Title: Effects of Roundabouts on Traffic Safety for Bicyclists: an Observational Study.

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ABSTRACT

A before-and-after study of injury accidents with bicyclists on 95 roundabouts in Flanders-Belgium was carried out. The study design accounted for effects of general safety trends and regression-to-the-mean. Conversions of intersections into roundabouts turn out to have caused a significant increase of 29% (95% C.I. [2%; 63%]) in the number of injury accidents with bicyclists. The increase is even higher for accidents involving fatal or serious injuries (49-50%). Compared to the formerly proven favourable effects of roundabouts on safety in general, this result is unexpectedly poor. However, the effects of roundabouts on bicycle accidents differ depending on when these roundabouts are built inside or outside urban areas. Inside urban areas the construction of a roundabout did increase the number of injury accidents involving bicyclists by 48% (95% C.I. [10%; 100%]). For accidents inside urban area with fatal or serious injuries, we see an average increase of 80 to 81%. Outside urban areas however the zero-hypothesis of ‘no safety effect for bicyclists’ cannot be rejected (best estimate: + 5% accidents, not significant).

KEY WORDS

Roundabout, bicyclist, safety, intersection

1. INTRODUCTION

Roundabouts in general have a positive effect on traffic safety, at least for accidents causing injuries. During the last decades several surveys were carried out into the effects of roundabouts on traffic safety. A meta-analysis on 28 studies in 8 different countries revealed a best estimate of a reduction of injury accidents of 30-50% *(1).* Other studies, not included in the former one and using a proper design, delivered similar results *(2) (3)*. All those surveys reported a considerably stronger decrease in the number of severest accidents (fatalities and accidents involving serious injuries) compared to the decrease of the total number of injury accidents. The effects on property-damage only accidents are however highly uncertain *(1)*.

Less is known about the safety effects of roundabouts for particular types of road users, such as bicyclists *(4)*. Roundabouts seem to induce a higher number of bicyclist-involved accidents than might be expected from the presence of bicycles in overall traffic. In Great-Britain the involvement of bicyclists in accidents on roundabouts was found to be 10 to 15 times higher than the involvement of car occupants, taking into account the exposure rates *(5)*. In the Netherlands safety records of 185 roundabouts were studied and a reduction of 30% was reported in the number of victims among bicyclists to the period before construction of the roundabout, while the overall number of traffic victims decreased by 95% (car occupants), 63% (motorcyclists), 63% (pedestrians) and 64% (other road users) *(6)*. Unfortunately, the study design could not take into account the possible effects of general trends in traffic safety and the regression-to-the-mean-effect.

It is important to know whether roundabouts have a different impact on the safety of different types of road users in order to develop adequate decision criteria for situations when a roundabout should be constructed or not.

An evaluation study therefore was carried out on the effects of roundabouts on accidents involving bicyclists. The question was whether the resulting effect would be the same as for accidents in general, both for the totality of injury accidents as for the severest accidents (accidents resulting in fatal or serious injuries). Supplementary questions were whether the effect would be on average different if the roundabout was constructed inside or outside urban area (as traffic conditions inside built-up areas may be considerably different from conditions outside built-up areas, e.g. number of bicyclists, average speed of cars, road width, presence of trucks, etc.). A final aim was to find out whether the effects on the number of accidents involving bicyclists would be different on intersections that were signal-controlled before the conversion to a roundabout compared to locations with no traffic signals in the before-situation.

2. DATA COLLECTION

A sample of 95 roundabouts in the Flanders region of Belgium was studied. The roundabout data were obtained from the Flemish Infrastructure Agency (part of the Department of Mobility and Public Works). The sample was selected according to the following successive selection criteria applied on the initial dataset:

- Roundabouts on roads owned by the Flemish Infrastructure Agency (so called numbered roads).
- Roundabouts constructed between 1994 and 2000.
- 3 or 4 roundabouts selected randomly in each of the 28 administrative road districts in the Flanders region.

All the investigated roundabouts are located on roads owned by the Flemish Infrastructure Agency. Other roundabouts were not included as no data for them were available. This Agency owns mainly roads with significant traffic, where other, smaller and less busy roads are usually owned by municipalities. The average traffic volume on the type of roads in question is 11 611 vehicles per day *(7)*.

For the purpose of this study only those roundabouts that were constructed between 1994 and 2000 were taken into account. Accident data were available from 1991 until the end of 2001. Consequently a time period of accident data of at least 3 years before and 1 year after the construction of each roundabout was available for the analysis.

Exact location data for each roundabout were available so that accident data could be matched with the roundabout data. 42 roundabouts from the sample are located inside urban areas (areas inside urban area boundary signs, general speed limit of 50km/h), 53 outside urban areas (general speed limit of 90 or 70 km/h) (see table 1). 21 roundabouts were constructed on intersections that were signal-controlled in the before-situation, 62 roundabouts were constructed on intersections with no traffic signals before. For 12 locations it is not known which type of intersection design was present before.

TABLE 1 Treatment Group Locations (Roundabouts)

	No traffic signals before	Traffic signals before	Unknown	TOTAL
Inside Urban areas	28	7	7	42
Outside urban areas	34	14	5	53
TOTAL	62	21	12	95

A comparison group of 172 intersections was created. To achieve this, intersections were selected in the neighbourhood of the roundabout locations. Preference for comparison group locations was given to intersections on the same main road as the nearby roundabout location. Moreover preference for the cross road on the comparison location was given to the same category as the cross road on the roundabout location. The road categories were found on a street map. In order to avoid possible interaction effects of the comparison group locations with the observed roundabout locations, comparison group locations had to be at least 500 meter away from the observed roundabout locations. 76 locations from the resulting comparison group are located inside urban areas, 96 outside (see table 2). Apart from the confirmation that they are not roundabouts, no information is available about the type of traffic regulation on the intersections in the comparison group. On these types of roads either signal-controlled, or priority-ruled intersections (one direction has priority) may occur.

TABLE 2 Comparison Group Locations

	Number of locations in comparison group
Inside Urban areas	76
Outside urban areas	96
TOTAL	172

Detailed accident data were available from the National Statistical Institution for the period 1991-2001. This database consists of all registered traffic accidents causing injuries. Only accidents where at least one bicyclist was involved were included. Accidents were divided into 3 classes based on the severest injury that was reported in the accident: accidents involving at least one fatally injured person (killed immediately or within 30 days after the accident), accidents involving at least one seriously injured (person hospitalized for at least 24 hours) and accidents involving at least one slightly injured. No distinction was made about which road user was injured, the bicyclist or any other road user such as a car driver or occupant, a motorcyclist, another bicyclist or whoever.

Locations of accidents on numbered roads are identified by the police by references to the nearest hectometre pole on the road. All the accidents that were exactly located on the hectometre pole of the location were included in this study. Subsequently accidents that were located on the following or the former hectometre pole were added, except when the observed accident could clearly be attributed to another intersection. This approach was chosen in order to include possible safety effects of roundabouts in the neighbourhood of the roundabout as they might occur *(8)*. At least one road on each location, both for the treatment group as for the comparison group, was a numbered road.

The same selection criteria were applied for accidents on locations in the comparison group as for accidents on locations in the treatment group.

The total number of accidents included in the treatment group was 423, of which 325 with only slight injuries, 91 with at least one serious injury and 7 with a fatal injury (see table 3). The total number of accidents in the comparison group is 649, of which 486 with only slight injuries, 142 with serious injuries and 21 with fatal injuries.

TABLE 3 Number of Accidents Considered

	Treatment group	Comparison group
Number of accidents involving at least 1 slight injury	325	486
Number of accidents involving at least 1 serious injury	91	142
Number of accidents involving a fatal injury	7	21
TOTAL	423	649

Tables 4 and 5 give the number of accidents for the treatment group, split up by the location inside and outside urban areas and by the before-situation at the location (traffic signal or not). In Table 4 this was done for all injury accidents, in table 5 only for the most severe accidents, i.e. accidents involving serious or fatal injuries.

TABLE 4 Number of Accidents – Treatment group

	Traffic signals before	No traffic signals before	Unknown	TOTAL
Inside Urban areas	50	155	42	247
Outside urban areas	66	108	2	176
TOTAL	116	263	44	423

TABLE 5 Number of Severe Accidents (with fatal or serious injuries) – Treatment Group

	Traffic signals before	No traffic signals before	Unknown	TOTAL
Inside Urban areas	10	36	6	52
Outside urban areas	18	28	0	46
TOTAL	28	64	6	98

TABLE 6 Number of Accidents – Comparison Group

	Number of accidents involving injuries	Number of accidents involving fatal or serious injuries
Inside Urban areas	340	74
Outside urban areas	309	89
TOTAL	649	163

Table 6 shows the number of accidents for the comparison group, split up by the location inside or outside urban areas.

3. METHODOLOGY

The objective was to ascertain the effect of a measure (construction of roundabouts) on a particular type of accidents (accidents involving bicyclists). The study was designed as a before and after study with a comparison group, controlling for general trends in traffic safety and possible effects of regression-to-the-mean *(9) (10) (11)*.

The first stage was to calculate the effectiveness for each location in the treatment group separately. Consequently the results were combined in a meta-analysis.

The effectiveness is expressed as an odds-ratio of the evolution in the treatment group after the measure has been taken compared to the evolution in the comparison group in the same time period (Eq. 1).

$$EFF_l = \frac{TREAT_{l,\,after} \,/\, TREAT_{l,\,before,\,regr}}{COMP_{after} \,/\, COMP_{before}} \qquad (1)$$

The values of $TREAT_{l,after}$, $COMP_{after}$ and $COMP_{before}$ are count values and can simply be derived from the data. The value for $TREAT_{l,after}$ is the count number of accidents that happened on the location l during the years after the year when the roundabout was constructed. The values for $COMP_{after}$ and $COMP_{before}$ are the total count numbers of accidents for all locations in the comparison group respectively after and before the year during which the roundabout has been constructed. The values for the year during which the roundabout was constructed are always excluded, both in the treatment group and in the comparison group.

The use of the comparison group allows for a correction of general trend effects that could be present in the accident evolution on the studied locations.

The value of $TREAT_{l,before,regr}$ reflects the estimated number of accidents on the treatment location l before construction of the roundabout, taking into account the effect of regression to-the-mean. The regression-to-the-mean effect is likely to occur at locations where a decision has been taken to construct a roundabout as the Infrastructure Agency considers an increased number of accidents as an important criterion for constructing a roundabout at a certain location. The value is calculated as a result of the formula (Eq 2):

$$TREAT_{l,\,regr,\,T} = w * (\mu_{(TREAT_l\ +\ COMP)} * T) + (1-w) * (\sum_{t=1}^{T} TREAT_{l,\,t}) \qquad (2)$$

$$\text{with } w = \frac{1}{1 + k * \mu_{(TREAT_l\ +\ COMP)} * T} \qquad (3)$$

$$\text{and } k = \frac{\sigma^2_{(TREAT_l\ +\ COMP)} - \mu_{(TREAT_l\ +\ COMP)}}{\mu^2_{(TREAT_l\ +\ COMP)}} \qquad (4)$$

The value k (Eq 4) expresses the overdispersion factor. This value is specific for the negative binomial distribution and reflects the amount in which the data are more spread than it would be the case in a Poisson-distribution. The value k must be positive and is calculated from the data itself. k-values were derived for each location separately, using all available accident data. However, when analysing the accidents involving fatal or serious injuries, the k-value appeared to be close to zero or even turned sometimes out to be negative. In the former case, this could reveal a problem of erroneous pure Poisson characteristics due to the small size of the sample and the low sample mean (12). In the latter case this is even contradictory to the basic assumption of the negative-binomial distribution of accidents (variance larger than the mean). As the use of a different value for k might lead to different results and an unreliably estimated overdispersion parameter could significantly undermine estimates *(12)*, we used two scenarios when considering accidents involving fatalities or serious injuries. In the first scenario the same value for k was used for accidents involving fatalities or serious injuries as for all accidents. In the second scenario k was derived from the data itself (which was possible for all locations inside built-up areas and not possible for any of the locations outside built-up areas) or an extremely small, but positive fixed value for k was used ($k=10^{-10}$) (in the case of the locations outside built-up areas).

The value w (Eq 3) reflects the weighting of the group in comparison to the weighting of the location itself when estimating the number of accidents on the observed location before construction of the roundabout. The higher the overdispersion factor k, the lower the weighting of the group and the more information is attributed to the count data of the observed location itself.

Equation 2 expresses the estimated number of accidents at the observed location in a time period T.

Consequently the value of EFF_l can be calculated. This value reflects the best estimate for the impact of the construction of a roundabout at location l. $Ln(EFF_l)$ denotes the natural logarithm of EFF_l. As EFF_l has a lognormal distribution (13) the variance s^2 of $Ln(EFF_l)$ can be calculated as

$$s_l^2 = \frac{1}{TREAT_{l,\,after}} + \frac{1}{TREAT_{l,\,before,\,regr}} + \frac{1}{COMP_{after}} + \frac{1}{COMP_{before}} \tag{5}$$

The 95% confidence interval can be derived as

$$CI_{EFF_l} = EXP\left[Ln(EFF_l) \pm 1.96 * s\right] \tag{6}$$

This method was applied to calculate best estimates and confidence intervals for each roundabout location separately. After doing this, a meta-analysis was carried out in order to retrieve generalized impacts on groups of locations. The generalized effect is expressed as

$$EFF_{ALL} = EXP\left[\frac{\sum_{l=1}^{n} w_l * Ln(EFF_l)}{\sum_{l=1}^{n} w_l}\right] \tag{7}$$

with $w_l = \frac{1}{s_l^2}$ (8)

The confidence interval for EFF_{ALL} is derived in a similar way as in equation 6.

$$CI_{EFF_{ALL}} = EXP\left[\frac{\sum_{l=1}^{n} w_l * Ln(EFF_l)}{\sum_{l=1}^{n} w_l} \pm 1.96 * \frac{1}{\sqrt{\sum_{l=1}^{n} w_l}}\right] \tag{9}$$

4. RESULTS

Both treatment group and comparison group were divided into locations inside and outside urban areas. Consequently analyses were made for roundabouts inside urban areas using all locations in the comparison group inside urban areas as a comparison group for this estimation. The treatment locations were divided into three groups, depending whether the investigated intersection was equipped with traffic signals or not in the before-situation (“traffic signals before”, “no traffic signals before”, “traffic signals unknown”). The effectiveness-index was calculated for each treatment location using the described methodology. After calculating the effectiveness-index for all the locations in the same group a meta-analysis was made for the whole group.

Table 7 shows the results of the analyses. The best estimate for the overall effect of roundabouts on injury accidents involving bicyclists is an increase of 29%. The best estimate for the effect on accidents involving fatal and serious injuries is an increase of 49 or 50%. Both effects are significant at the 0.05-level.

Performing the meta-analysis for all locations inside built-up areas reveals an increase of accidents of probably 48% (effectiveness-index 1.48) after the roundabout construction. The result is significant at the 0.01-level.

On intersections inside built-up areas and not equipped with traffic signals before, a significant increase of accidents involving bicyclists of 44% is noted. On intersections with traffic signals before, the best estimate is an increase of 23% of accidents. However, this result is clearly not significant. Estimations were also made for the group of the most serious accidents, i.e. accidents involving fatal and serious injuries. The results show a significant 81% increase in accidents involving bicyclists inside built-up areas. The results for the different before-situations, i.e. traffic signals or not, are not significant.

Subsequently the same procedure was followed for locations outside urban areas. When it comes to all injury accidents the overall best estimate of the impact is close to one, which means that the zero-hypothesis of “no effect” cannot be rejected at all. Nor do we see a significant effect for accidents involving fatal and serious injuries. The overall best estimate shows an increase of 28% of accidents. Nevertheless, the confidence interval is broad and even a decrease in accidents cannot statistically be excluded.

In order to reveal whether there are any significant differences in the results for different before-situations (traffic signals or not) or different locations (inside or outside built-up area), a series of two-tailed t-tests with two samples assuming unequal population variances was performed. Table 8 shows the results. Significant differences are found for “all accidents causing injuries” outside built-up area (a best estimate of index 1.37 on intersections with traffic signals before versus an index of 0.89 on intersections without traffic signals before). Furthermore, the t-test shows a significant difference between locations with traffic signals before (best estimate index 1.30) and locations without traffic signals before (index 1.21) for all accidents at all locations.

Moreover significant differences are found for locations inside versus outside built-up areas at intersections that were not equipped with traffic signals before (at least when looking at accidents involving fatal or serious injuries and to a lesser degree when looking at all accidents).

TABLE 7 Results

		Traffic signals before	No traffic signals before	Traffic signals before = unknown	All locations
Inside built-up area	All injury accidents	1.23 [0.62-2.45] (ns)	1.44 [1.01-2.07] (*)	2.33 [0.97-5.65] (ns)	1.48 [1.10-2.00] (**)
	Accidents with fatally and seriously injured	1.60 [0.44-5.84] (ns) ° 1.63 [0.45-5.90] (ns) °°	1.87 [0.98-3.59] (ns) ° 1.86 [0.98-3.55] (ns) °°	1.80 [0.43-7.45] (ns) ° 1.73 [0.43-6.95] (ns) °°	1.81 [1.06-3.10] (*) ° 1.80 [1.06-3.07] (*) °°
Outside built-up area	All injury accidents	1.37 [0.72-2.59] (ns)	0.89 [0.55-1.44] (ns)	1.20 [0.28-5.22] (ns)	1.05 [0.72-1.52] (ns)
	Accidents with fatally and seriously injured	1.75 [0.71-4.32] (ns) ° 1.97 [0.77-4.99] (ns) °°°	1.03 [0.56-1.89] (ns) ° 1.05 [0.57-1.92] (ns) °°°	2.06 [0.42-10.17] (ns) ° 1.66 [0.36-7.74] (ns) °°°	1.28 [0.79-2.06] (ns) ° 1.30 [0.80-2.10] (ns) °°°
All locations	All injury accidents	1.30 [0.81-2.08] (ns)	1.21 [0.91-1.61] (ns)	1.96 [0.92-4.17] (ns)	1.29 [1.02-1.63] (*)
	Accidents with fatally and seriously injured	1.70 [0.81-3.56] (ns) ° 1.84 [0.87-3.92] (ns) °°°°	1.36 [0.88-2.12] (ns) ° 1.37 [0.88-2.13] (ns) °°°°	1.91 [0.66-5.52] (ns) ° 1.70 [0.61-4.77] (ns) °°°°	1.49 [1.04-2.13] (*) ° 1.50 [1.05-2.15] (*) °°°°

ns = non significant, * = p≤0.05, ** = p≤0.01
° overdispersion value k = k-value derived from data for all injury accidents
°° overdispersion value k = k-value derived from data only for accidents with fatally and seriously injured
°°° overdispersion value k could not be derived from data (VAR<AVG). Use of fixed k = 10^{-10}
°°°° with use of results with k-value for "all injury accidents"

FIGURE 1 Funnel Graph – Best Estimates of the Effectiveness-Index – All Roundabouts – All Accidents.

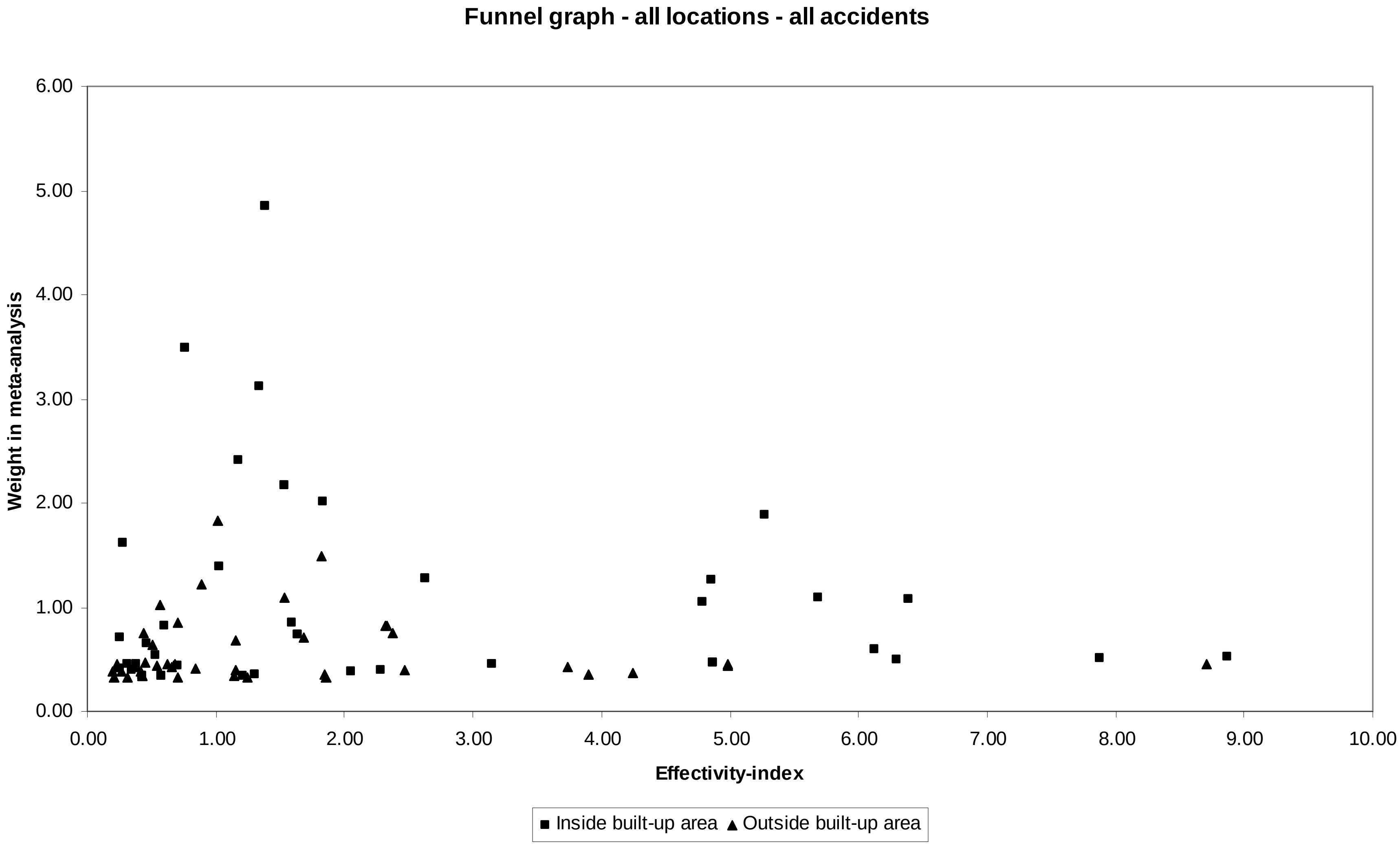

TABLE 8 t-tests

			t-statistic	p-value	
Inside built-up area	All injury accidents	signals vs no signals before	0.49	0.64	ns
	Accidents with fatally and seriously injured°	signals vs no signals before	-0.99	0.34	ns
Outside built-up area	All injury accidents	signals vs no signals before	3.17	0.00	**
	Accidents with fatally and seriously injured °	signals vs no signals before	1.17	0.25	ns
All locations	All injury accidents	signals vs no signals before	2.35	0.02	*
	Accidents with fatally and seriously injured °	signals vs no signals before	0.56	0.58	ns
All locations	All injury accidents	inside vs outside built-up area	1.72	0.09	ns
	Accidents with fatally and seriously injured °	inside vs outside built-up area	2.04	0.04	*
Signals before	All injury accidents	inside vs outside built-up area	-0.33	0.75	ns
	Accidents with fatally and seriously injured°	inside vs outside built-up area	0.01	0.99	ns
No signals before	All injury accidents	inside vs outside built-up area	1.99	0.05	nearly sign.
	Accidents with fatally and seriously injured°	inside vs outside built-up area	2.20	0.03	*

ns = non significant, * = p≤0.05, ** = p≤0.01
° used results with k-value derived from all injury accidents

5. DISCUSSION

We are aware of only one previous before-and-after study investigating the effects of roundabouts on different types of road users. This study *(6)* provided indications of a less positive effect of roundabouts on injuries among bicyclists compared to other road users, but did not consider general trends and regression-to-the-mean. According to the results above, the effect does not look positive at all. This finding could provide an explanation for the higher-than-expected prevalence of injury accidents involving bicyclists on roundabouts as has been noted in some countries *(5) (14)*. However, it is recommendable to perform similar studies in other countries in order to confirm whether results are comparable.

Our best estimate for the overall effect of roundabouts on the number of injury accidents involving bicyclists is a significant increase of 29% (95% C.I. [2%; 63%]. The effect on severe accidents is even worse: an increase of 49 to 50% . It is interesting to compare these results with a former study *(3)* that studied the effects of roundabouts on safety among all types of accidents in the same region and used a strongly comparable dataset. This study revealed an overall decrease of 34% of accidents causing injuries (95% C.I. [-43%; -28%]) and a decrease of 38% [-15%; -54%] for accidents involving fatal and serious injuries.

The contradictory results for accidents involving bicyclists and all accidents raise the question whether it is recommendable or not – at least from a safety point of view – to construct roundabouts. Although roundabouts turn out to be a safe solution in general, the results for bicyclist's safety are clearly poor.

The effects on bicyclist's safety differ depending on the location of the roundabouts. It is unquestionable that the effect of roundabouts inside urban areas is bad. Outside urban areas the effect on safety for bicyclists is about zero: not better nor worse compared to the before-situation. It's more difficult to judge the effect depending on the type of intersection in the before-situation: inside urban areas the results seem to be somewhat worse for locations without traffic signals in the before-situation compared to locations with traffic signals. However, the differences between "traffic signals before" and "no traffic signals before" are not significant and even contradictory when regarding both categories "all accidents causing injuries" and "accidents involving fatally or seriously injured".

Outside urban areas the differences between "traffic signals before" and "no traffic signals before" are more distinct. Intersections with traffic signals in the before-situation perform significantly worse in comparison to non-signalised intersections.

One must take into account that an estimated effect is always a "most likely" effect that may conceal many differences between individual locations. Figure 1 illustrates this. The figure shows the estimations for the results in table 7 (all accidents, 95 data points). It is obvious that results at individual intersections differ considerably. The lowest estimated effect is a 80% decrease (index 0.2), the highest an increase of 771% (index 8.71). Generally, it could be expected that the data points with the highest weightings are closer to the general best estimate, which should show a more or less normal distribution. To a large extent this seems to be the case.

The variations between the individual results can be explained mainly by the stochastic nature of accidents as rare events, but there might also be something more. Looking at figure 1, there are some indications of a double peak in the curve. This could reveal the presence of distinct subgroups in the sample of roundabouts with different safety effects. Looking at the second peak, in the neighbourhood of coordinates (5.27; 1.89), all intersections are located inside built-up areas. However, as one of the major conclusions in this study is that roundabouts inside built-up areas perform less well compared to roundabouts outside built-up areas when it comes to the safety of bicyclists, a higher representation of locations inside built-up areas in the group of the worst performing locations shouldn't be really surprising. The available data don't enable to give an accurate explanation for the second peak in the curve. Unknown influencing factors may exist. For example, no information was available about the kind of bicyclist facility (motorised traffic and bicyclists mixed together, separated cycle lanes, cycle paths or whatever) present at the roundabouts studied, while specific design characteristics may have an important effect on accidents for specific groups of road users *(4)*. More research on this topic should be carried out.

One of the restrictions of this study is the lack of data about the evolution of traffic volume on the locations studied, or the evolution of motorised traffic and bicyclist traffic. By using a large comparison group it was possible to account for both general trends in traffic volume as well as possible evolutions in modal choice. In addition, one cannot exclude the effect of roundabouts on bicyclists' exposure. Although there is no evidence of such at present, it is possible that some bicyclists will change their route after the construction of a roundabout, either resulting in an increased use of the roundabout or a decrease in the use, depending on personal preferences. Either changes in the route choice could make the results in this study weaker (if roundabouts attract bicyclists this would create a higher risk exposure for bicyclists at the site, but a corresponding lower risk elsewhere, in which case we are too pessimistic in our estimates) but the results might also be stronger (if bicyclists use roundabouts less than the previous type of intersection, in which case our estimations are even too modest). As no data on bicyclists' exposure were available, we couldn't account for possible changes in the choice of route. Further research in this area is nevertheless recommended.

6. CONCLUSIONS

As roundabouts are in general improving safety on intersections, there are few reasons for doubting the added-value of roundabouts as far as safety is concerned. But, looking at the poor results for cycle accidents and keeping in mind the attention that many governments pay to vulnerable road users like bicyclists, roundabouts don't seem to be an appropriate solution in all circumstances in which they were built in the past. At least in urban, built-up areas where speeds are lower and bicyclists are more numerous, road authorities should look at pros and cons carefully before constructing a roundabout. Further research should reveal whether it is possible to define more specific circumstances in which roundabouts should be constructed or not and whether some geometric features of roundabouts correlate with less or more accidents involving bicyclists.

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