individual cyclist experiences fewer occasions of being overlooked by cars and fewer safety critical situations (near-misses). Video observation data confirm this pattern. However, the SiN effect seems to be countered by another mechanism taking place at the same time: the influx of inexperienced and risk-taking cyclists through the season. Thus car drivers and pedestrians also report to find themselves being surprised by cyclists in traffic late in the season.

1. Introduction

A common argument against a shift from motorized to non-motorized travel is the concern about a potential increase in numbers of accidents resulting from such a policy. A common counter argument is *Safety in numbers*. Safety in Numbers (SiN) is used to explain the non-linear statistical relationships between the number of pedestrians (or bicyclists) and the number of injuries for the same group (Elvik, 2009; Geyer et al., 2006; Jacobsen, 2003). The mechanism has been proven in a number of cross sectional and longitudinal studies, summarised in a quite recent meta-analysis (Elvik and Bjørnskau, 2016). The concept has been subject to debate, regarding its existence (Bhatia and Wier, 2011), its mathematical characteristics (Brindle, 1994; Elvik, 2013; Knowles et al., 2009) and also related to this, regarding a clear understanding of *the mechanism* behind the effect.

The mechanism that has most frequently been proposed, is that motorists become more attentive, and change their behaviour, when exposed to higher numbers of pedestrians and cyclists (Jacobsen, 2003). Another possible mechanism is improved interplay between road users groups when road users acquire experience with each other, and develop more correct expectations (Phillips et al., 2011). Still another suggested mechanism is that the cyclists and pedestrians entering the population at a later stage may be more risk averse and cautious (Fyhri et al., 2012). It has also been suggested that the effect can be a result of safer environmental conditions, including engineering countermeasures or differences in pedestrian norms and behaviours (Bhatia and Wier, 2011). However, these hypotheses have yet to be tested. Knowledge about these mechanisms is essential (Bhatia and Wier, 2011) and is necessary to adopt a safe active transport policy aiming at a shift to increased use of sustainable urban transport.

The Scandinavian countries, and in particular Norway are interesting cases to test the SiN effect, as there is a substantial seasonal variation in bicycle use. The cycle share in winter is in the range of 1–2% of all trips, and rises to 8% in summer (Hjorthol et al., 2014).

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Pedestrians are a more steady presence in traffic. In fact, the share of pedestrians is somewhat *higher* in winter, around 22%, and drops to around 18% in summer (probably due to some bicyclists shifting to walking when conditions are not good enough for cycling). In the current study, we will test the attentiveness-mechanism by looking at interplay in traffic as a function of seasonal variation in bicycle use.

The seasonal variation is substantial, meaning that every spring there is a dramatic increase in the number of bicycles that other road users are exposed to each subsequent week. By studying conflicts and interactions at the same study sites, it is possible to keep a close control with any other potential influencing factors, and only look at the effect of changes in the share of one of the road user groups. In other words, this situation can be used as an experiment of whether motorists become more attentive, and change their behaviour, when exposed to an increasing number of cyclists.

Traffic accidents are often a result of inadequate road user interaction, but research on the importance of road user interaction for accidents is rather limited. The importance of correct expectations and the ability to predict other road users' behaviour has not been studied much, despite the fact that such abilities are vital in order to avoid accidents (Bjørnskau, 1994; Bjørnskau, 1996; Rothengatter, 1991).

When the proportions of different road user groups change, for instance through an increase in soft transport modes, interaction patterns may also change. Bjørnskau (2016) has documented how road user interaction can change over time as a result of dynamic interplay. One example is pedestrian crossings, where cars yield to cyclists contrary to the traffic rules (Bjørnskau, 2016). Another is how novice drivers change their use of the headlights and adapt to the dominant practice of dipping, contrary to what is prescribed in driver education (Bjørnskau, 1994).

Studying interaction among road users, rather than behaviour from one single road user group, creates substantial methodological challenges, which might be one reason for the scarcity of previous controlled experimental studies. In the context of Safety in Numbers, a relevant experience from a bicyclist's point of view is that of being overlooked by other road users. However, whether a bicyclist is overlooked in a given situation will depend on the bicyclists' own behaviour in that situation as well as the behaviour from the surrounding road users.

In order to overcome these challenges a multidisciplinary approach is needed. Traditional surveys function quite well to provide valid descriptions of different road users perceptions and own experiences and can also to a certain extent describe interaction patterns (Bjørnskau and Fyhri, 2012). Observational techniques can function well to supplement the picture. One promising approach that has gained a renewed interest in later years is to use surrogate accident measures, such as conflicts and to record these with video. The Swedish Traffic Conflict Technique (TCT) is one among several such methods (Hydén, 1996; Laureshyn, 2010), but is the only one that has been validated with strong relation found to the number of police-reported accidents (Svensson, 1992). The method also exhibits strong *process validity* (similarity in how conflicts to accidents develop), and is especially valuable for the studies of vulnerable road users' safety since this group is under-represented in the accident statistics (Transportstyrelsen, 2012).

2. Objectives

The objective of the current study is to investigate if interplay between bicyclists and car drivers improves when more bicyclists enter the streets throughout the cycling season. In order to investigate this, we use data from two data collection procedures, a combined field and panel survey of road users and video observation of conflicts at selected intersections.

Specifically, we hypothesize that:

1. The number of times bicyclists are not seen by car drivers is reduced, from April to June and from June to September (survey data);
2. The number of times bicyclists are not seen by pedestrians is reduced, from April to June and from June to September (survey data);
3. The number of times car drivers are surprised by a bicyclist is reduced from April to June and from June to September (survey data);
4. The number of times pedestrians are surprised by a bicyclist is reduced from April to June and from June to September (survey data);
5. The number of times cyclists are involved in safety critical situations (near-misses) with other road users is reduced from April to June and from June to September (survey data);
6. The number of traffic conflicts between car drivers and bicyclists are reduced from April to June and from June to September (video observations).

We present the methodology, results and initial discussion separately for each data collection procedure, and provide a discussion synthesising the results from both procedures at the end.

3. Survey data

3.1. Method

Data were collected in a series of field surveys among road users in some preselected streets and parking lots in Oslo, Norway. The surveys were conducted at three time-points in 2013: April (15th–29th), June (10th–21st) and September (02nd–13th). The data collection period spanned over two weeks at each time point. Interviews were conducted on weekdays, and during daytime. Most interviews were conducted in the morning and afternoon, during rush hours, in order to recruit enough respondents at each location.

Pedestrians and bicyclists were interviewed at three different locations in Oslo. The locations were selected so that we would recruit "average" road users, have enough traffic, and to ensure that those interviewed would have had sufficiently long travels so that they could have experienced interactions with other road users. The interviewers were in principle asked to stop any pedestrian or bicyclists approaching them. However, as we were mostly interested in bicyclists' perceptions, on some days the interviewers were asked to recruit twice as many bicyclists as pedestrians. The interview took approximately 4–5 min to complete, and data were registered using tablet PCs. All who participated were promised a ticket in draw for a prize worth 5000 NOK (approx. 600 €). Interviews were only conducted on days with no rain.

Respondents were asked a range of questions, all regarding the trip they just had made (or were in the process of undertaking):

- Trip length in minutes
- Number of times they had experienced specific situations with poor interplay
- Assessment of interplay with cars and pedestrians (bicyclists for pedestrians)
- Experiences of near-misses
- Feeling of safety

Table 1
Sample size for field and panel surveys for cyclists and for field samples for car drivers and pedestrians.

	Car drivers	Pedestrians	Cyclists			
	Field	Field	Field	Panel 1 April and June	Panel 2 June and September	Panel 3 April, June and September
April	222	232	327	152		109
June	246	139	284		196	
September	203	247	463			
Total	671	618	1074	152	196	109

Table 2
Sample characteristics of bicyclists. Percent (except for age).

	April	June	September
Mountain bike	44	34	37
"Hybrid bike" (city bike)	39	38	33
Racer bike	5	7	9
Rented bike	1	1	1
Classical bike	10	19	19
Other types	1	1	1
5 days/week or more	73	72	73
2–4 days/week	24	26	25
1 day/week	2	1	1
1–3 days/month	0	0	0
Rarely	0	0	1
Whole year bicyclist	46	33	36
Male	57	58	53
Mean age	44.6	43.8	43.1
N	212	288	480

Table 3
Linear regression analysis of number of times bicyclists are not seen by cars on current trip. Standardized parameter estimates (β-values).

	Bicyclists
Gender	
Age	−0.82*
Interview place	
Time of day	
Distance	0.16***
Accustomed to route	
Mountain bike	
Month	−0.88**
Adj R2	0.03

* p < 0.1.
** p < 0.01.
*** p < 0.001.

In addition, background questions about amount of cycling, seasonal variation in cycling and age were asked. The interviewers registered gender, bicycle type and type of equipment.

Car drivers were interviewed at parking lots outside commercial centres and at street side parking lots in the city centre.

Respondents (bicyclists, pedestrians, and car drivers) who completed the interview were asked if we could contact them anew, and those who said yes, were asked to leave their email address. One week after the field interviews the respondents received a survey at home where they were asked some further questions about their experiences with being in traffic during the last week, and about interplay with other road users. In order to establish a panel survey design, those who completed this survey in Oslo, were asked if we could contact them again at the next phase of the survey (in June and September). For car drivers and pedestrians, only the field data are analysed in this paper. Sample size for the three field samples and for the three panel samples of bicyclists are presented in Table 1.

3.2. Sample

Table 2 shows the sample characteristics of the Norwegian bicyclists recruited in the field in April, June and September.

Notably, many of the respondents use mountain bikes. This share is as high as 44 % in spring, and falls to 34% in mid-summer. This is typical of the Norwegian cycling population where mountain bikes for a while has been the most popular cycle type, even for urban cyclists. In addition, we can see that many of those who are interviewed are quite accustomed bicycle users. As many as 73% cycle "every day" (i.e. five or more days a week). This share is quite stable throughout the season. Still, the April sample probably contains more experienced cyclists than the others, as there is a higher share (46%) who cycle all year than in the other samples. The samples have a somewhat higher share of males than females, and are biased towards middle-aged participants (mean age ranges from 43.1 to 44.6; approximately 4% are under 25 years and 3% are above 65 years).

3.3. Results

3.3.1. H1: bicyclists not being seen by cars

In the field survey, the respondents were asked to think about the trip they had made today, and about their encounters with cars in various situations, at intersections etc. Then they were asked about how many times they had experienced four concrete situations of poor interplay with cars. Fig. 1 shows the mean number of times bicyclists have experienced situations with poor interplay on the current trip in April, June and September.

A one-way between groups ANOVA was conducted in order to explore the effect of season on different types of interplay with cars. The number of times the cyclists experience overlookings by a car falls from an average of 0.47 in April to 0.27 in June and to 0.25 in September ($F(2, 1070) = 9{,}3$, $p < 0.001$). Post hoc tests (Tukey HSD) revealed that only the fall from April to June was statistically significant. The number of times bicyclists experience that cars block their roadway is also significantly influenced by season ($F(2, 1070) = 8{,}9$, $p < 0.001$). The post hoc tests (Tukey HSD) again showed that only the fall from April ($M = 0.55$, $SD = 1.03$) to June ($M = 0.36$, $SD = 0.77$)) was statistically significant ($p = 0.01$). There is no statistically significant change in the number of times bicyclists are seen but not respected (i.e. that cars have not yielded at intersections or roundabouts).

In order to control for any seasonal variation that may exist in the sample population, we conducted a multiple regression analysis. In this analysis, we included number of times bicyclists have experienced to be unnoticed by cars on current trip as a dependent variable, and age, gender, interview location, time of day, distance cycled, knowledge of present cycling route and season as predicted variables (Table 3).

The results of the analysis show that both age and travel distance predict whether bicyclists are overlooked. The effect of season (month) is quite substantial ($\beta = -0.88$).

In the panel survey, the respondents were asked to think back to their last week in traffic, they were asked, "Think back to your encounters with cars last week. Imagine that you have met 100 such car drivers during the past week. Approximately how many of these will have. . .." "not yielded for you at an intersection" etc. (five items). Responses were to be given on a sliding scale with 11

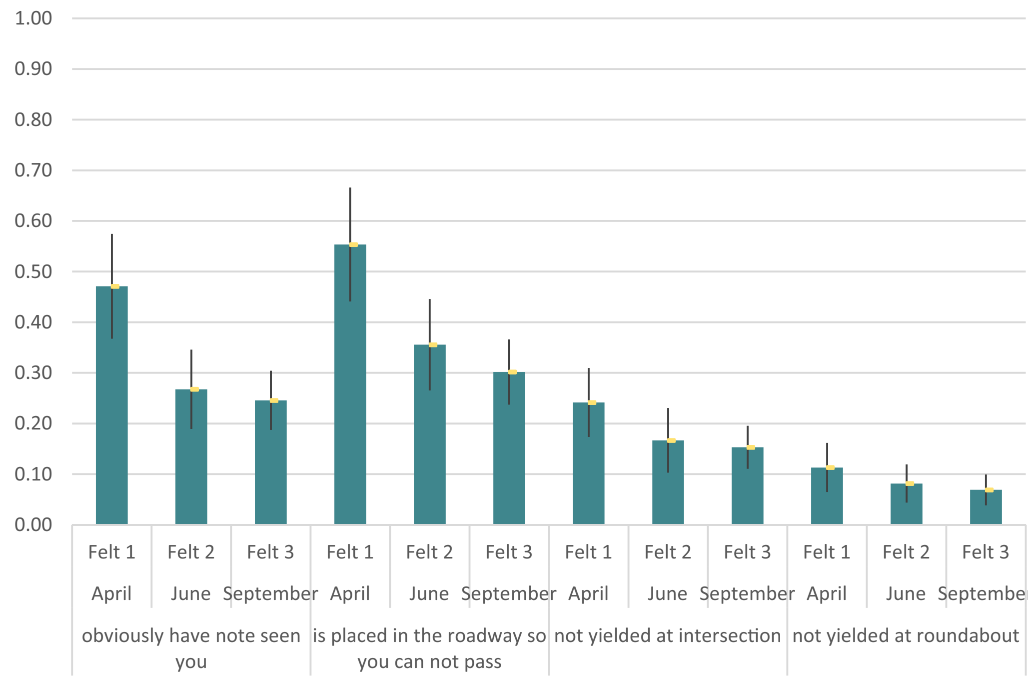

Fig. 1. Mean number of times (with upper and lower confidence intervals) bicyclists have experienced poor interplay on the current trip with car drivers in April, June and September.

Table 4
Descriptive statistics for cyclists being overlooked by cars in April, June and September.

	Mean	*SD*	*N*
April	16.86	17.91	86
June	13.60	19.40	86
September	11.40	13.30	86

intervals ranging from "none" via 10, 20 etc. to "all". The means and standard deviations are presented below (Table 4).

In order to test seasonal effect of bicyclists' number of overlooks from car drivers, a one-way repeated measures ANOVA was conducted. The sample for the analysis were 86 out of the 109 bicyclists (some were left out due to missing data) who had responded to all three of the home surveys (Panel 3). The number of overlooks drops from 16.9 in April to 13.6 in June and further to 11.4 in September. There was a statistically significant effect for season (Wilks' Lambda = 0.851, $F(2, 84) = 7.36$, $p < 0.001$, multivariate partial eta squared = 0.15.

3.3.2. *H2: bicyclists not being seen by pedestrians*

In order to test seasonal effect of bicyclists' number of overlooks from pedestrians, a one-way repeated measures ANOVA was conducted. The analysis revealed no effect of season (Wilks' Lambda = 0.986, $F(2, 84) = 0.581$, $p = 0.56$). Upon closer inspection, there seemed to be a tendency for a non-linear change in the number of overlooks. A paired-samples *t*-test was therefore conducted to compare overlooks in April and June, and in June and September, respectively.

Table 5 shows the mean number of times bicyclists have experienced not being seen by a pedestrian, and that a pedestrian has behaved unpredictably in April, as well as the change from April to June, and from June to September.

There is no change in the number of overlooks from April to June. There is a statistically significant drop in the number of times bicyclists are not seen by pedestrians from June to September, $t(172) = 2.1$, $p = 0.04$).

Table 5
Number of times bicyclists have experienced not being seen by a pedestrian in April, and change from April to June, and from June to September.

	April	*Change from April to June*	*Change from June to September*
Not seen by pedestrian	22.33	0.37	−2.97*
N		136	172

* p < 0.05.

3.3.3. *H3 and H4: car drivers and pedestrians being surprised by bicylists*

The pedestrians and car drivers were asked how many bicyclists they thought they had seen on the current trip and how many of these had appeared surprising on them (Table 6).

For pedestrians, the number of bicyclists encountered are as expected, increasing through the season. The number of times pedestrians are surprised is also increasing from June to September. For car drivers, there is an increase in the number of bicyclists they encounter from April to June. From June to September the number of bicycles encountered drops. The number of surprises is rather steady with a small increase from June to September.

A linear regression was conducted using number of surprises as dependent variable, and among other things month as a dummy variable (Table 7). Exposure (number of cyclists met on the current trip) was included as independent variables.

The regression model shows that, when controlling for exposure (number of encounters with cyclists), age and gender, the monthly change in number of surprises is not statistically significant.

3.3.4. *H5: near-misses between bicyclists and other road users*

The bicyclists were asked if they had been involved in near-misses with a car or a pedestrian on the current trip. Fig. 2 shows the percentage of bicyclists who have had near-misses with cars/pedestrians for each of the three months.

The share of bicyclists who have had a near-misses drops from April to June, and then increases from June to September. This holds for both cars and pedestrians as counterparts.

Table 6
Number of cyclists encountered on current trip, number of times being surprised by a cyclist for pedestrians and car drivers. Mean.

	Pedestrians		Car Drivers	
	Number of bicyclists	Number of times surprised	Number of bicyclists	Number of times surprised
April	6.4	0.44	4.8	0.34
June	7.2	0.49	6.3	0.31
September	9.1	0.77	5.9	0.42

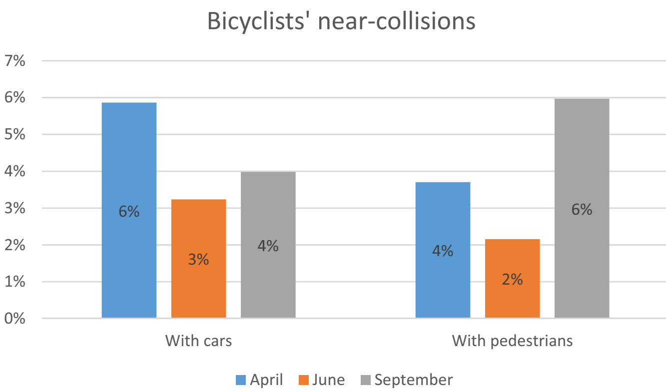

Fig. 2. Bicyclists having had near-misses with cars and pedestrians on current trip in April, June and September. Percent.

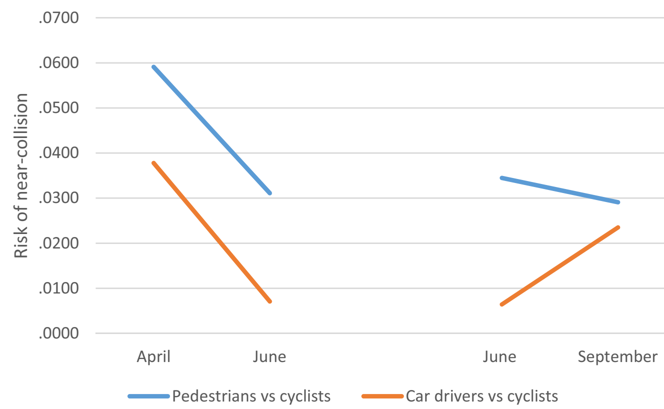

Fig. 3. Risk of near-misses with cyclists during the last week for pedestrians and car drivers. Percent.

In order to control for changes in the bicyclist population between each interview period, we have conducted two logistic regression analyses (stepwise). Prior to analyses, we tested and confirmed that all the independent variables were well below acceptable levels of multicollinearity (bivariate correlations were in the range 0–0.2). Bivariate correlations with the dependent variable were also tested. The highest correlation was between being overlooked and experiencing near misses (r = 0.2 for cars and r = 0.21 for pedestrians). Some variables had lower than normally recommended bivariate correlations with the dependent variable, but were included due to theoretical considerations about their potential contribution to explaining near-misses. At step 1 month, gender, age, time of day and distance cycled was included. At step 2 number of times being overlooked by cars/pedestrians on current trip was added.

For near-misses with car drivers there is a statistically significant reduction from April to June, but no change to September at step 1. Time of day (afternoon having a lower likelihood of near-misses) is also statistically significant. When number of overlooks is entered at step 2, the seasonal effect is not statistically significant any more.

For near-misses with pedestrians there is a substantial reduction from April to June, but this change is not statistically significant. The increase in near-misses from April (and from June) to September is statistically significant. Age is also statistically significant (decreased risk of near-misses with increasing age). These effects hold even when we control for number of overlooks at step 2.

Having been overlooked by cars results in an increased likelihood of also being involved in near-misses with cars (Exp(B) = 1.99). In the same manner, having been overlooked by pedestrians results in an increased likelihood of also being involved in near-misses with pedestrians (Exp(B) = 1.88).

Thus, for both types of near-misses, there is a clear and statistically significant relationship between being overlooked by the opposing road user group and being involved in a near-miss.

The car drivers and pedestrians were also asked if they had experienced a near-miss during the last week in the panel survey. Panel 1 (April to June) and panel 2 (June to September) were used as units of analysis. In order to calculate exposure we used number of trips

Table 7
Linear regression, number of times pedestrians and car drivers are surprised by a bicyclist, baseline April.

	Pedestrians	*Car drivers*
June	−0.02	−0.04
Sept	0.05	0.03
Gender	−0.06	−0.05
Age	−0.01	0.15*
Number of encounters with cyclists	0.38**	0.16**
Adj R2	0.128	0.049

* p < 0.01.
** p < 0.001.

reported during last week and multiplied with an index figure of estimated number of cyclists (April = 1, June = 1.5, September = 1.4). The index figure for number of cyclists is derived from two sources: (1) The National Travel Behaviour Survey data (Hjorthol et al., 2014), subsample drawn from southeast Norway, mean number of trips per person/day (N = 3 158) and (2) Bicycle counters (inductive loop) placed at four different locations in Oslo (N = 28 725). Risk was calculated as occurrence of near-misses/exposure to cyclists.

Fig. 3 shows the risk of near-collisions with a cyclist for pedestrians/car drivers interviewed in April and June on the left side, and in June and September on the right side. Note that the mean numbers for the left side June and the right side June differs somewhat, since they represent different, but slightly overlapping, population samples (Panel 1 and Panel 2, as presented in Table 1).

A paired-samples *t*-test was conducted to compare risk of near-misses in April and June, and in June and September, respectively. Data were first transformed using the Freeman-Tukey transform for Poisson data (Bisgaard and Fuller, 1994).

The drop in risk for near-misses with cyclists is statistically significant for both car drivers $t(30) = 2.1$, $p = 0.04$) and pedestrians $t(46) = 1.8$, $p = 0.07$) from April to June. From June to September there is an increased risk for car drivers $t(44) = -1.9$, $p = 0.06$), and no change for pedestrians (Table 8).

Table 8
Logistic regression analyses of near-misses on current trip with cars and pedestrians as counterparts. Exp(b).

	Cars		*Pedestrians*	
	Step 1	Step 2	Step 1	Step 2
Month				
June	0.38**	0.46	0.36	0.43
September	0.65	0.85	1.89*	2.17*
Gender	1.19	1.29	0.90	1.00
Age	0.99	1.00	0.96**	0.96**
Time of day				
Mid day	0.75	0.74	0.85	0.65
Afternoon	0.27**	0.25**	1.18	1.19
Distance cycled	1.17	1.05	1.09	0.91
# overlooks		1.99***		1.88***
Adj R_2 (Nagelkerke)	0.06	0.13	0.07	0.18

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

4. Video observations of traffic conflicts (H6: conflicts between bicyclists and other road users)

4.1. Method

Behavioural and conflict analyses were done based on video observations. At each intersection, a camera covered with a weather-protected box was mounted to a building in order to have a good overview of the intersection. The video was recorded with relatively low resolution (640 × 480 pixels), which did not allow recognising individual persons or reading number plates on cars, but was sufficient to see and interpret the road user actions. The video was split in 30-min intervals and stored on a mini-computer connected to the camera.

Video-recordings were analysed using the program T-analyst [10] developed at Lund University. The program was specifically designed to analyse road user interaction based on video data. T-analyst efficiently manages a large number of detected events in long video recordings, allows to label them and afterwards filter them based on the labelling. Moreover, trajectories of road-users can be extracted, based on which specific parameters related to interaction between road-users are calculated. First, a pre-screening of the footage by students took place, in which every possible violation and conflict was registered. The students' instructions were to mark any "unusual" situation such as strange route, congestion, "narrow coming", powerful braking, etc. Generally, the number of pre-selected situations was about ten times higher than the final conflict count and therefore the risk of missing a relevant conflict at this stage is judged to be low. Afterwards the selected events were reviewed, analysed and categorized by a person trained in using the Swedish traffic conflict technique. A number of validation studies of the technique (covered in Hydén, 1996) showed that trained observers agree very well on both detecting potential conflicts and in judging speeds and distances to estimate the severity of a conflict. Since in this study we used objective speeds and trajectories extracted from video, the subjective component of judging a conflict by a human observer was further minimised.

4.2. Exposure measures and risk

In order to be able to compare cyclist risks, it is necessary to relate the number of observed conflicts to some measure of activity that generates the conflicts. Chapman (1973, p. 99) defined exposure as «amount of opportunity for accidents of a certain type in a given time in given area ». In practice, different exposure measures are available, each having pros and cons:

4.2.1. Traffic flow

Cyclist counts is the most natural and easy to collect measure of cycling activity. The problem is that the relation between the cyclist flow and the risk it generates is quite complex, since the number of motor vehicles has a direct effect on the frequency of the cyclists' interactions with them is not really taken into account (Ekman, 1996).

4.2.2. Integrated measure of cyclist and motor vehicle flows

This seems as a reasonable approach at first glance, but there are no commonly defined approaches on how to aggregate the two measures (Hakkert and Baumeister, 2002); should we multiply, add, or make some kind of factorisation?

4.2.3. Encounters

An encounter between a motor vehicle and a cyclist can be seen as an elementary event in traffic that may, but not necessarily will, turn into a conflict/accident. In this respect encounter corresponds best to the statistical concept of a binominal trial and the risk can be interpreted as the proportion of the encounters that result in a conflict/accident (Elvik, 2015). The main challenge is that counting the encounters is a quite demanding task that often has to be done manually.

In the current paper we tested the first two types of the exposure (cyclist counts and combined motor vehicle-cyclist measure).

4.3. Study sites

The study is based on observations done at four intersections in Oslo, Norway (Fig. 4)

- Site I. Toftes gate – Seilduksgata. A small intersection in central part of the city with one lane in each direction for motor traffic and cycle lanes on both side on one of the streets. Estimated ADT 10.000 vehicles.
- Site II. Suhms gate – Kirkeveien. A large intersection on a main arterial street (a part of the second city ring). Three lanes for motor traffic and cycle lane on the main street in each direction. Advanced stop lines for the cyclists. Estimated ADT 28.000 vehicles.
- Site III. Vogts gate – Marcus Thranes gate. Another intersection on the second city ring. Cycle lanes on the main street, but only on one side of the intersection. Tram line going through the intersection on the minor street. Estimated ADT 29.000 vehicles.
- Site IV. Mogata – Jutuveien – Stavangergata. A roundabout in residential part of the city. One incoming lane for motor traffic in each leg, cycling lanes at two legs merging with the motor traffic just before the intersection. Estimated ADT 15.000 vehicles.

4.4. Video recordings

The original plan was to observe each site during 5 working days between 6:00 and 21:00 in spring, summer and autumn. The main bulk of the video recordings were done in 2013, but some complementary recordings were done during the spring of 2014. No video was collected at Mogata (Site IV) for the spring period. Due to a technical failure, autumn period at Suhms gate (Site II) contained only video between 6:00 and 11:00. To extend the observation time, the number of days analysed was doubled.

4.5. Exposure estimation

Bicyclist, motor vehicle and encounter counts were performed during 8 half-hour periods: 7:00–7:30, 8:00–8:30, 9:00–9:30, 10:00–10:30 in the morning and 14:00–14:30, 15:00–15:30,

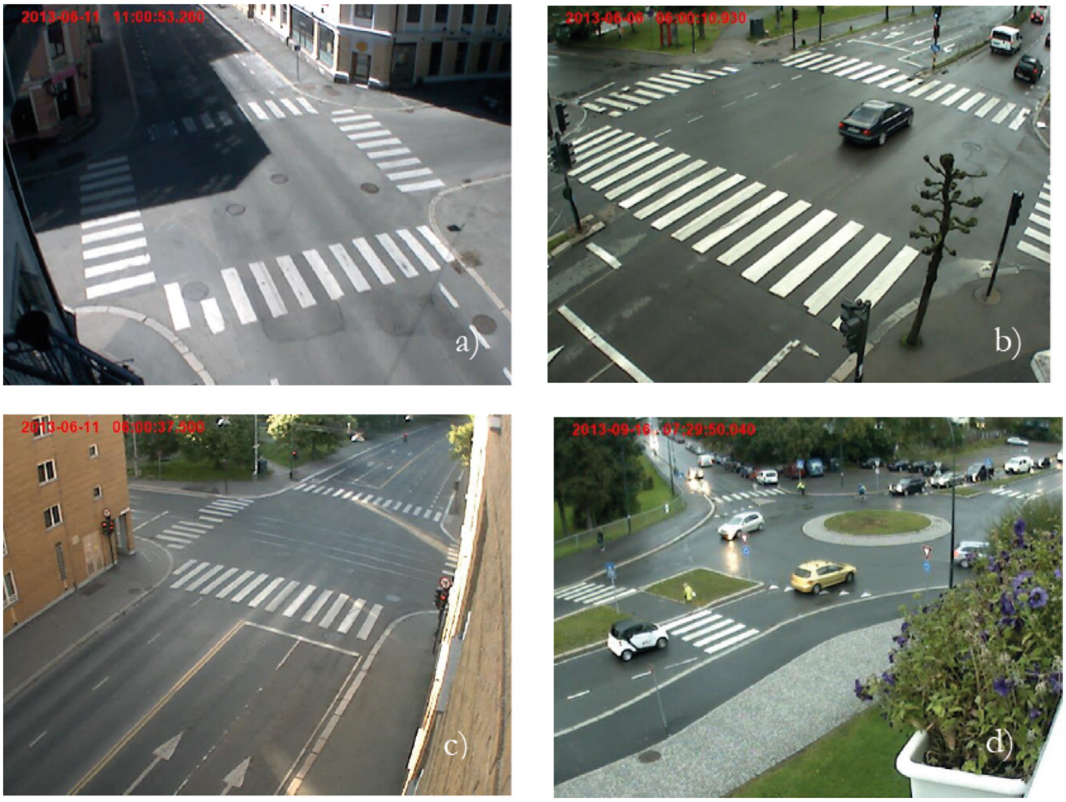

Fig. 4. The views of the studied intersections in Oslo: (a) Toftes gate – Seilduksgata; (b) Suhms gate – Kirkeveien; (c) Vogts gate – Marcus Thranes gate; (d) Mogata – Jutuveien – Stavangergata.

Table 9
Exposure (number of cyclists), conflicts, and risk of conflict at all four intersections in April, June and September.

		April	June	September
Exposure	Sites observed	I–III	I–IV	I–IV
	Hours	180	300	275
	Cyclists (C)	15,060	38770	46,513
	Motor vehicles (MV)	225,198	413,459	390,422
	$\Sigma(^{C}/_{h} \cdot {}^{MV}/_{h})/10^6$	23.68	63.18	77.52
Conflicts	all types	19	51	37
Risk	Conflicts · 10^3/cyclists	1.26*	1.32*	0.80*
	Conflicts · 10^6/ $\Sigma(^{C}/_{h} \cdot {}^{MV}/_{h})$	0.80	0.81	0.48

* Difference in risk (conflicts per cyclist) is not statistically significant from spring to summer, but statistically significant at 95% from summer to autumn (two proportion Z-test).

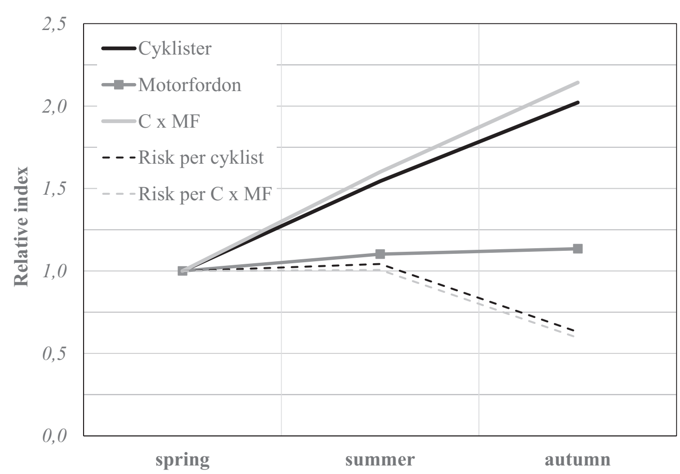

Fig. 5. Relative change in exposure and risk based on aggregated results from the sites I–IV (index for April = 1).

16:00–16:30, 17:00–17:30 in the afternoon. Three exposure measures were estimated then for each site:

- Cyclist number. The total number of cyclist during the observation period were obtained using available daily variation profiles for the same or similar intersections.
- Combined motor vehicle – cyclist measure. The measure was calculated as a sum of the products of hourly cyclist and motor vehicle flows (Hakkert and Baumeister, 2002). Again, to obtain the hourly flows for the periods when no counts were performed, daily variation profiles for cyclists and motor vehicles were used.

5. Results

For each individual intersection, the number of conflicts were too low to produce any statistically significant differences, even though the pattern of change was the same. Table 9 summarizes the exposure, number of conflicts and risk of conflict for all of the four intersections. Data from each individual intersection are presented in the Appendix. The number of conflicts per cyclist does not change much from April to June, but falls towards September. The decrease in risk from June to September is statistically significant at $\alpha = 0.05$ level (two-proportion Z-test).

A similar pattern can be seen even if the motor vehicle × cyclist-measure is used as the exposure. It is not possible, however, to test statistically the risk change since one unit of such exposure (1 motor vehicle × cyclist) is not strictly speaking a trial in statistical terms.

Fig. 5 below shows the relative change in the number of cyclists, motor vehicles, combined (motor vehicle × cyclist) measure and the risks based on different exposure definitions. One can observe that the cyclist number is increasing both from April to June and from June to September, while the amount of motor vehicles does not change much. As a result, the combined exposure measure follows the cyclist number quite close, and the two risks are also very similar. However, this is rather a coincidence and one cannot generalise by saying that cyclist counts is an equally good exposure measure as the combined measure, which takes into account motor vehicles.

6. Discussion

The cross-sectional survey results show that bicyclists experience an improved interaction with car drivers (fewer overlook situations) from April to June, and a further improvement from June to September. The panel data, where the same people are interviewed at three different time points, show the same picture: bicyclists are less often involved in situations where other road users apparently have not seen them late in the cycling season than early. Thus, we confirm our hypotheses 1 and 2. However, when looking at the picture from the other side, car drivers and pedestrians do not experience a change in number of times they are surprised by a bicyclist through the season (hypotheses 3 and 4). They do, however experience fewer near-collisions, confirming our hypothesis 5. The video observation data shows a quite clear pattern of increase of conflicts (but not *risk*) from spring to summer and a subsequent drop in conflicts *and risk* later in the season (hypothesis 6).

All in all, these data can be interpreted in light of a Safety in Numbers mechanism where the sudden increase of cyclists in spring and early summer results in an increase of situations where overlooking and near-misses happen. This situation is then followed by a situation where the other road users get used to the presence of bicyclists, and then learn to expect them on the roads. This again results in fewer conflicts.

One important limitation with the survey data is that they are self-report data, and hence what is observed is the road users' interpretation of different situations. We have tried to eliminate the element of interpretation as much as possible, by asking the respondents to report number of times concrete situations have happened, rather than giving assessments of the quality of interplay, and believe this to be a strength of the data. Even though respondents have trouble with remembering the exact figures for such events, we believe that these measures, when aggregated to a group, give a valid and reliable estimate of the quality of interplay among road users. Still we cannot rule out that the cyclists' interpretation of what is an overlooking, or a near-miss changes with increased cycling experience through the season.

An important advantage with the field survey data is that the respondents are close to the relevant situations in time and space. This makes it easier for them to remember "small encounters" with other road users, encounters that are easily forgotten in a normal interview situation at home.

As we have shown, not only the number of cyclists, but also the composition of the cyclist population changes during the season, with more experienced and well equipped cyclists being dominant in spring compared to later in the season. For the field survey data, we have controlled for this difference in the regression analysis, by including the most relevant background variables. However, there will always be uncertainty involved in such statistical control. The panel survey data has an advantage in that we have better control of other factors that might influence people's responses, thus strengthening our conclusions.

An important finding is that there is a clear and statistically significant relationship between being overlooked by the opposing road user group and being involved in a near-miss. This finding indicates that our measure of poor interplay (being overlooked) has a certain ecological validity, i.e. that it functions as a surrogate measure for the mechanism involved in producing poor traffic safety for bicyclists. On the other hand, the validity of a "near-miss" as a safety surrogate can also be questioned. There are some indications that only very severe incidents should be used as safety surrogates, while messy, but not very serious situations can on the opposite be indicators of good safety (as they keep road users alert) (Svensson, 1998). In this study we had no control on how serious situations the interviewed cyclist perceived as "near-misses".

A strength of this study is that we combine three different data types (cross sectional survey data, panel data and observation data) to study the same phenomenon. Such method triangulation is often called for, but is rarely conducted. The fact that all the three data types point in the same direction but that there still are some differences, illustrates the importance of such an approach.

Some questions still remain unanswered. First, the pattern of change differs somewhat depending on what measure we are looking at. The survey data shows a drop in number of times cyclists are overlooked by cars from April to June, and a further drop to September. There is no change in number of times car drivers are surprised by cyclists in the season. The largest drop seems to be at the beginning of the season. Both car drivers and cyclists report a drop in near-misses from April to June, and a small increase from June to September. The video data shows a somewhat different pattern, with unchanged conflict risk from April to June followed by a drop from June to September ("delayed effect").

One explanation for this discrepancy could be that the exposure counts that were used in traffic conflict analysis based on video differed from the official counts utilised for calculating exposure for cyclists in the survey data. The use of different exposure measures deserves some mention in this respect. For the survey data we have used two different sources of information for calculating seasonal variation in cycling levels (for the analysis of pedestrians and car drivers encounters with cyclists): 1) The National Travel behaviour data (for southeast Norway), showing a substantial increase from April to June, and a small decrease from June to September *and* 2) The road authorities' bicycle counters, showing a very large increase from April to June, and a large drop to September0F.[1] As these data differed substantially, and it was not possible to determine what was the right seasonal pattern, we decided to use an average of these two. Our own counts from the video shows a different pattern, with a substantial increase from June to September. It could be argued that we should have used these data when estimating exposure in the survey. A sensitivity analysis of the survey data using exposure ratios from the video data did however, not change the pattern of differences. Also, as mentioned in Section 4.2, the number of cyclists has serious limitations as an exposure measure. It is more theoretically plausible to use the number of encounters between cyclists and motor vehicles (at least in the observational studies), however to do these counts manually is a very laborious task and some automated tool (like automated video analysis software) is required.

The first data collection of the current study was done immediately after the Easter vacation in April 2013. In Norway, cycling levels shift dramatically from before to after Easter, since many people use this as a kind of red-letter day to bring out their bicycles after winter. Ideally, data collection should therefore have started before Easter, in order to capture this large influx of new cyclists even better. The reason for choosing the period right after Easter, was to balance the time and costs of data collection with a period

[1] These figures are from 2013, the year that the interviews were collected. In 2014, new (visible column) counters were installed. Two out of four of these counters registered a drop from June to September, one registered no change, and one reported an increase.

with still comparably low numbers of cyclists. An important note regarding the seasonal variation is the influence of weather on cycling levels. As it happened, the first few days after Easter, when interviews commenced, were rather cold, so that the first cyclists might have delayed their upstart of cycling somewhat. Still, future studies should aim at maximising the changes in cycling levels even more than we managed by starting the study periods earlier, or even maybe doing whole-year studies. For the remaining interview periods, weather conditions were quite normal for the summer season in Norway, i.e. around 15–20 °C, and mostly sunny or light clouds, with occasional rainy days (when interviews were paused). The September period had no rain, and was somewhat warmer than normal, with temperatures above 20° on some days.

Another unanswered question is "Why is there no SiN effect for car drivers and pedestrians when it comes to surprises (H3 and H4), but a change in near-misses (H5)? As we saw, the number of surprises was only related to the number of encounters, and did not change through the season (i.e. there was no learning effect). The number of interviewed pedestrians and car drivers is far lower than the number of cyclists, so one explanation could be that this is just methodological artefact. Further, the analyses rely on the respondents' own assessments of numbers of encountered cyclists, which is probably a number with a large error margin. However, looking at the crude data, we see that pedestrians and car drivers both report more surprises in September than in June. So, even if the own assessments of encountered cyclists were to be replaced by more objective figures of cycling numbers, the tendency of the data is in the wrong direction.

One possible explanation could be because of a change in cycling population that counters the beneficial effect of changes in expectancies. As we have shown previously cycling through red was found to be more frequent in June than in April (de Goede et al., 2014). This suggests that with increasing numbers of cyclists in Norway, the share of 'risk-taking' or unexperienced cyclists increases. This may even counteract and hide a potential SIN effect. In other words, car drivers might become more aware of cyclists throughout the season, but the benefits of this might be cancelled out by the increased level of risky behaviour by bicyclists. This is only speculations, and the question still remains why the observed change in number of near-misses is not preceded by a change in number of surprises. Is it a methodological artefact or is it related to some other mechanism counteracting positive effects of increased numbers? Further research should therefore aim at linking car drivers' (and pedestrians') experiences of being surprised by cyclists with number of near-misses, using better measures of surprises, near misses, and exposure.

A final question that remains to be answered is 'Who learns?' If we are to believe these data, interaction between car drivers and cyclists improves though the season. We have taken this as a proof of car drivers becoming more used to cyclists, and hence more expecting of encountering them in traffic. However, it could also be the case that cyclists through interaction with car drivers become better at reading traffic and finding their place, and thereby less often finding themselves in conflict-like situations. Our background data (Table 2) shows that the cyclists interviewed in September are less likely to be whole year cyclists than those interviewed in April, which gives some support to such a contention. Future research should aim at testing if cyclists become more proficient with increased experience through the season, in the same fashion as novice drivers show a rapid learning curve in their first months of their driving carrier (Sagberg and Bjornskau, 2006).

In this paper we have attempted to test the predominant mechanism of the Safety in Numbers phenomenon, that an increased number of cyclists in a given road environment results in an increased attentiveness from other road users. We have found a strong support for this mechanism, but we have also seen indications that there are more to such shifts than just changes in numbers. More specifically, we argue that with increasing numbers, different *types* of bicyclists also enter into the population. Some of these new cyclists can be less experienced and more risk taking, as we have indicated. On the other hand, some of these new cyclists can also be less risk-taking than the "early adopters". The effects of these population differences might thus both attenuate and accentuate the positive effects of increased attentiveness from motorists. A final verdict on Safety in Numbers can thus not be given just yet.

Appendix A.

Table A1

Table A1
Exposure (number of cyclists), conflicts, and risk of conflict at Site I Toftes gate – Seilduksgata in April, June and September.

	April	*June*	*September*	
Exposure	Hours	75	75	75
	Cyclists (C)	3889	6245	8485
	Motor vehicles (MV)	36,080	40,380	38,964
	$\Sigma(^{C}/_{h} \cdot {}^{MV}/_{h})/10^6$	2.21	3.57	4.93
Conflicts	all types	3	2	4
Risk	Conflicts · 10^3/ cyclists	0.77	0.32	0.47
	Conflicts · 10^6/ $\Sigma(^{C}/_{h} \cdot {}^{MV}/_{h})$	1.35	0.56	0.81

Table A2

Table A2
Exposure (number of cyclists), conflicts, and risk of conflict at Site II Suhms gate – Kirkeveien in April, June and September.

	April	*June*	*September*	
Exposure	Hours	30	75	50
	Cyclists (C)	5591	13,385	15,081
	Motor vehicles (MV)	50,096	123,652	90,368
	$\Sigma(^{C}/_{h} \cdot {}^{MV}/_{h})/10^6$	10.58	25.01	28.81
Conflicts	all types	4	22	14
Risk	Conflicts · 10^3/ cyclists	0.72	1.64	0.93
	Conflicts · 10^6/ $\Sigma(^{C}/_{h} \cdot {}^{MV}/_{h})$	0.38	0.88	0.49

Table A3

Table A3
Exposure (number of cyclists), conflicts, and risk of conflict at Site III Vogts gate-Marcus Thranes gate in April, June and September.

	April	*June*	*September*	
Exposure	Hours	75	75	75
	Cyclists (C)	5580	7960	11,228
	Motor vehicles (MV)	139,021	133,560	132,298
	$\Sigma(^{C}/_{h} \cdot {}^{MV}/_{h})/10^6$	10.89	14.92	20.85
Conflicts	all types	12	18	11
Risk	Conflicts · 10^3/ cyclists	2.15	2.26	0.98
	Conflicts · 10^6/ $\Sigma(^{C}/_{h} \cdot {}^{MV}/_{h})$	1.10	1.21	0.53

Table A4

Table A4
Exposure (number of cyclists), conflicts, and risk of conflict at Site IV, roundabout Mogata – Jutuveien – Stavangergata in June and September.

	June	*September*	
Exposure	Hours	75	75
	Cyclists (C)	11,180	11,719
	Motor vehicles (MV)	115,867	128,792
	$\Sigma(^{C}/_{h} \cdot {}^{MV}/_{h})/10^6$	19.68	22.93
Conflicts	all types	9	8
Risk	Conflicts · 10^3/ cyclists	0.81	0.68
	Conflicts · 10^6/ $\Sigma(^{C}/_{h} \cdot {}^{MV}/_{h})$	0.46	0.35

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