Is There a Spillover Effect of a Right Turn on Red Permission for Bicyclists?

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Abstract

Some countries allow bicyclists to perform a right turn on red (RTOR) at a number of signalized intersections to promote cycling by reducing the required physical effort and trip time. Implementation of this law could lead to both local and supralocal effects on road safety. Using an experimental survey approach, this study explores whether a so-called 'spillover effect' of the measure can be expected. This effect implies that allowing bicyclists to turn right on red at some places causes bicyclists to also turn right on red more often at places where this is not allowed.

The answers from 768 respondents indicate that respondents with a high awareness of the existence of a RTOR rule for bicyclists turn right on red significantly more often at locations where this is not allowed than respondents with a low awareness of the rule. This indicates that implementation of the RTOR rule for bicyclists can lead to a substantial spillover effect, i.e. an increase in red light running at other locations. This might lead to safety issues at locations where no RTOR for bicyclists is allowed, since road authorities could have decided not to allow RTOR for bicyclists at these locations for safety reasons.

Keywords

Right turn on red for bicyclists, RTOR, cycling behaviour, experimental survey, spillover effect

1 Introduction

Organizing the way people travel in a more sustainable way is one of the key challenges of policy makers in the field of transportation (Gehlert et al., 2013). Many governments therefore focus on encouraging the use of the bicycle in order to reduce the number of cars on the road, and their corresponding negative impacts such as congestion and emissions (Buehler & Pucher, 2012; Ming Wen & Rissel, 2008; Su et al., 2010). Even in countries that do not have a strong cycling culture, such as the United States and Canada, bicycle use and policy attention are increasing, especially in large cities (Akar et al., 2012; Buehler & Pucher, 2012; Pucher & Buehler, 2011).

One of the possibilities to promote the use of the bicycle is to make cycling more convenient and faster (Paige Willis et al., 2013). This can be done, for instance, by avoiding unnecessary stops. In this respect, some countries have adopted a policy of allowing bicyclists to run the red light when turning right at certain signalized intersections, the so-called "right turn on red (RTOR) for bicyclists".

Although the RTOR rule for bicyclists is not a road safety measure, but rather a measure to increase efficiency of travel, implementation of the rule should not lead to an increase in risk. Currently, bicyclists are already overrepresented in many countries' crash statistics, and when cycling would increase in the future, this problem might become more prominent (Weijermars & Wesemann, 2013). Therefore, the safety effects of measures aimed at encouraging bicycle use should be carefully monitored.

Even though RTOR for bicyclists is adopted in a number of countries, including the United States, Canada, The Netherlands, France, and Belgium, the safety effects of this rule have not been evaluated in scientific literature before. Research about the safety effects of RTOR for bicyclists is therefore needed. This study investigates whether a spillover effect (i.e. an unintended increase in red light violations at other places or in other situations) can be expected from the RTOR rule for bicyclists using an experimental survey design. The study takes place in Belgium, where RTOR for bicyclists has recently been adopted.

2 Background

In the United States and in Canada, RTOR is in most states allowed by default for all drivers, usually after coming to a full stop, unless a traffic sign indicates otherwise (Federal Highway Administration, 2009). As part of this rule, also cyclists are allowed to turn right on red.

European countries on the other hand generally do not allow RTOR for drivers. However, some countries (including The Netherlands, Belgium and France) have implemented a RTOR for bicyclists rule. The content of this rule seems fairly similar in these European countries (Belgian Road Safety Institute, 2012; Berthod & Hiron, 2012; CROW, 1991). It is a rule that allows bicyclists (and moped drivers) to turn right through the yellow and red light at specific intersections where a traffic sign or traffic light indicates this permission (figure 1 shows an example of the sign that is used in Belgium). RTOR for bicyclists is therefore not a general rule, but a location-specific rule that can be implemented by the local road authority. For each intersection, the road authority should judge whether the implementation of RTOR for bicyclists can cause additional safety concerns. When executing a RTOR, the bicyclists are required to yield to other road users they might come in conflict with. Usually, this will be crossing pedestrians or bicyclists, but in case the bicyclists turn right onto a mixed traffic road they can also come in conflict with motorized vehicles coming from their left-hand side. Note that, despite its name, the rule can also apply to bicyclists driving straight through at a T-intersection at the side that does not have a connecting side road.

The RTOR for bicyclists can have two important safety effects, i.e. local effects and supralocal effects. To the best of the authors' knowledge, none of these two possible effects have been formally examined in scientific literature so far.

Figure 1: **Traffic sign indicating that RTOR for bicyclists is allowed (Belgium).**

One report has been found that discusses the local effects of the rule at the intersections where it applies (Belgian Road Safety Institute, 2012). The study discusses the results of a small-scale observational study of a pilot project of the RTOR rule for bicyclists in Belgium. The observational study concludes that RTOR does not lead to additional local conflicts at the study locations; bicyclists performing a RTOR usually do this carefully and yield to the road users that have the formal right-of-way. Especially at locations where the bicyclists turn right onto a bicycle track (and therefore do not encounter motorized traffic) the RTOR is less likely to result in an increase in serious crashes, since the additional potential conflicts that are caused by the rule are mainly among vulnerable road users. Crashes among vulnerable road users generally have a relatively low severity (Graw & König, 2002). On the other hand, research into RTOR permission for motor vehicles, which is a common practice in a number of countries such as Canada and the United States, indicates that this rule has led to a significant increase in right turn crashes (Elvik et al., 2009; Zador et al., 1982; Zador, 1984). Even though transferability of this finding to RTOR for bicyclists is unsure, it still can be considered as an indication of a possible effect.

Supralocal effects have in popular media often been claimed as an argument against allowing RTOR for bicyclists. It is claimed that the RTOR rule may lead to confusion and erodes the value of the red light as an absolute obligation to stop, which can lead to an increase in red light running at places where it is not allowed, which can be considered to be a so-called 'spillover effect'. A spillover effect can generally be defined as an effect of a measure at locations other than the ones that are actually treated by the measure (Condeço-Melhorado et al., 2011; Erke, 2009; Shin & Washington, 2007). Therefore, studies that aim to examine spillover effects, or want to take them into account, gather data about the outcome variable(s) of interest both at treatment sites and at non-treatment sites (Ko et al., 2013; Shin & Washington, 2007). When the measurements from the outcome variable(s) at the non-treatment sites differ between the situation before the implementation of the treatment and the situation after the implementation (after controlling for confounding factors such as trend effects), it can be concluded that a spillover effect takes place.

Within the frame of this study, it has been decided to focus study efforts on examining whether a spillover effect exists from the RTOR rule for bicyclists.

3 Study design

The existence of a spillover effect for the RTOR rule for bicyclists is investigated using an online experimental survey design. The study focuses on whether a spillover effect exists, and whether it is related to some socio-demographic variables. The core of the survey is a series of pictures from the viewpoint of a bicyclist, showing a situation where the respondents need to indicate whether they will turn right on red in that particular situation or not. At the start of the survey, the respondents are assigned randomly to either the experimental group or the control group. The experimental group is triggered to have a higher awareness of the existence of the RTOR rule compared to the control group. In case the respondents in the experimental group indicate a higher probability of making a RTOR at locations where it is not allowed, and both groups are similar in all other characteristics, it can be concluded that the difference in responses is caused by the higher awareness of this rule. In that case, it can be considered as an indication of the existence of a spillover effect of the RTOR rule for bicyclists.

3.1 About the survey

The study takes place in Belgium, where the law about RTOR for bicyclists has been approved by the Federal Parliament in 2011. Since February 2012, road authorities are allowed to implement the rule on-field.

The survey is filled out by a convenience sample of 768 respondents. In order to collect data from a sufficiently large sample, we have contacted a list of volunteers who participated in earlier studies from our institute, staff members from a number of organizations such as our university and the municipal administration, social media and a number of online forums. The survey consists of four main blocks, as can be seen in figure 2. Each of the blocks is described in detail in the following sections.

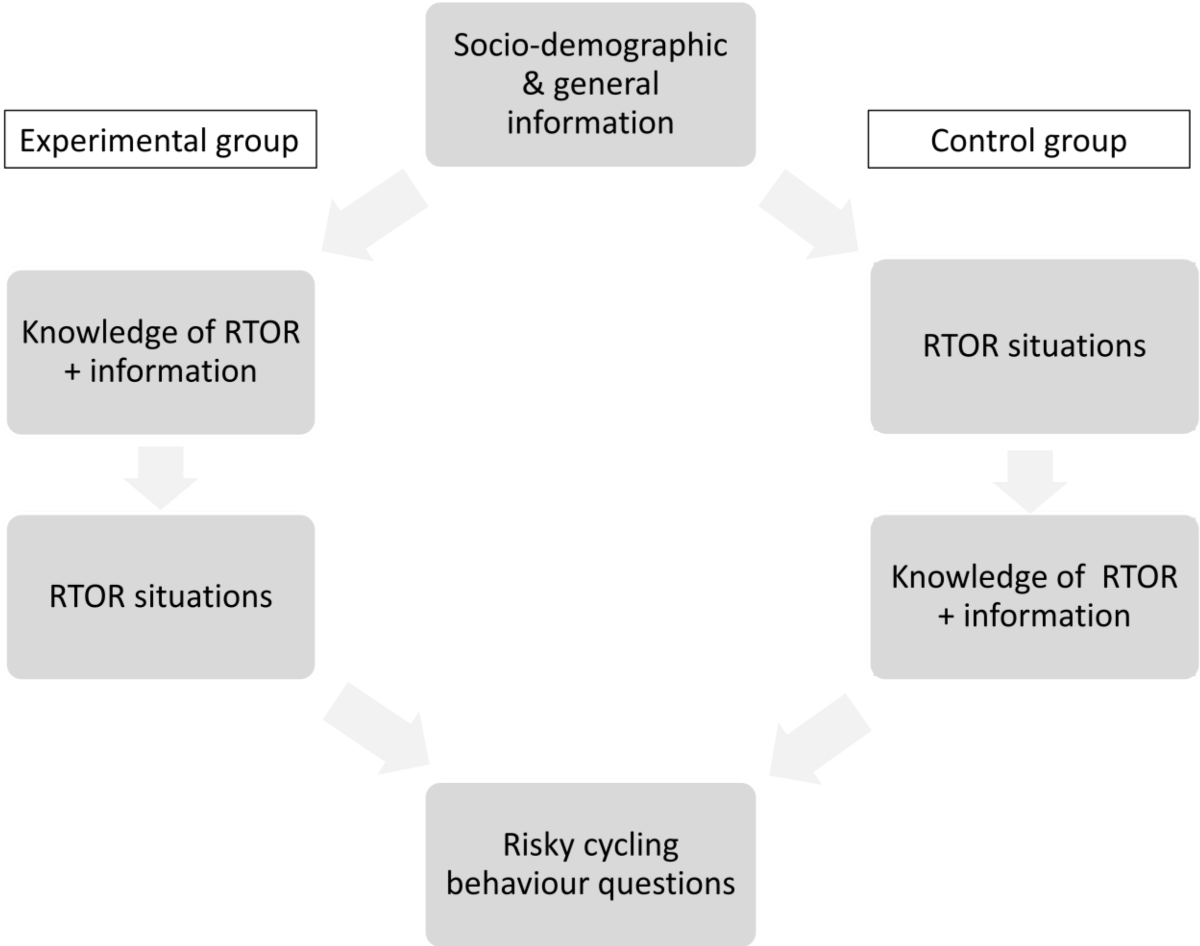

Figure 2: Survey structure.

3.1.1 Socio-demographic variables and general information about the respondents

First, a brief introduction to the survey is provided. Respondents are told that they are participating in a survey about bicycle behaviour. More detailed information about the purpose of the study is not provided to avoid biased responses.

The first block encompasses questions about socio-demographic and other general information about the respondent. Variables that could have an influence on bicycle behaviour are included, such as gender, age, education, license ownership, frequency of bicycle use,... More details about the collected variables are presented in table 1.

3.1.2 Respondents' knowledge about RTOR for bicyclists and provision of correct information

In the second block, the traffic sign that indicates that RTOR for bicyclists is allowed is shown to the respondents, and they are asked whether they know the meaning of the sign. Next, the correct meaning of the sign is displayed; i.e. RTOR for bicyclists is allowed at signalized intersections where this sign is mounted, but not at other places. The latter is emphasized in the explanation of the rule to avoid confusion for people who were unaware of the rule before the start of the survey. In the experimental group, this block precedes the questions of the RTOR situations from the third block. This way, the group has an increased awareness of the existence of the RTOR rule while answering these questions. Respondents in the control group on the other hand answer the questions of the RTOR situations before this block about the RTOR rule. This way, their awareness of the rule is lower while answering the RTOR situations, while we can still check how many of these respondents know about the rule.

The fact that the RTOR rule for bicyclists is already in place has the advantage that it increases the realism of the survey setting. A disadvantage of the fact that the rule is already in place could however be that also respondents in the control group can be aware of the existence of the rule without receiving a trigger, which would make them less suitable as a member of the control group. However, since the RTOR rule for bicyclists is implemented only at a very limited number of locations in the study area, our assumption is that respondents generally have a very low awareness of the existence of the rule during their everyday behaviour, even if they know it exists. This makes the respondents still suitable as subjects for the control group, even though the rule is already in place. This assumption will be tested in the data analysis.

3.1.3 Stated behaviour in RTOR situations

The third block displays six pictures of intersections where a ROTR rule could be implemented. The picture is taken from the viewpoint of the bicyclist, and the traffic light is red. The respondent is asked "Will you turn right through the red light at this situation?". The answer is provided on a 7-point Likert scale, ranging from "1 – Very likely" till "7 – Very unlikely". In order to avoid socially desirable answers, the instructions about this part of the survey clearly indicate that we are interested in the respondents' actual behaviour, not their knowledge about the traffic rules that are in place.

At one of the six intersections, RTOR for bicyclists is allowed (the sign is digitally added to the picture), at the other five intersections RTOR for bicyclists is not allowed. To investigate the existence of a spillover effect of RTOR for bicyclists, respondents' behaviour at the intersections where it is not allowed (i.e., non-treatment sites) is of primary importance. However, one intersection where RTOR is allowed is included for two reasons:

- To mask the true purpose of the study
- As a double-check to see whether the trigger has worked as intended. In case no difference in behaviour would be found between the experimental group and the control group for locations where RTOR is not allowed (i.e., no spillover effect), it would otherwise not be possible to deduct whether this lack of difference indicates that there is no spillover effect, or that it simply indicates that the trigger has not been strong enough. In case the trigger has worked, the data should show that the experimental group turns right on red significantly more often at the location where RTOR is allowed for bicyclists (i.e. the treatment site) than the control group.

The display order of the six situations is randomized, which avoids interfering factors such as survey fatigue, learning effects, etc… (Shadish et al., 2002).

In order to limit the possible impact of situational and infrastructural elements, a number of features have been kept constant throughout the displayed situations. We have chosen to display a number of situations that have a relatively low complexity, and have a low perceived level of danger regarding the RTOR:

- The bicyclists turn right onto a bicycle path in every situation, and therefore they do not need to merge with motorized traffic. To avoid any misunderstanding, it has also been stressed in the instructions about this part of the survey that respondents' always turn right onto a bicycle path, although this should also be quite clearly visible on each displayed picture.
- No queuing vehicles at the stop line at the intersection leg the picture is taken from.
- No heavy vehicles on the conflicting road.
- No other vulnerable road users.
- Comparable weather conditions. It has been decided to take the most 'normal' weather condition of the study region, i.e. dry weather, but cloudy.

The six pictures that are used in these questions can be seen in figure 3 a-f. At intersection F, RTOR for bicyclists is allowed (the sign is digitally added below the traffic lights).

3.1.4 Riskiness of respondents' cycling behavior

The fourth block aims to provide some indication of respondents' general willingness to take risks while cycling. The questions are a selection from the questionnaire developed by Feenstra et al. (2011) to measure risky cycling behavior. We have adopted the questions from this questionnaire that describe deliberate cycling violations that can have a safety risk (11 questions in total). Respondents are asked how often they have displayed that particular behavior during the past 2 years. The answering possibilities are also adopted from the original questionnaire, and range from "never" to "always" on a six-point scale.

a) Intersection A
b) Intersection B
c) Intersection C
d) Intersection D
e) Intersection E
f) Intersection F: bicycle RTOR allowed

Figure 3: Pictures of bicycle RTOR situations.

3.2 Data analysis

First, we analyze whether the experimental group and the control group are comparable. To draw valid conclusions, it is important that the experimental group and the control group are as comparable as possible except for the trigger they have received (Shadish et al., 2002). Since respondents are randomly assigned to either of both groups, the null hypothesis is that both groups are similar in all aspects. For any variable that is used in the analyses, we check whether this null hypothesis needs to be rejected at the 95% confidence interval (95% CI). For continuous variables such as age, we use an independent samples t-test to check whether there is a significant difference between both groups. For categorical variables, a Pearson's chi-square test is used.

Next, a comparison is made between the respondents in the control group who know about the rule, and the ones that do not know about the rule. Respondents' answers regarding the situations where RTOR is not allowed are compared. This tests whether the assumption that even respondents who know about the rule have a very low awareness of the rule in their everyday behaviour is correct. In case there is no significant difference between both groups, the assumption is justified that even respondents who know about the rule have such a low awareness of it that it does not affect their everyday behaviour. In case a significant difference would be found between both groups, only the completely uninformed respondents from the control group (i.e., no trigger and no knowledge of the rule) should be used to compare the results of the experimental group with. A MANOVA test is used to examine this because it allows to define multiple dependent variables. The answers to the five situations where RTOR for bicyclists is not allowed (intersections A-E) are therefore the dependent variables in this test.

Then, a MANOVA test is used to examine whether there is a significant difference in the probability of turning right on red where it is not allowed between the experimental group and the control group. Again, the answers to the pictures of intersections A-E are the dependent variables. In case the MANOVA test indicates a significant difference between both groups, a number of additional analyses will be performed.

First, a separate ANOVA analysis for each intersection is performed to check whether there is a significant difference between both groups at each individual intersection.

Next, a multivariate analysis of covariates (MANCOVA) is performed to check whether the impact of the trigger still holds when we correct for other characteristics of the respondents that have a significant influence on the probability of turning right on red. The independent variables are inserted in the analysis using a stepwise forward procedure. All variables that are significant at the 95% CI are kept in the analysis.

The final question is whether the strength of the spillover effect differs between socio-demographic groups. In order to check this, interaction effects between the assignment to either the experimental or control group and other variables are analyzed during the stepwise MANCOVA analysis. In case the interaction effect between the group assignment variable and another variable is significant, it indicates that the spillover effect is not similar for all categories of that variable, and that therefore not all types of respondents are equally affected.

4 Results

4.1 Descriptive statistics

Table 1 shows the descriptive statistics of the control group (2nd column) and the experimental group (3rd column). The 4th column provides the results from the tests that are executed to see whether both groups are comparable or not. The variable 'risk factor' is an indicator of the riskiness of respondents' overall cycling behaviour. It is calculated by taking the mean of the answer to the 11 questions about general risky behaviour while cycling (fourth block of the survey).

TABLE 1 Descriptive Statistics of Independent Variables and Comparison Between Control Group and Experimental Group

Variable	Control group (N=377)	Experimental group (N=391)	Significant difference between groups?
Age	Mean: 35.157 years S.E.: 0.798	Mean: 33.348 years S.E.: 0.762	$t(766) = -1.640$; $p = 0.101$
Gender	Male: 174 Female: 203	Male: 179 Female: 212	$\chi^2(1) = 0.011$; $p = 0.917$
Education	Low: 24 Secondary: 125 Higher: 228	Low: 17 Secondary: 133 Higher: 241	$\chi^2(2) = 1.549$; $p = 0.461$
Knowledge of RTOR sign?	Yes: 143 No: 234	Yes: 140 No: 251	$\chi^2(1) = 0.373$; $p = 0.550$
Employment status	Employed: 222 Not employed: 31 Student: 124	Employed: 198 Not employed: 35 Student: 158	$\chi^2(2) = 5.460$; $p = 0.065$
Driving license?	Yes: 325 No: 52	Yes: 334 No: 57	$\chi^2(1) = 0.097$; $p = 0.755$
Frequency of cycling	Daily: 131 Weekly: 102 Monthly: 63 Few times / year: 65 Never: 16	Daily: 155 Weekly: 100 Monthly: 52 Few times / year: 68 Never: 16	$\chi^2(4) = 2.899$; $p = 0.575$
Risk factor (= mean of 11 risky cycling behaviour questions) (lower value = less risky behaviour)	Mean: 1.717 S.E.: 0.023 Missing: 8	Mean: 1.776 S.E.: 0.026 Missing: 1	$t(757) = 1.723$; $p = 0.085$
Been involved as bicyclist in a crash during last 2 years?	Yes: 19 No: 349 Missing: 9	Yes: 26 No: 364 Missing: 1	$\chi^2(1) = 0.767$; $p = 0.381$

Regarding the overall sample characteristics, it can be seen that students are somewhat overrepresented in the sample, which also translates to a relatively young average age. A relatively large share of respondents are highly educated. It can be seen that about one third of respondents indicate that they know the RTOR sign.

The results from the group comparison show that there are no statistically significant differences between the control group and the experimental group, although the number of students is slightly higher in the experimental group. Related to this finding, we also see a slightly lower mean age of the experimental group, and a slightly higher risk factor. Nevertheless, it can be concluded that both groups are sufficiently comparable.

4.2 Comparison of respondents with and without knowledge of the RTOR rule in the control group

A MANOVA test is used to examine whether the scores for the five situations where no RTOR is allowed (intersections A-E) differ among respondents who know about the RTOR rule for bicyclists and the ones that do not. The test shows that the differences in the probability of performing a (prohibited) RTOR between respondents in the control group that do not know the rule and the ones that do know the rule are small and not statistically significant, $F(5, 371) = 1.392$, $p = 0.226$.

This supports the assumption that even the respondents in the control group who know about the rule have a low awareness of it in their everyday behaviour. Therefore, it is decided to use both the informed and the uninformed respondents in the control group as one single control group to compare the results of the experimental group with. This offers the benefit of having a larger control group, while the risk of 'contaminating' the control group by including respondents who have some foreknowledge about the experimental condition is considered to be limited.

4.3 Difference between both groups regarding the RTOR situations

To test whether there is a difference between the experimental group and the control group regarding the probability of turning right on red where it is not allowed, a MANOVA test is run. Again, respondents' answers for intersections A-E are the five dependent variables. The MANOVA test indicates that the experimental group has a significantly higher probability of turning right on red at locations where it is not allowed, $F(5, 762) = 4.086$, $p = 0.001$.

The respondents' answers for each intersection and the corresponding ANOVA tests are summarized in table 2. It can be seen that respondents in the experimental group are significantly more likely to make a RTOR where it is not allowed in four out of the five situations that have been inquired. Furthermore, it can be seen that the difference between both groups is largest at the intersection where RTOR for bicyclists is allowed, $F(1, 766) = 57.614$, $p < 0.001$. This was to be expected, and it is an indication that the trigger has worked as intended.

Table 2: **Mean per group for RTOR situations and results of ANOVA test per intersection**

	Control Group	Experimental Group	Significant difference between groups? (ANOVA)
RTOR at intersection A? (1= very likely; 7 = very unlikely)	Mean: 5.26 S.E.: 0.103	Mean: 4.73 S.E.: 0.106	Yes, F(1, 766) = 12.752; **p< 0.001**
RTOR at intersection B? (1= very likely; 7 = very unlikely)	Mean: 4.90 S.E.: 0.108	Mean: 4.36 S.E.: 0.108	Yes, F(1, 766) = 12.623; **p<0.001**
RTOR at intersection C? (1= very likely; 7 = very unlikely)	Mean: 4.54 S.E.: 0.111	Mean: 4.21 S.E.: 0.114	Yes, F(1, 766) = 4.213; **p=0.040**
RTOR at intersection D? (1= very likely; 7 = very unlikely)	Mean: 4.79 S.E.: 0.111	Mean: 4.49 S.E.: 0.107	Yes, F(1, 766) = 3.895; **p=0.049**
RTOR at intersection E? (1= very likely; 7 = very unlikely)	Mean: 4.31 S.E.: 0.114	Mean: 4.09 S.E.: 0.113	No, F(1, 766) = 1.979; p=0.160
RTOR at intersection F? (RTOR allowed!) (1= very likely; 7 = very unlikely)	Mean: 5.12 S.E.: 0.109	Mean: 3.93 S.E.: 0.112	Yes, F(1, 766) = 57.614; **p<0.001**

4.4 Results of the MANCOVA analysis

A MANCOVA test is used to analyze whether the difference between both groups still holds when correcting for other variables that may affect the likeliness of turning right on red where it is not allowed. Like in the MANOVA analysis, the dependent variables are the answers to intersections A-E.

After correcting for other elements, the group to which the respondent is assigned still has a significant influence on the probability. Respondents of the experimental group have a significantly higher probability of turning right on red where it is not allowed, F(5, 750) = 3.378, p = 0.005.

Other variables that have a significant influence on the probability of turning right on red where it is not allowed are gender, age and risk factor. Men are significantly more likely to perform a RTOR that is not allowed than women, F(5, 750) = 2.689, p = 0.020. Younger respondents are more likely to turn right on red at locations where this is not allowed than older respondents, F(5, 750) = 8.571, p < 0.001. Respondents with a higher risk factor are more likely to turn right on red where it is not allowed than respondents with a lower risk factor, F(5, 750) = 13.178, p < 0.001. None of the other variables had a significant impact on the probability of turning right on red where it is not allowed. These variables are therefore not included in the final model.

No interaction effects between the group assignment variable and any of the other variables are statistically significant. This indicates that no evidence is found that the spillover effect is stronger for certain socio-demographic groups than for others. The relative increase in RTOR where it is not allowed that is caused by a higher awareness of the rule is therefore comparable for all socio-demographic groups of respondents.

5 Discussion

The major new finding in this study is that the awareness of a rule that allows bicyclists to turn right on red at some locations appears to lead to an increase in turning right on red at locations where it is not allowed. It should be noted that only one type of manoeuvre is examined in this study, i.e. RTOR manoeuvres onto a bicycle track. Therefore, a spillover effect of the RTOR rule for bicyclists is only shown for this type of manoeuvres. Performing this type of RTOR where it is not allowed can be considered as a violation with a fairly low level of risk. However, it can be an indication that also in other situations than the ones that we have studied, red light running could increase.

Therefore, further research on this topic is strongly recommended. Further research should investigate whether the spillover effect of the measure extends to other RTOR situations with a higher perceived risk, such as RTOR onto a mixed traffic lane. Further research could also examine whether a spillover effect of the RTOR rule for bicyclists can be found for other cycling manoeuvres (such as crossing a road through red), or even to other modes (e.g. an increase in jaywalking for pedestrians). Since this study makes use of stated behaviour rather than observed behaviour, it is also recommended to examine the spillover effect of RTOR for bicyclists by using observational studies or possibly a bicycle simulator.

The MANCOVA analysis shows that, besides the assignment to either the experimental or the control group, also the variables gender, age and risk factor have a significant influence on the probability of making a RTOR at locations where it is not allowed. The findings for these variables are in line with existing literature.

Men are significantly more likely to perform a RTOR that is not allowed than women. This finding is in line with previous research about red light running by bicyclists (Johnson et al., 2011, 2013; Wu, Yao, & Zhang, 2012), and the finding that men generally perform more risky driving behaviour than women (Al-Balbissi, 2003; Evans, 2004). Younger respondents indicate a significantly higher probability of performing a RTOR that is not allowed than older respondents, which is again in line with findings from previous studies about red light running for bicyclists (Johnson et al., 2013; Wu et al., 2012) and general literature about risky behaviour (Evans, 2004).

Also, respondents with a higher risk factor (i.e. respondents who indicate that they more often execute a number of risky cycling behaviours) have a higher probability to perform a RTOR that is not allowed than respondents who have a lower risk factor. This indicates a correlation between different types of risky behaviour: respondents who indicate that they frequently perform certain risky cycling behaviours, are also more likely to perform another specific risky cycling behaviour. This is in line with existing literature showing a strong co-occurrence of different types of risky behaviours such as risky driving, alcohol and substance abuse and criminal offences (Evans, 2004; Junger et al., 2001; Palamara et al., 2012).

Johnson et al. (2013) found that also education level, employment status and bicycle crash involvement have a significant influence on the probability of committing red light violations. However, these variables did not have a significant influence on RTOR at locations where it is not allowed in this study.

Further research could also focus on exploring the impact of infrastructural and situational characteristics on RTOR behaviour by bicyclists. The data analyses show that the difference in RTOR probability between the experimental group and the control group is not constant among all locations where no RTOR is allowed. This can be an indication that the strength of the spillover effect is not constant, and can depend on certain infrastructural and/or situational aspects.

It has been decided to use both the respondents with and without foreknowledge of the RTOR rule for bicyclists in the control group as one single control group to compare the results of the experimental group with to have a larger control group. This involves a risk of contaminating the control group by including respondents who in fact may display behaviour that is to some extent affected by the existence of the rule. In case this would be true, the effect on the study results would be an underestimation of the spillover effect, since these respondents would behave more like the respondents in the experimental group who have been exposed to the trigger. The true strength of the spillover effect could therefore be underestimated.

Another interesting question that could be addressed in future research is whether the permission of a RTOR for motor vehicle drivers can also lead to spillover effects. RTOR for motor vehicle drivers is frequently applied in the United States and in Canada, and is also implemented at a limited number of intersections in some European countries such as Germany, Poland and Lithuania. In case a spillover effect would be found for RTOR for motor vehicles too, this could be another important argument against this rule, in addition to the finding that a RTOR for motor vehicles can lead to a significant increase in injury crashes (Elvik et al., 2009; Zador et al., 1982; Zador, 1984).

It can be questioned which resulting effect the found spillover effect is likely to have on the level of road safety. The fact that road authorities have decided not to implement RTOR for bicyclists on all signalized intersections suggests that they expect that RTOR for bicyclists can cause safety issues at some locations. If the current RTOR rule for bicyclists leads to a spillover effect to locations where road authorities currently do not allow them, it seems legitimate to expect that at least some of these spillover right turns on red could be performed at locations or in situations where they might cause safety risks. In that sense, the spillover effect of the RTOR rule for bicyclists can be considered as an effect that poses a safety risk. According to the precautionary principle, it can be argued that governments should not introduce measures such as RTOR for bicyclists, unless they are certain that they do not have negative safety impacts. Further research is needed to assess possible negative safety effects, in particular related to locations or situations that are considered to pose safety threats.

6 Conclusions

The main conclusion of the paper is that the implementation of a rule that allows bicyclists to turn right on red at some locations ("RTOR for bicyclists") leads to a spillover effect, i.e. an increase in RTOR at locations where it is not allowed. Other factors that increase RTOR for bicyclists at locations where it is not allowed are gender, age, and the stated riskiness of respondents' general cycling behaviour. The findings for these characteristics are in line with existing literature: men commit RTOR where they are not allowed more often than women, younger people more often than older people, and people who generally cycle more risky more often than people who generally cycle less risky.

The findings from this study show that road authorities should consider spillover effects likely to be present in case RTOR for bicyclists is allowed at some locations. These spillovers might, but are not sure to result in safety issues at locations where no RTOR for bicyclists is allowed. Further research is needed on this topic to confirm the findings from this paper, and to examine whether this spillover effect extends to other forms of red light running, and to assess some possible negative safety effects.

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