Understanding safety critical interactions between bicycles and motor vehicles in Europe by means of Naturalistic Driving techniques

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ABSTRACT

Although prevention of bicycle–motorized-vehicle-crashes will result in significant improvements in bicycle mortality rates, little is known about the actual safety critical events leading up to these crashes. Recently, the understanding of critical events has been advanced by the use of Naturalistic driving techniques. This technique gathers data about driving in 'natural conditions' by means of the instrumentation of a large fleet of cars with sensors and cameras. To date, these studies have mainly focussed on car-car interactions rather than on interactions with vulnerable road users. This paper discusses the potential of Naturalistic Driving for understanding critical interactions with vulnerable road users. To this end it presents some of the results from additional analysis of the data from previous Naturalistic Driving studies. In addition, the paper presents the objectives and design of the recently started large scale Naturalistic Driving study UDRIVE in which a large fleet of motorized vehicles will be equipped with cameras and sensors, resulting in data on 470 years of driving. In contrast to previous and ongoing Naturalistic Driving studies, UDRIVE is – amongst other issues- specifically designed to address interactions with cyclists and pedestrians.

Keywords: Naturalistic Driving, interactions, method

1 INTRODUCTION

Cyclists are vulnerable road users as they are physically unprotected, and therefore have a high risk to get seriously injured, especially in collisions with motorized traffic[1]. Whereas in the last decades the safety of car occupants has substantially improved, the safety of pedestrians and cyclists has seen far less improvement[1]. As a result, the share of pedestrians and cyclists in the total number of road casualties is growing[2]. For example, in the Netherlands, cyclists now account for about a quarter of all road fatalities and for more than half of all severe injuries. Most pedestrians and cyclists are killed in urban areas, at intersections, often in collisions with motorized traffic [2]. Although in-depth crash investigations provide information about the actual crash itself[e.g., 3], these studies provide little information about the safety critical interactions between cyclists and car drivers that precede these events. These safety critical interactions contain information about how these interactions differ from 'safe interactions', why some actions evolve into a crash, and finally which factors prevent near-crash situations from turning into a crash. That type of information is a precondition for the design, selection, and implementation of effective countermeasures.

Safety critical interactions between cars have been studied extensively, mostly in driving simulators and in experiments that used instrumented vehicles. These methods have greatly con-

tributed to the understanding of driver behaviour. However, these methods also have several limitations especially for the understanding of interactions with vulnerable road users. Results from simulator studies may not always be easily transferred to real traffic environment, because of the current limitations of the quality of the simulation of vulnerable road user behaviour. Also results from experiments using instrumented cars may differ from 'normal driving', as participants know that they drive for the purpose of the experiment, and may therefore not behave in a similar manner as they would have done in their day-to-day driving. Thus, simulator and instrumented car studies do not capture driving behaviour in natural conditions.

Recently, the application of the Naturalistic driving method has overcome some of these limitations. Naturalistic Driving is a fairly new research method that has been developed in the late nineties of the previous century and that has continuously been refined ever since. It involves the equipment of 'normal' cars, driven by 'normal' people in 'normal' day-to-day driving with sensors and unobtrusive cameras[4, 5]. This has become technically possible because of the enormous developments in the last couple of decades in information and communication technologies, improvements in storage capacities, data-mining, image processing and low-cost camera technology. The first major Naturalistic Driving study was conducted in the USA by Dingus and colleagues who instrumented the cars of one hundred drivers who commuted on a regular basis in the Northern Virginia/Washington D.C metropolitan area[6]. They gathered data over a 12-month period and during this time the vehicles were driven over 3,000,000 km with a total of 43,000 hours of exposure involving 67 (mostly minor) crashes and 761 near-crashes. As part of the second Strategic Highway Research Program (SHRP2) in the USA , the follow-up project is to collect almost 4,000 vehicle years of data from over 1950 drivers[5]. These Naturalistic Driving studies have contributed to our current understanding of the impact of, for example, inattention and distraction amongst drivers on crash risk [7] and the influence of peer passengers on risky behaviour among novice drivers [8].

So far, ND studies have mainly focussed on car-car interactions and only seldom on the interactions of car drivers with vulnerable road users. This is going to change with the start of the ND European project UDRIVE that had its kick-off in October 2012. In this project, one Work Package is dedicated to study Vulnerable Road Users. Before presenting the details of this project and the expected results, for the purpose of illustrating the kind of knowledge that might be derived from projects like UDRIVE, the present paper first discusses the results from two small pilot studies that used ND type of data.

## 2 DRIVER GLANCE FREQUENCY AND PRESENCE OF VULNERABLE ROAD USERS

To explore the usefulness of ND observations to study interactions with vulnerable road users, driver glances on intersections were analysed in an available ND dataset from the INTERACTION project. The data was originally collected in a field experiment, in which 20 participants drove an instrumented car, over a pre-set route in real traffic with two observers present in the car. Although, the study design was that of an 'experiment', the camera registrations provide similar data as a 'true' Naturalistic Driving study.

With this dataset, driver 'looking' behaviour at intersections was analysed in relation to the *probability* of the presence of vulnerable road users and the *'actual presence and manoeuvre'*. In the analysis, the intersections in the route were classified as having a 'high probability of vulnerable road users present' if the intersection design contained 'crossings' for vulnerable road users. If such crossings were absent the intersection was classified as having a 'low probability of vulnerable road users present'. The analyses are still underway, but some preliminary data on glance frequency are presented here.

Figure 1 shows a relationship between the glance frequencies and intersection type. Compared to intersections with a low probability, intersections with a high probability elicit *higher* glance frequencies for most VRU maneuvers. Although these data still need further analysis whereby also glance duration and direction needs to be taken into account, such a pattern might suggest a possible role of expectations on gaze frequency. Further, these patterns might support

the hypothesis that these expectations are elicited by "cues" in the road infrastructure rather than by the presence or the maneuver of the VRU.

Information of this kind may provide empirical input for current issues on cycling safety. For instance, for the explanation of the 'safety in numbers' theory[9, 10]. This theory describes the phenomenon that areas with high numbers of cyclists are safer than areas with low numbers of cyclists. Two possible explanations for this pattern have been suggested. One explanation is that increasing numbers of cyclists will 'automatically' improve safety because of changes in driver expectations[9]. The alternative explanation is that areas with high number of cyclists also offer 'good' cycle facilities[11]. Despite the great consequences of the correctness of either of the explanations for policy development, to date no data are available to put both hypotheses to the test. As illustrated in this preliminary analysis, Naturalistic Driving data may enable the analysis of driver's glance behavior in relation to the driver's previous experiences with the presence of cyclists, the lay-out of the intersection and the actual presence of the cyclists.
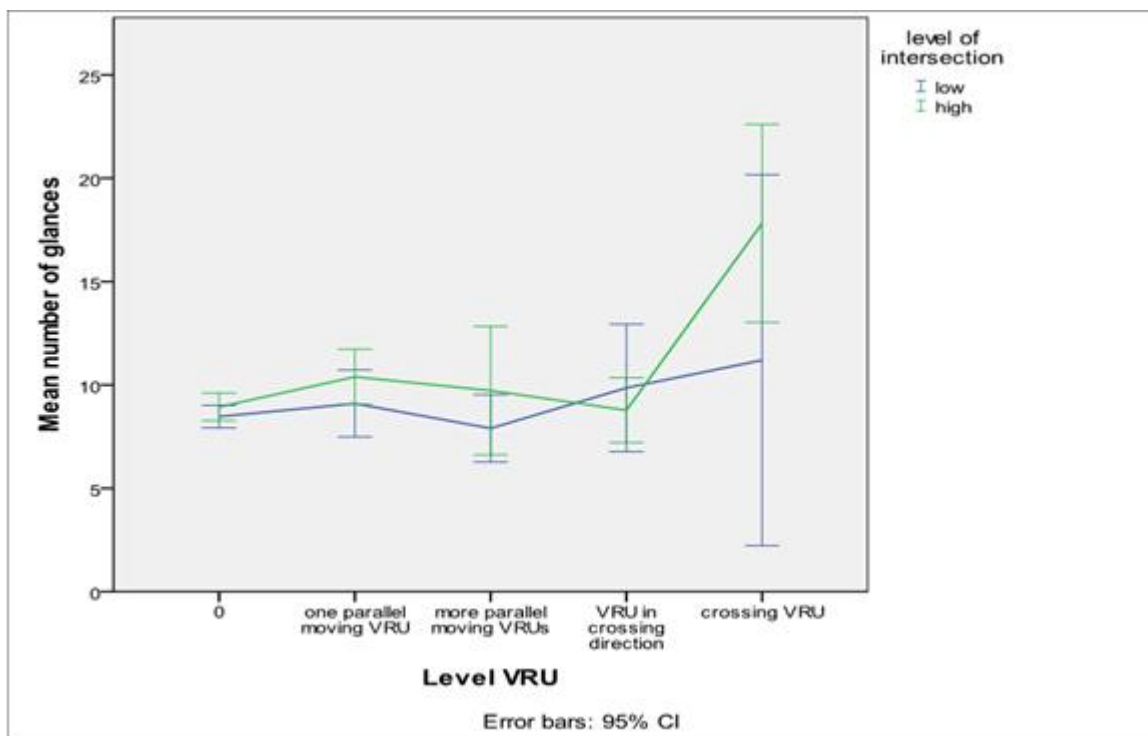
Figure 1. The average number of glances in the 20 intersection situations determined by the presence (level) of VRUs, by the probability a VRU would occur (low-high).
Note: 0 = no VRUs present, I = one parallel moving VRU, II = more than one parallel moving VRU, III = VRU in crossing direction, but not yet actually crossing, IV = actually crossing VRU.

3 TWO OBSERVATION PERSPECTIVES: NATURALISTIC DRIVING AND SITE-BASED

Most Naturalistic Driving studies explore safety-critical conditions from the car driver's perspective. This provides a restricted understanding of the interactions between cars and cyclists in relation to the characteristics of intersections. A combination of site-based and Naturalistic Driving observations, therefore, could provide complementary information about these safety-

critical interactions. In-vehicle data collection enables the study of an individual's driving behaviour over time and in different situations. Site-based observations offer information about the position and speed of other road users, including cyclists and pedestrians, near the participant's vehicle.

The Dutch field trial within the European naturalistic driving project PROLOGUE explored the value and feasibility of combining in-vehicle and site-based observation techniques[12]. The trial equipped a four-legged urban intersection with cameras for site-based observation. The intersection was regulated with traffic lights and had a speed limit of 50 km/h and adjacent cycle paths. Eight cars of drivers who regularly crossed this intersection were equipped with the ND technology.

The phasing of the traffic lights generates potential conflicts between right-turning cars and cyclists who continued along the same road. Both receive the green signal almost simultaneously, with that difference that the green light for cyclists starts a few seconds earlier than that for cars. In addition, the stopping line for cyclists is located a few meters further into the intersection than that for cars. These features provide a head start for cyclists.

The study analysed the driver's glance behaviour, speed, and acceleration, as well as the number of conflicts and the post-encroachment time, under two conditions: (a) the car driver had to wait at the light (Waiting drivers) *or* could continue because of having a green light (Continue drivers) and (b) a cyclist was present *or* not.

Compared to the 'Continue drivers', the driver's glance duration and frequency were higher and driving speed lower among 'waiting drivers'. This difference may be due to the intersection layout. For 'waiting drivers', this layout restricted the possibility to detect a vulnerable road users to a greater extent than for 'continue' drivers. The lower speed and higher glance frequency and duration may thus indicate that 'waiting' drivers may adapt to these visual restrictions by putting *more effort into detecting the presence of cyclists*. Moreover, because of the lower speed of 'waiting drivers' and the head start of cyclists, the conflicts were also less severe than those for 'continue drivers'.

These analyses illustrate that only by combining the results from in-vehicle and site-based observations the intricate relationship concerning intersection design, traffic light phasing, and driver–bicyclist interactions is revealed. The two complimentary perspectives offer the opportunity to understand what happens inside the vehicle (drivers looking behaviour) in relation to what is happening outside the vehicle (presence of cyclists and potential level of conflict). Thus, despite the richness of its data, the interpretation of Naturalistic Driving data still benefits from complementing it with data from other sources.

4 NATURALISTIC DRIVING STUDY ON VULNERABLE ROAD USERS: UDRIVE

The analyses in the previous sections were derived from studies that did not explicitly address the safety of vulnerable road users. In October 2012 the large scale European Naturalistic driving study UDRIVE has started that – among other objectives – explicitly aims to address the interactions between motorized traffic and vulnerable road users. SWOV is coordinator of this project in which 7 countries participate. Table 1 gives an overview of the distribution of the instrumented 'vehicle years' by country. A 'vehicle year' is the data of one year of driving/riding. Thus a UDRIVE car driven for three years yields three vehicle years of data.

In this project safety critical events as well as 'normal' behaviour will be studied, thereby focusing on the most safety critical manoeuvres such as right and left hand turns and negotiation of pedestrian crossings. The observed behaviours include driver's gaze, use of mirrors, acceleration/deceleration, and vehicle course. The analyses will compare behaviour in similar situations but with and without a vulnerable road user present.

In the first step of the project the research questions will be selected. These questions will guide the instrumentation of the vehicles and the recording of the data. Examples of such questions are:

- What are the factors contributing to safety critical events?

- How do drivers behave in the vicinity of vulnerable road users in terms of passing distance, speed and gaze?
- How do drivers behave in traffic situations where vulnerable road users might be present, but not yet visible?
- Are these behaviours affected by age and gender of vulnerable road users?
- How do driver expectations influence this behaviour?

Table 1. Amount of vehicles per vehicle type and country; one year data collection per vehicle

	Passenger car years	Truck years	PTW years
Austria			30
France	60		
Germany	60		
Netherlands		150	
Spain			50
Poland	60		
United Kingdom	60		

All safety critical events will be identified and studied in depth to gain understanding in the contributing factors. SWOV is responsible for this Work Package on vulnerable road users in UDRIVE. The experiences from the studies here discussed have provided some pioneering ground work for this.

5 CONCLUSIONS

Naturalistic driving will provide the research community with rich and detailed information on interactions between cyclists and motorized traffic. UDRIVE will probably provide far more data than can be analysed within the lifetime of the project and thus provides the opportunity for additional data analysis for many years to come.

Application of the knowledge is wide. For instance, emergency braking systems for protection of vulnerable road users are currently in development. In order to optimise warning and braking systems, the behaviour of vulnerable road users and the interactions with drivers needs to be better understood [13]. Note though, that despite the richness of data, Naturalistic driving has also its limitations. It will provide high quality information on the behaviour of motorized traffic in the vicinity of vulnerable road users, but compared to that, it will gather little information on the behaviour of vulnerable road users themselves. The next step would be the 'instrumentation' of cyclists and pedestrians. The first studies using these techniques are now underway.

Acknowledgement

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