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Contents

Summary	3
THE ROLE OF ROAD DESIGN TO SUPPORT BICYCLISTS YIELDING BEHAVIOR AT T-INTERSECTIONS ON SEGREGATED PATHS: A FEASIBILITY STUDY IN BICYCLE SIMULATOR	4
1. Background	4
2. Project set up	4
2.3 Purpose	4
2.4 Objectives	5
2.5 Project period	5
2.6 Partners	5
3. Method and activities	5
4. Results and Deliverables	7
5. Conclusions, Lessons Learnt and Next Steps	11
6. Dissemination and Publications	12
7. Acknowledgement	12



Summary

Segregated spaces are common countermeasures to improve traffic safety. However, they have often resulted in poor-designed shared spaces, where road users with different behavioral patterns and needs, e.g., bicyclists and pedestrians, are kept together. Extensive research has documented the impact of the amount of information conveyed by road signs on cognitive processing, as too little information creates ambiguity and too much information results in redundancy.

The present study sets out to identify the effective amount of information conveyed by road markings and signs to support the bicyclist's cognitive and behavioral tasks and improve the perception of safety at T-intersections on segregated paths. Moreover, the study intends to verify the effectiveness of bicycle simulators to investigate the interaction between vulnerable road users, i.e. bicyclists and pedestrians.

A sample of experienced cyclists ($n = 10$) took part to this experimental study in the bicycle simulator Sim VI at VTI. The study had a 3×2 within-subjects design, i.e. information amount conveyed by road marking and signs (1=little information, 2=moderate information, 3=high information amount) and bicycle task (1= go straight, 2= right turn). We collected measures of perceived safety, perceived comfort, perceived control, and the subjective experience as well as speed, braking and lane positioning. We also run a manipulation check and a feasibility check concerning the bicycle simulator. Despite the study's findings are not conclusive, they provide some important insights for designing research developments and framing guidelines for transportation planning.

Poorly marked and poorly signalized intersections demonstrates having a negative impact on both the cycling performance and the cycling experience and preferences. Thus, providing a moderate amount of information, i.e., centerline and edge lines, seems to be enough to detect a significant improvement for cyclists. Moreover, our findings suggest that the 'goodness' of information amount might be moderated by other factors, such as the complexity of the traffic environment (i.e. traffic density) and the cycling task (i.e. going straight and right turn).

Simulator technology demonstrates to have great potential for the research on traffic safety for vulnerable users. However, the challenges associated to the use of bicycle simulators to study traffic interactions between vulnerable road users are undoubtable and the present study helped to better identify the points to work on in the future.

In conclusion, the findings analyzed so far are promising and would generate a larger successful project application.



THE ROLE OF ROAD DESIGN TO SUPPORT BICYCLISTS YIELDING BEHAVIOR AT T-INTERSECTIONS ON SEGREGATED PATHS: A FEASIBILITY STUDY IN BICYCLE SIMULATOR

1. Background

Segregated spaces to keep the vulnerable road users (VRUs) away from the car lane have often been used as countermeasures to improve traffic safety. However, it has often resulted in poor-designed common spaces, where road users with different behavioral patterns and needs, e.g., bicyclists and pedestrians, are kept together.

Intersections are critical spots in the traffic system. When regulating the traffic flow between bicycle and walking paths, poor-signalized intersections are even more problematic because of the lack of regulation in place to guide priority negotiation.

Yielding behavior requires a large amount of visual, mental and physical resources for the bicyclist as it involves several cognitive and behavioral tasks, including information processing, adjusting speed (e.g. deceleration) and lane positioning.

A failure to yield the right of way may be determined by many factors, including the road marking and vertical signs. Extensive research has documented the impact of the amount of information conveyed by road signs on cognitive processing, as too little information creates ambiguity and too much information results in redundancy (Kaplan, Bortei-Doku, & Prato, 2018). However, it is still unclear what is the right amount of information at certain traffic segments to support quick, relevant behavioral decisions, and eventually to increase traffic safety.

2. Project set up

2.3 Purpose

The expected results of the project comply with the SAFER's vision in at least two ways:

- a. To put the methodological foundation to identify safety countermeasures targeting the vulnerable road users, i.e. bicyclists, to enable a safer use of the traffic environments and encourage active transportation modes and sharing mobility;
- b. To capitalize the common effort towards a Vision Zero, creating bridges between disciplines, and consolidating the collaboration between different stakeholders.



2.4 Objectives

The present study sets out to identify the effective amount of information conveyed by road markings and signs to support the bicyclist's cognitive and behavioral tasks and improve the perception of safety at T-intersections on segregated paths. Moreover, the study intends to verify the effectiveness of bicycle simulators to investigate the interaction between vulnerable road users, i.e. bicyclists and pedestrians.

2.5 Project period

The current research project run from April 15th, 2020 until September 15th, 2020.

2.6 Partners

The University of Gothenburg - GU

The Swedish National Road and Transport Research Institute - VTI

3. Method and activities

A sample of convenience ($n = 10$; 5 females) aged $m = 37$ ($s.d. = 8.10$) took part to the study.

Participants reported they cycle on average 4 days per week ($s.d. = 0.87$) and around 6 hours per week ($s.d. = 3.70$). They also self-assessed their cycling skills as above average on a 7-point scale ($m = 5.3$, $s.d. = 1.3$).

Since the study was conducted in a bicycle simulator, only people tall between 170-180 cm were included in the sample, to ensure similar perception of the simulated scenario (Thorslund & Lindström, 2020).

The experimental study had a 3×2 within-subjects design, i.e. information amount conveyed by road marking and signs (1=little information, 2=moderate information, 3=high information amount) and bicycle task (1= go straight, 2= right turn).

Six experimental scenarios were created *ad hoc* for the current research by crossing the levels of the two independent variables. The presentation order was randomized across participants using the latin square design (Williams, 1949).

The experimental task consists of the cyclist approaching and passing through three T-intersections at segregated shared space, varying for information amount. Each intersection was presented twice to allow the participants undertaking the cycling tasks (i.e. right turn and go straight).

To simulate the context for negotiation of the right of way, one simulated cyclists and one pedestrian coming from the opposite direction were included in the simulated scenes. The simulated users' speed was logged to the one of the participant, to ensure that they would happen at the intersection when the participant did (Figure 1).



The study was run in the bicycle simulator at VTI (Gothenburg), which comprised the existing facility Sim IV.

The procedure, location and time details of each experimental section are illustrated in Table 1.

PHASES AND TASKS	LOCATION	DURATION
PRE-EXPERIMENT		
Informed consent, Instructions, Pre-experimental questionnaire: Background information, self-rated cycling skills.	Lab room at VTI – Göteborg (outside the simulator)	10 min.
EXPERIMENT		
Set-up check		5 min.
Familiarization task	On the simulator	10 min.
Administration of 6 experimental conditions. Experimental task: Participants are instructed to ride on the bike lane, pass across the intersection and stop at the road cones. After each condition, participants are asked to answer some questions concerning perceived safety, perceived comfort, self-reported hazard perception, perceived workload, manipulation check. One researcher sits behind the participant and orally administers the questions to the participant.	On the simulator	Each experimental condition: approx. 3 min.
POST-EXPERIMENT		
Administration of a questionnaire comprising of: a feasibility measure for the task, a measure of the sense of presence, a measure of the Psychological Feasibility of a Virtual Cycling Environment. Semi-structured interview and debriefing.	Lab room at VTI (outside the simulator)	10 min.
		Tot. duration for each session: approx. 60 min.

Table 1 – Procedure, location and duration of each experimental session

Besides demographics, cycling habits, and a self-assessment of the cyclists' skills, we collected measures of perceived safety, perceived comfort, perceived control, and a subjective measure of cognitive workload (Bittner, Byers, Hill, Zaklad, Christ, 1989). Furthermore, we measured the participant's performance, in terms of speed, braking and lane positioning (Thorslund & Lindström, 2020) in three road segments: a) approaching the intersection; b) passing across the intersection; c) exit the intersection. Studying the cycling behavior at different road segments of the intersection is relevant since specific cycling tasks are associated to each road segment. For the purpose of this study, we focused on the cycling tasks associated to the road segment preceding the intersection (A) and the intersection itself (B), since they are crucial to the negotiation for the right of way. We performed a manipulation check and a feasibility check concerning the simulated task



(Jäger, Nyffeler, Muri, Mosimann, & Nef, 2015). and the bicycle simulator. Moreover, we collected a measure of the sense of presence (Lessiter, Freeman, Keogh, Davidoff, 2001). Finally, we conducted a short semi-structured interview to collect inputs from the participants. The interview covered both the experience with the bicycle simulator, the experimental task and design, and the experimental procedure.

The data collection was run in compliance with the COVID-19-related hygiene procedure in place at VTI.

Due to the small sample size, a series of non-parametric tests for related-samples (i.e. Wilcoxon test, Friedman test) were applied on information amount and task and performance measures, perception of comfort, perception of safety, perceived cognitive workload, and the measure to run the feasibility check of the simulator, the task and the manipulation check.

All the answers from the interviews were qualitatively analyzed.



Figure 1 – Extract from the simulated scenario (i.e., condition of high information amount and ‘go-straight’ cycling task). The two simulated road users are also illustrated.

4. Results and Deliverables

The study’s findings show initial interesting results.

Manipulation check. Participants reported that the moderate and the high information conditions provided a minimum information amount to support decision-making at the T-intersections compared to the low information amount $X^2(2) = 11.52; p > .01$. The high-information amount was rated as significantly less confusing compared to the moderate and the low information amount conditions $X^2(2) = 10.50; p > .01$. Moreover, in the post-experimental interviews, participants were asked to recall how many design conditions they could identify; most of them (9 out of 10) were able to correctly identify three different road marking conditions. These results confirm that the manipulation check was successful.



What is the effective amount of road marking at T-intersections? The findings show no straightforward answer to this question. The subjective ratings of the T-intersection conditions resulted being affected by the type of cycling task, i.e. going straight or turning right at T-intersection; participants reported feeling significantly safer ($Z = -2.04$; $p > .05$) and in control ($Z = -2.04$; $p > .05$) when going straight than when turning right at the intersections in the moderate information condition, while no significant differences were found in the low and high information conditions. Parallel results were found for speed: participants travelled to a higher speed when going straight compared to when turning right ($Z = 2.80$; $p > .01$), especially in the moderate information condition. Findings from lane positioning also provide interesting insights (Figure 2), despite no statistically significant differences were found; providing a moderate amount of information seems to encourage a centered positioning of the cyclist on the bike lane (vs. positioning on the right, closer to the sidewalk) before entering the intersection (A). Taking a centered positioning might be a proxy of understanding how to use the space and might support safer interactions with other road users (i.e., cyclist coming from the opposite direction, pedestrians).

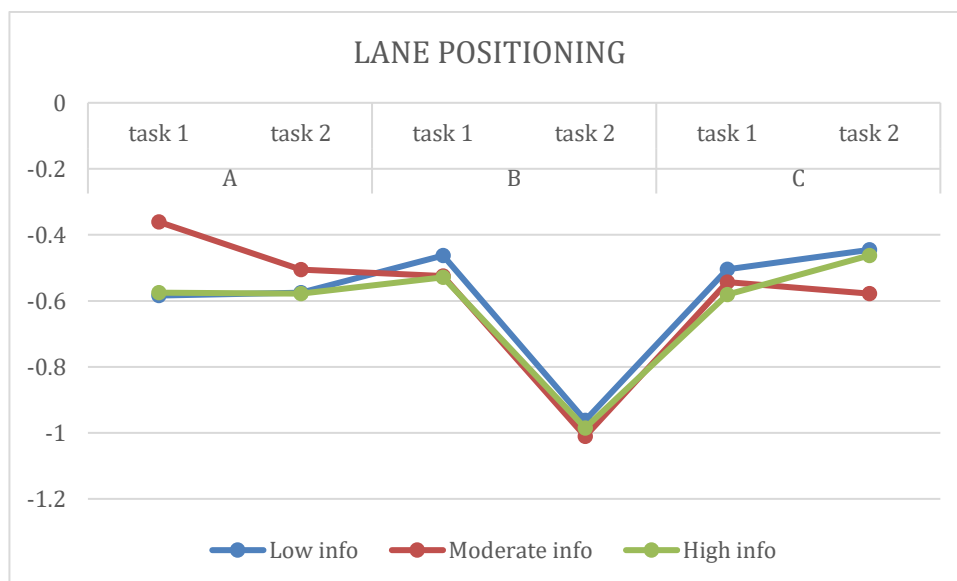


Figure 2 – The participants' lane positioning plotted by 'Information amount' (Low, moderate, high), cycling task (1 = go straight; 2 = right turn) and road segment (A = before the intersection, B = intersection, C = after the intersection).

Interesting results were also found for perceived frustration: in general, participants reported feeling more frustrated when turning right at the intersections than when going straight. In particular, they reported feeling more frustrated when turning right at the intersection in the poor information condition compared to when going straight at the same intersection ($Z = 2.03$; $p > .05$). These findings are coupled by the participants' braking scores: Figure 3 shows that participants braked more when turning right compared to when going straight when approaching the intersection (A); this was slightly



higher in the condition of low information, despite no statistical significant differences have been observed between the three levels of information amount. The cycling behavior on the road segment preceding the intersection is relevant since it corresponds to the initiation of the negotiation process for the right of way. Thus, these findings seem to suggest that in the poor information condition participants braked more while approaching the intersection because they had more difficulties figuring out picking the right behavior based on other road users' behavior.

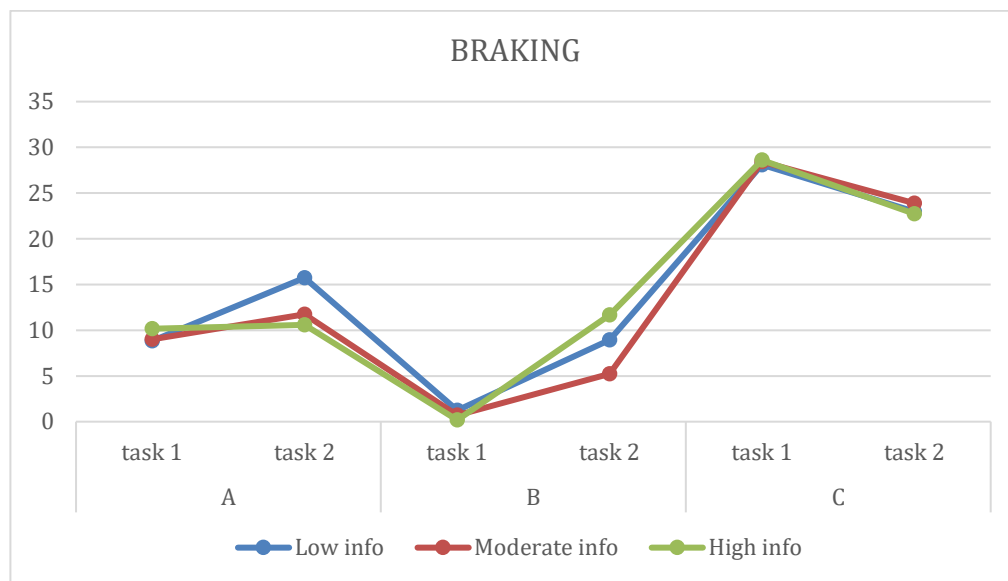


Figure 3 – The participants' lane positioning plotted by information amount (Low, moderate, high), cycling task (1 = go straight; 2 = right turn) and road segment (A = before the intersection, B = intersection, C = after the intersection).

The findings from the post-experimental interviews also reveal that participants' evaluation, experience and behavior within traffic situations is greatly affected by the familiarity with specific design conditions, in terms of information amount conveyed by the road marking and signs. Most of the participants reported being exposed to poorly signalized bicycle tracks in real life; because of this, they did not rate poorly the low information amount conditions *per se*. However, when contrasting the low information conditions to the moderate and high information conditions, all the participants acknowledged that well-signalized intersections greatly improved their experience and cycling behavior on shared path intersections. High information conditions were, thus, the most preferred by the greater part of the sample, who specifically appreciated the presence of crosswalks and give-the-way markings.

Is the cycling simulator an effective tool to study the impact of road signs on cyclists' negotiation of the right of way at T-intersections? Overall, the feasibility test of the simulated task was successful since the participants' average score was 5.56 on a 7-point scale (sd= 1.21; Figure 4). The lowest score was appointed to "Challenge"; in the post-



experimental interviews, most of the participants evaluated the simulated traffic situations as too calm if compared to real traffic situations, and this was especially due to the low presence of road users moving around. In fact, most of the participants reported they are used to deal with more challenging traffic situations in real life and that the experimental task was too easy. For an illustration, one participant stated '*Having just one pedestrian is easy to control for*'. Since the complexity of traffic task affects the reliance on the physical environment, it is reasonable to suspect a *floor effect* in the manipulation of the information amount conditions and this would partially explain the lack of significant differences found between the three levels of the information amount factor.

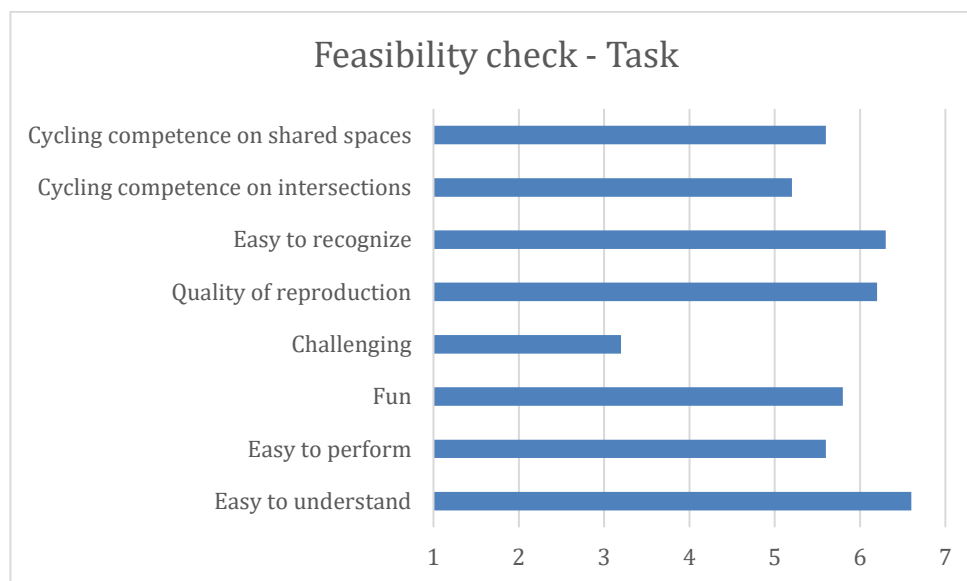


Figure 4 – Means for items of the feasibility test of the simulated task. Participants were asked to rate each item on a 7-point scale from 1 (totally disagree) to 7 (totally agree).

Results from the feasibility check showed that the bicycle simulator scored quite poorly in the participants' evaluations ($m = 3.28$; $sd = 1.08$; on a 7-point scale). The realism of the bicycle simulator was penalized by structural constraints of the simulator set up, which made it difficult a smooth interaction with the bike. For instance, participants reported having troubles steering, pedaling, using their body, and exploring the visual field as they do in a real cycling situation. Another point raised by the participants in the interviews was the lack of interaction with the other road users. Non-verbal behavior, including establishing eye contact with other users, is crucial in traffic negotiation especially between vulnerable road users, who did not have indicators and braking system to signaling their intentions, unlike motorized vehicle users. Due to the structural constraint of the simulator, it was not possible to recreate a setting affording realistic non-verbal interactions.

Nevertheless, the participants' sense of presence revealed to be quite good ($m = 4.64$; $sd = 1.14$; on a 7-point scale; Figure 5).

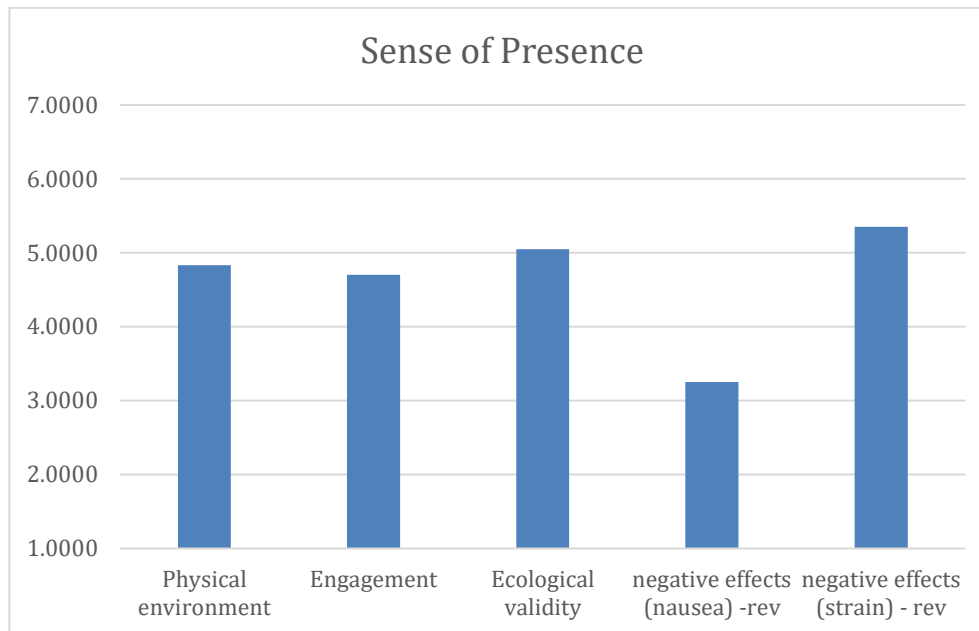


Table 5 – Means for the sub-dimensions of the sense of presence inventory (ITC-SOPI, Lessiter et al. 2001). Participants were asked to rate each item on a 7-point scale from 1 (totally disagree) to 7 (totally agree).

5. Conclusions, Lessons Learnt and Next Steps

Despite this study's results are inconclusive, they provide some important insights for designing research developments and framing guidelines for transportation planning.

First, poorly marked and poorly signalized intersections have a negative impact on both the cycling performance and the cycling experience and preferences. Thus, providing a moderate amount of information, i.e., centerline and edge lines, is enough to detect a significant improvement for cyclists.

However, it remains unclear what is the magnitude of improvement of the high information condition compared to the moderate amount condition and when the amount of information provided becomes detrimental to support the cyclists' task and experience. Specifically, our findings seem to suggest that the 'goodness' of information amount might be moderated by other factors, such as the complexity of the traffic environment (i.e. traffic density) and the cycling task (i.e. going straight and right turn). For instance, it is plausible to expect that adding complexity to the traffic situation may help to address the floor effect detected across the levels of the factor 'information amount'. Further studies to address these points are thus encouraged in the future. Other factors that might be important to control for in futures developments of this project are familiarity with specific road marking configuration and the participants' cycling styles (Kircher Nygårdhs, & Ahlstrom, 2018)



A second takeaway of this study concerns simulators. Simulator technology demonstrates to have great potential for the research on traffic safety for vulnerable users. However, the challenges associated to the use of bicycle simulators to study traffic interactions between vulnerable road users are undoubtable and the present study helped to better identify the points to work on in the future.

A first shortcoming of the use of the bicycle simulator as identified by the participants concerned the interaction with the bicycle and thus with the environment. The bicycle-cyclist interaction was perceived as quite unrealistic by the study's participants because of the impossibility to use proprioception, and explore the visual field as done in real cycling situations. One way to address the problem of realism is by using immersive virtual environment, which allow a fluid and more flexible experience in the virtual scenarios.

A second problem to tackle in the simulation of traffic situations for vulnerable road users is to provide more realistic interactions with virtual road users, since cyclists and pedestrians mostly rely on non-verbal behavioral cues exchanged between users to make traffic decisions. This might be possible by allowing a more sophisticated design of the simulated road-users behavior or by using traffic simulators where more than one participant can interact in the same simulated scenario.

Conclusively, we aimed at using this project's findings as the stepping-stone for a larger application (i.e. *FORMAS' call for early-career researchers, Spring 2021*), to implement the improvements in the study design listed above, collect data from a larger sample, and possibly studying other vulnerable road users' behavioral tasks, such as the ones for pedestrians and kick-scooter riders.

6. Dissemination and Publications

We aim to publish the results from the current project in a peer-reviewed scientific journal, e.g., *Human Factors: the Journal of the Human Factors and Ergonomics Society*.

7. Acknowledgement

I wish to thank you Niklas Strand for his initial effort put in the project drafting. I also wish to thank you Bruno Augusto and Andreas Käck, VTI, for their great support during both the project design, scenarios implementation and assistance during data collection.

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