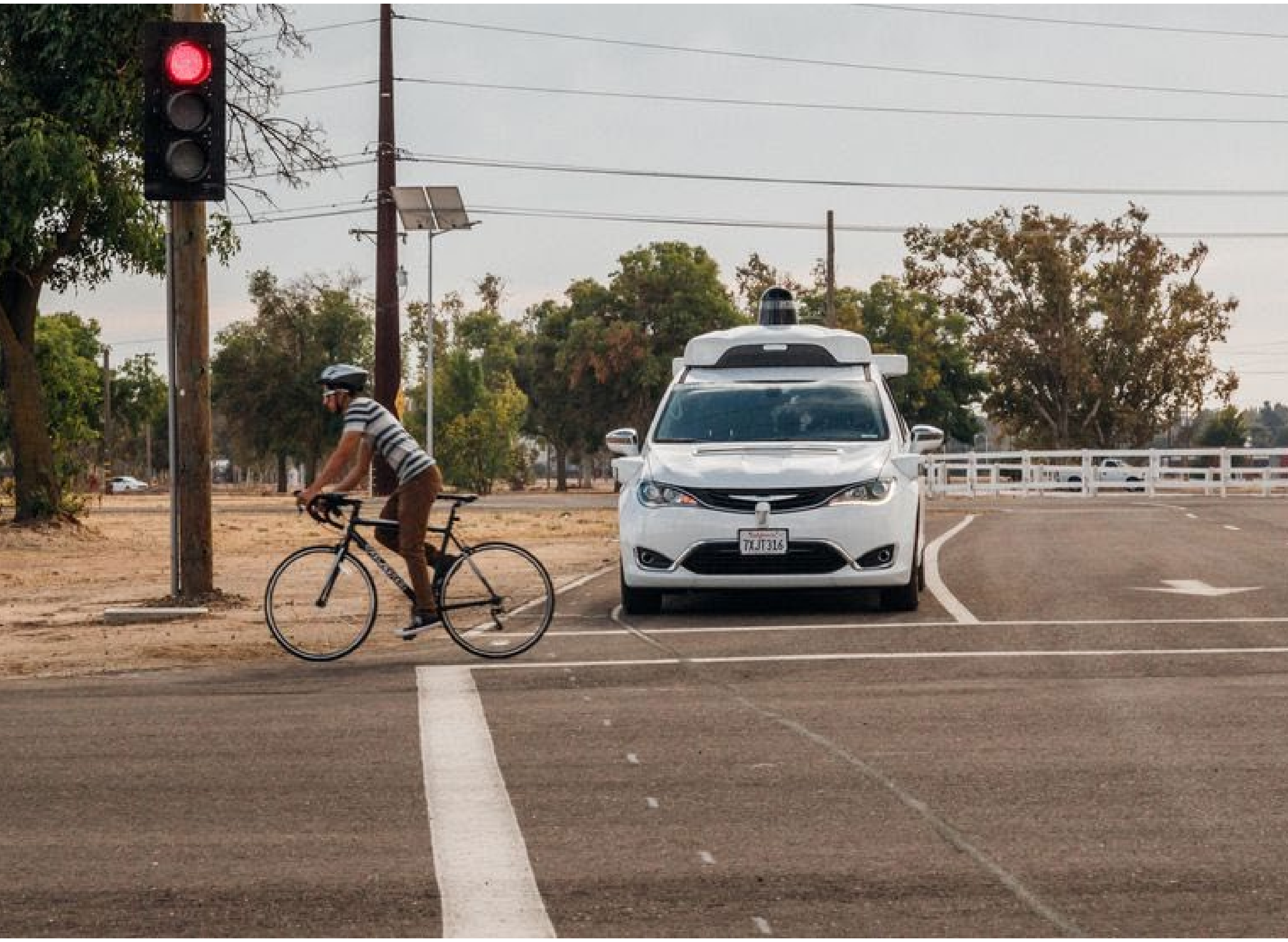
A study on cyclists' crossing behaviour when interacting with automated vehicles compared to conventional vehicles using virtual reality

by Anouk de Vries



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A study on cyclists' crossing behaviour when interacting with automated vehicles compared to conventional vehicles using virtual reality

By Anouk de Vries

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Preface

This research: “A study on cyclists’ crossing behaviour when interacting with automated vehicles compared to conventional vehicles using virtual reality” has been written to conclude my study, at the Technical University of Delft, for the master Transport, Infrastructure and Logistics.

I would like to thank Pablo Nuñez Velasco for introducing and engaging me to this subject and his inexhaustible enthusiasm. I really appreciated that your door was always open, and you always took the time to advise me and read every part I wrote. I would like to thank Haneen Farah as well, for supervising and advising me and help me to ask the right questions. Furthermore, I would like to express my appreciation to Marjan Hagenzieker and Jan Anne Annema for their input during our meetings.

A special thanks to all my participants, for joining the experiment, without them this research would not be possible. Lastly, I would like to express my gratitude to Hugo Bijmans, for helping me create the video recordings and providing me with lots of (video editing) advice.

I hope you enjoy reading.

Anouk de Vries,

Delft, June 2019

Abstract

With the introduction of Automated Vehicles (AVs), new potential traffic situations could emerge on the roads. Although several studies on AVs have been conducted, most of these studies focus on the AV technology or on the driver, while there is less emphasis on how these AVs could interact and communicate with other road users. The interactions of vulnerable road users with AVs versus Conventional Vehicles (CVs) or the amount of trust in AVs versus in CVs, can be different. Due to the high fatality and injury rates and the large number of cyclists in the Netherlands, this research will focus on cyclists. Currently, there is little knowledge about cyclists' behaviour, interacting with these AVs. The main goal of this study is to investigate whether the crossing behaviour of cyclists differs when interacting with an AV compared to a CV.

An experiment in Virtual Reality has been performed to study crossing decisions of participants when interacting with both AVs and CVs. Multiple scenarios were shown to the participants, who could either choose to: 'continue cycling', 'cycle faster' or 'slow down'. A mixed model with repeated measures was estimated to identify which variables influence participants' crossing decisions. The included variables were: vehicle type, gap distance, crossing priority, risk taking, stated trust and the interaction between the vehicle type and stated trust. The results show that there is no significant difference in the crossing decision between the two types of vehicles when the total group of participants is considered. However, when participants are divided into groups based on their stated trust in AVs, significant statistical differences were observed in the crossing behaviour between the two types of vehicles. Participants who have more trust in AVs compared to CVs, crossed more often in front of AVs. The ones who trusted AVs less, choose to slow down more often in front of the AVs. The awareness of the type of vehicle increased their preference based on their stated trust even more and made the differences in the crossing behaviour between the groups bigger.

This study shows that cyclists adapt their behaviour when interacting with AVs, based on their amount of trust in AV technology. These findings are important to reminisce for the continuous developing of AV technology. Furthermore, additional research can build upon this study to formulate a policy on AVs. To see how the behaviour of cyclists will evolve in the future, more research about the learning effects of interacting with AVs is necessary.

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1. Introduction

On a sunny day, I was waiting at the side of the road for my driving instructor to pick me up. When I saw her coming from a distance, two cyclists approached the road. They were estimating whether to cross in front of the vehicle, when one said to the other: “Let’s go, it is just a driving school vehicle, it will stop anyway.” It was striking to me then, that they adjusted their behaviour on the appearance of the vehicle. If this change in behaviour was shown towards driving school vehicles, it raised the question how we will adjust to new types of vehicles, like automated vehicles.

Vehicles are becoming more and more automated: bicycles turn into e-bikes and cars come with all sorts of automation (NHTSA, 2017). Furthermore, pilots are being performed with fully automated vehicles: Waymo, a driverless car project, has already self-driven more than 9 million miles (Waymo, 2018), and research groups are conducting tests with self-driving in the Netherlands (DAVI, 2018). Automated vehicles (AVs) need to detect and recognize other road users to interact with them. AVs do not only need to interact with other motorized vehicles, but also with non-motorized road users, such as pedestrians and cyclists. Pedestrians and cyclists can be categorized as vulnerable road users (VRUs), because they are not protected by a shell (SWOV, 2012). In collision with non-vulnerable road users, this results in both a higher fatality and severe injury rate for the VRUs than for non-vulnerable road users. Pedestrians and cyclists are having a 30 times higher fatality and risk factor in collision with cars and vans as compared to their drivers (SWOV, 2012). Therefore, safe interaction with this group of road users is literally vital.

A report of the WHO shows that in 2016 pedestrians and cyclists made up for respectively 22% and 5% of all the fatalities split to transport mode worldwide (Toroyan, 2015). How many of these fatalities happened due to human errors, is a wildly discussed subject. Some say over 90% of the crashes is believed to be due to errors by the driver, such as recognition errors (41%), decision errors (34%), performance errors (10%) and non-performance errors (7%) (NHTSA, 2008). Others state that 40% of all fatal motor vehicle crashes in the U.S., involved some combination of alcohol, drugs, distraction and/or fatigue. If these *human related factors* could be eliminated, the amount of accidents would decrease, and in the end, lives could be spared. Factors as alcohol, drugs, distraction or fatigue would not bother an AV, which could potentially decrease the fatality rate, if the automation does not endure malfunctions and when no side-effects occur (Fagnant & Kockelman, 2015). Therefore, if AVs could possibly reduce the amount of accidents and victims, this would be worth to investigate.

Besides detecting and recognizing VRUs, AVs should also be able to predict the path of these VRUs, to safely interact with them. Predicting the path of these VRUs accurately is difficult, even for humans based on only indirect visual cues (Westerhuis & De Waard, 2017). Research of Westerhuis & de Waard (2017) showed that participants were uncertain which way a cyclist would turn based on a photo, when they did not use their arm to indicate the direction. So, the cues that AVs must rely on are very subtle, which makes it tough to base their decision solely on visual cues.

Multiple studies have been done on recognizing other road users from the point of view of AVs (Schmidt & Färber, 2009) (Li et al., 2017) (Keller & Gavrila, 2014). Research focusses on recognizing and predicting the path of these road users and technical requirements, such as navigating and making it robust to changing weather conditions. If human factors are included, the factors that are normally sought are: driver experience, comfort and value for money (Stam, Allessandrini, & Site, 2015). While there is less emphasis on how these AVs will interact and communicate with other road users, such as manually driven cars and VRUs (Merat, Louw, Madigan, Wilbrink, & Schieben, 2018).

At the same time the other road users need to interact with these AVs as well. They need to adapt to a changing road traffic system and to a different type of 'road user' (Vissers, Van der Kint, Van Schagen, & Hagenzieker, 2016). In this changing traffic system, road users need to interact with (semi-) AVs, as well as with conventional vehicles (CVs).

An important factor in the interaction between VRUs and CVs is the drivers' behaviour, such as postures, gestures and eye-contact (Malmsten Lundgren et al., 2015). Eye-contact can be used by pedestrians to influence interactions and improve the stopping chance of a vehicle (Guéguen, Meineri, & Eyssartier, 2015). However, driver interactions are not possible in the case of an AV, as there is no physical driver present or the person in the driver seat is not in control. As a result, interaction with an AV could possibly differ from the interaction with a CV. Furthermore, the behaviour of VRUs can be influenced by the amount of trust they have in AV technology (Vissers et al., 2016). If VRUs trust AVs to always be able to stop, they might be tempted to take more risks. On the other side, if they do not trust AVs they could act more carefully. Therefore, the question remains how VRUs behave around AVs and whether this differs from how they behave around CVs.

It is important to know how VRUs will behave around AVs, because AVs are trained to recognize different types of behaviour of these road users (Keller & Gavrila, 2014). However, if the behaviour of road users differs once they are around AVs, the AVs should learn how to cope with that behaviour. If AVs are learning how VRUs are interacting with CVs and VRUs differ their behaviour around AVs, problems could occur in the interaction between VRUs and AVs.

Due to the high fatality and injury rates and the large amount of cyclists in the Netherlands, this research will focus on cyclists (Korving et al., 2016) (CBS, 2017). Furthermore, studies on the interaction of cyclists with AVs are still rare (Twisk, Vlakveld, Dijkstra, Reurings, & Wijnen, 2013). Most accidents between cyclists and motorized vehicles happen at crossings and during crossing manoeuvres (SWOV, 2010) (Reurings et al., 2012). Therefore, this research will focus on intersections, to see how cyclists interact in these situations.

The structure of this report is as follows: the literature background will be discussed in chapter 2, where after the research gaps and questions will be presented in chapter 3. In chapter 4 the methodology will be explained and the pilot studies as well as the final experiment will be described. The analysis and results of the final experiment will be presented in chapter 5 and chapter 6 includes the discussion. Finally, chapter 7 contains the conclusions of this report.

2. Literature review

In this chapter the main safety risks for cyclists and the accident locations will be discussed, in paragraph 2.1. In paragraph 2.2 the crossing determents will be reviewed, and a closer look is taken at the possible differences in interaction with AVs. The personal characteristics that determine the crossing behaviour are explained in paragraph 2.3. Lastly, in paragraph 2.4 the virtual reality technology will be described.

2.1 Cyclists safety

To determine the main risk factors for cyclists, a closer look is taken at road accidents. The type of accidents and the locations of these accidents is examined.

Fatalities

Cyclists and pedestrians make up for a large share of all fatalities split to transport mode worldwide. The WHO stated in its report that pedestrians made up for 22% and cycling contributes with 5% (Toroyan, 2015). Large differences could be seen per region, in Europe pedestrian fatalities were 27% and cyclists showed a percentage of 4%. Between countries in Europe there are differences visible as well, in contradiction to other European countries the Netherlands showed a larger percentage of cyclists, than of pedestrians, respectively 30% and 9% in 2015 (Korving, Goldenbeld, van Schagen, Weijermars, Bijleveld, Wesseling, Bos & Stippeldonk, 2016). This can be explained by the fact that the Netherlands is a typical ‘bicycle country’ and the bicycle is a more popular mode of transport (Evgenikos et al., 2016). Research of CBS showed that in 2017, for the first time ever, the largest share of fatalities in traffic were cyclists, with a total of 206 fatalities (CBS, 2017).

Injuries

Accidents do not only result in fatalities, injuries happen as well. The registration of these injuries is not accurate worldwide, nor on a European level. In the Netherlands hospital data is used and this indicated that cyclists make up for 63% of all serious road injuries (Korving, Goldenbeld, et al. 2016). Therefore, cyclers make up for almost two third of all injured road users, while they only account for 7,5% of all kilometres travelled (CBS, 2018b). So, cyclers take the lead in the injurie statistics as well as in the amount of road fatalities. Fifty-two percent of these accidents happened in collisions without motorized vehicles and 11% occurred in accidents with motorized vehicles (Korving et al., 2016). Collisions with motorized vehicles are usually more severe, because the difference in mass between the colliding parties often also determines the severity of the accident (Van Kampen, 2000). Therefore, it would make a difference when crash statistics between bicycles and motorized vehicles could decrease.

Crossings

Most of the cycling accidents with motorized vehicles happen on crossings, 3 times more than on road sections (SWOV, 2010). When looking at manoeuvres, it appears that most of the accidents with cyclists happen when they are crossing the road, as 78% of the accidents between motorized vehicles and cyclists occurred during a manoeuvre type categorized as ‘intersecting’ or ‘crossing’ (SWOV, 2010). This type of manoeuvres occurred on crossing facilities in 28% of the fatal and 31% of the inpatient crashes. Crossings seem to be the main location on the road for collisions between motorized vehicles and cyclists. As can be seen in Table 1, 61% of the accidents happened on a crossing, and the highest amount was found on priority crossings.

Table 1 Location on the road of accidents between bicycles and motorized vehicles (Reurings et al., 2012)

Location on the road	**Motorized vehicle**
Straight road section	29%
Turn	9%
Crossing with traffic lights	9%
A priority crossing	30%
Equal crossing	17%
A roundabout with priority to the cyclists	3%
A roundabout without priority to the cyclists	2%
Total	100%

Cyclists from the right

Statistics show that cyclists are often hit on their side by the front of the car. They are more often hit on their left side than on their right side (Methorst, van Essen, Ormel, & Schepers, 2011). This shows that cyclists approaching from the right of the car, are more often involved in an accident than cyclist from the left. Research about cyclists' accidents also showed that they were over 50% more likely to be hit from the left than from the right (Van Kampen & Schoon, 2002). As priority-to-the-right applies in the Netherlands, cyclist from the right have priority over the vehicle. This could indicate that cyclists are not given that priority, or that they are less careful when in a priority situation. Moreover, cyclists have a higher change of crashes when they have right of way than in situations where the car has priority over them (Schepers, Kroeze, Sweers, & Wüst, 2011).

Urban area

Research of SWOV shows that accidents between motorized vehicles and bicycles happen more often on 50 km/h roads, as compared to 80 km/h roads, although the accidents are more severe on 80 km/h roads. This could be distorted, since it is not corrected for the amount of bicycle kilometres on these roads (SWOV, 2010). Furthermore, most accidents with cyclists happen in the urban area. It was indicated that 60% of all fatalities happen inside this area. From this percentage 65% happened on crossings. Therefore, crossings in the urban area can be the deadliest. For accidents with badly injured cyclists and victims who needed first aid was this respectively 80% and 86% inside the urban area (Methorst et al., 2011). So, not only fatalities happen mostly in the urban areas, non-deadly accidents do as well. Out of 80% accidents with badly injured cyclists, 70% happened on crossings. For the people who needed first aid the location of the accident was unknown (Reurings et al., 2012). It can be concluded that crossings in the urban areas are the locations where the interaction between cyclists and vehicles most often results in collisions. Therefore, it would be interesting to investigate these situations and try to improve the safety in these interactions.

Since accidents mostly occur on intersections, these situations will be part of this research. Hereby the unsignalized intersections will be chosen to study, because most collisions happen there. Also, interaction is more likely to happen at unsignalized intersections, where the priority needs to be sorted out by the road users themselves and not by traffic lights.

2.2 Interaction between cyclists and AVs

Pedestrians' crossing decisions are based on lots of different factors such as social factors, demographics, physical context, traffic characteristics and dynamic factors (Rasouli & Tsotsos, 2018). Most of these factors will not be influenced by a new type of vehicle; social factors, demographics and physical context will stay the same. However, due to other needs and functions the appearance of AVs will differ from CVs and the way road users communicate with the vehicle may change as well. In this paragraph the crossing determents will be discussed. Even as the possible differences in behaviour towards AVs compared to CVs.

Most research on interaction between VRUs and vehicles focusses on pedestrians or VRUs in total. Since little research could be found specifically about the interaction with cyclists and vehicles, research on pedestrians and VRUs is used as well.

Crossing determents

The crossing determents that are important for crossing behaviour in interaction with CVs and AVs as well are listed here. Important crossing information consists amongst other things of gap size, speed of the vehicle and braking behaviour. Personal characteristics that are of influence on crossing decisions will be discussed in paragraph 2.3.

Gap size & vehicle speed

The gap size is an important characteristic to base a crossing decision on, since it describes the time before the vehicle crosses. The accepted gap size is different for every person and differs per situation. Accepted gap sizes depend on different variables such as vehicle speed, traffic situation and amount of traffic (Opiela, Khasnabis, & Datta, 1980). The wide of the crossed road determines how long it will take to reach the other side of the road and is therefore important for the minimum accepted time gap.

The average accepted gap of cyclists was found to be between 3.6-3.9 seconds, and the minimum accepted gap was 1.1 seconds (Opiela et al., 1980; Plumert, Kearney, & Cremer, 2004). The roads were respectively 12 and 7.3 meters wide. A difference in vehicle speed (25 mph or 35 mph) was of influence on the accepted gaps. A higher speed of the vehicle resulted in bigger gap sizes and a lower speed in smaller gaps. However, it was noted that people seemed to react more to a difference in distance than a difference in speed (Plumert et al., 2004). However, research with pedestrians found that speed did not determine the crossing decision of younger pedestrians (20-30 years old) (Lobjois & Cavallo, 2007). For different approaching speeds of respectively 40, 50 and 60 kilometres an hour their accepted time gaps were around 3.5 seconds, so they were comparable to the gap sizes found for cyclists. The street they had to cross in this experiment was only 4.2 meters wide, but pedestrians have a slower crossing speed than cyclists, so it takes them as long to cross the road.

The traffic density has also an effect on the crossing behaviour, in high-density traffic people accept smaller gap sizes than they do in low-density traffic (Plumert & Kearney, 2015).

Speed of the cyclist

The cycling speed differs per person, location and moment. Research on average cycling speed in the Netherlands is not clear. Furthermore, e-bikes are sometimes in- and other times excluded in the average.

Research based on a national study on transportation movements, reported an average cycling speed in the Netherlands of 12,4 kilometres an hour on a “regular” bike, when e-bikes are excluded (KiM, 2016). E-bikes showed a higher average of 13,0 km/h, based on this data. Another research that followed cyclists all over the Netherlands for a week found an average of 17 km/h in 2017. Although they concluded that there were large differences between regions and especially in the big cities the average was slower. Amsterdam and Rotterdam showed the lowest averages with 13,8 km/h. Remarkable is the relatively big difference in average speed compared to 2016, when it was 15,8 km/h. It is possible that the increase in speed could be partly explained by the higher amount of e-bikes sold (RAI vereniging, 2018), since the average speed on an e-bike is higher (KiM, 2016).

Possible changes in interaction with AVs

The influence of the just discussed variables will probably not differ when the vehicle changes. However, some variables will be influenced by a shift to AV and are discussed here. The possible influences of social interaction and behavioural adaptation will be examined.

Braking behaviour

In interaction with AVs, people are most concerned about whether the vehicle has noticed them (Merat et al., 2018). This is similar to crossing behaviour in front of CVs. If the driver has seen that a VRU is crossing, he will try to avoid an accident. A fluctuation in speed can function as an indicator of the intentions of the driver (Rasouli, Kotseruba, & Tsotsos, 2017). Drivers who maintain their speed or accelerate use this to show their intention of continuing their way and not stopping for pedestrians (Várhelyi, 1998). When drivers brake much earlier than where they need to stop legally, they show their intention of letting the pedestrians pass first (Dey & Terken, 2017). Pedestrians may adjust their behaviour and change their crossing intentions on these differences in speed.

Social interaction

Social interaction can help pedestrians to determine whether it is safe to cross. A signal from the driver can let them know that they are noticed and could cross the road safely (Wolf, 2016). In the interaction between VRUs and CVs it could be seen that drivers' behaviour is an important factor. Postures, gestures and eye-contact, may influence the crossing intentions of the VRUs (Malmsten Lundgren et al., 2015). Furthermore, VRUs can use their own behaviour to increase the chances that a vehicle will let them cross. Eye-contact is a way to influence the interactions with the driver (Guéguen et al., 2015). In interaction with AVs such postures, gestures and eye-contact are absent. VRUs cannot determine their decisions on these factors and need to base them on others. The absence of these factors may therefore change the crossing intentions of VRUs, since the lack of eye-contact is shown to be a reason for not crossing (Malmsten Lundgren et al., 2017).

Behavioural adaptation

Unintended side effects of measurements may occur and influence the net safety improvement. For example more risk taking behaviour could be seen by drivers with an anti-lock braking system (Sagberg, Fosser, & Sætermo, 1997), as well as when road lightning was introduced (Assum, Bjørnskau, Fosser, & Sagberg, 1999). These examples show that people might perform more risk-taking behaviour if they feel safer. Taking extra risks as compensation for feeling safer is called offsetting-behaviour or risk compensation and is a form of behavioural adaptation (Litman, 2014). Due to this compensation, measures might not increase the safety as much as expected. If AVs become safer, the risks passengers of AVs take could increase, such as a lower rate of seatbelt use, however the risks other road users take could also increase (Millard-Ball, 2017). When cyclists want to cross a road, they take into consideration the chance they can get to the other side safely and consider the potential risks. Given that most drivers do not intentionally want to hurt cyclists, approaching cars will yield when a cyclist is crossing. However, there is always a risk that the driver is inattentive or under influence of and might not brake in time. This risk keeps cyclists from randomly crossing the road and accepting small crossing gaps. These risks of inattentive drivers or drivers who cannot react in time are eliminated with an AV. Furthermore, AVs will be programmed to be risk-averse, always obey the traffic rules and prevent collisions with cyclists. With the knowledge that an AV will always brake, cyclists can cross with impunity (Millard-Ball, 2017). This may provoke different behaviour and AVs may get to deal with some malicious actions, as can be seen towards autonomous robots in some malls (McFarland, 2017). Dangerous situations could happen when cyclists trust these AVs completely, since also the physical braking limitations of the AV itself is of importance. Therefore, it might not be able to stop in time, although it responded faster than a human driver (Sivak & Schoettle, 2015).

2.3 Personal characteristics

Not only external factors influence the crossing decision, personal characteristics may as well. Crossing behaviour could be modified by gender or by age.

Gender

Gender may be of influence on crossing behaviour, since differences are found in the amount of cycle fatalities per year. As can be seen in Figure 1, the amount of fatalities by men has been almost twice as high in the period 1996-2017 (CBS, 2018a). The difference in fatalities is so big, that this could indicate that there is a difference in crossing behaviour.

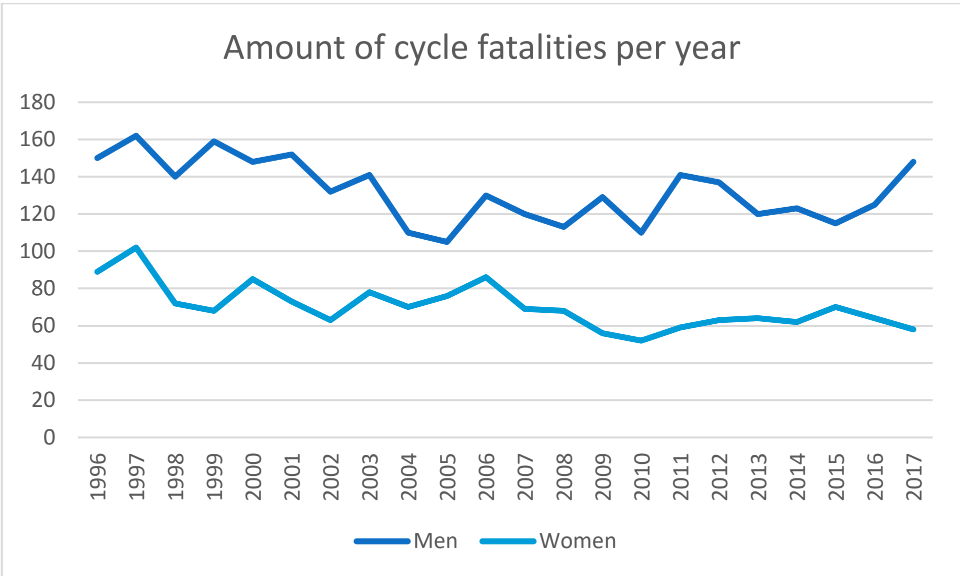

Figure 1 Amount of cycle fatalities per year for men and women in the Netherlands (CBS, 2018a)

Age

Differentiation in age is found to lead to changes in crossing behaviour. Age is found to influence the acceptances of gap sizes. Older pedestrians selected bigger gap sizes than younger pedestrians do (Demiroz, Onelcin, & Alver, 2015). Furthermore, older pedestrians and cyclists valued signalized intersections and cycle paths much more, than their younger equivalents (Bernhoft & Carstensen, 2008). Older VRU’s show therefore more cautious behaviour.

2.4 Virtual reality

A new method to study crossing behaviour is created with the founding of the new Virtual Reality (VR) technology. VR can be used to let participants immerse in the VR environment and may be able to replace real life experiments for researches that are expensive, difficult or dangerous to do in real life (Deb, Carruth, Sween, Strawderman, & Garrison, 2017). VR might be a useful tool for studies due to the increased realism and the absence of physical danger (Simpson, Johnston, & Richardson, 2003).

Despite the advantage of VR, its use in scientific research is quite scarce. Nevertheless, studies on the behaviour of pedestrians at crossings show that it is able to display differences in crossing behaviour (Clancy, Rucklidge, & Owen, 2006; Simpson et al., 2003). Although the amount of hits in the virtual environment was somewhat higher than in real-life, the participants did not show reckless behaviour and they adopted behaviour that is common in real-life (Plumert et al., 2004; Simpson et al., 2003). The behaviour seen in VR is similar to real-life behaviour found in literature and VR can be seen as a validate way to capture this (Deb et al., 2017). Furthermore, participants have more understanding of the scenarios when using VR and the results are more consistent (Farooq, Cherchi, & Sobhani, 2018).

Motion sickness

A side-effect of using VR can be that participants may get sick due to visually induced motion sickness (VIMS). The sensory conflict theory can explain the occurrence of VIMS, when using motion images (Lubeck, Bos, & Stins, 2015). A conflict between your sensory signals - coming from your visual, vestibular and proprioceptive systems - and your anticipated sensory signals can cause motion sickness (Bos, Bles, & Groen, 2008). In VR your eyes will see a moving vision, while your body notices that it is standing still, and this can cause conflicting signals. Although most people do not endure this, it is shown that not all people can tolerate the virtual environment (Deb et al., 2017).

Following this literature review the research gaps will be determined. These gaps will be discussed in chapter 3, and will lead towards research questions for this study.

3. Research gaps and questions

The research gaps and questions have been based on the literature review in chapter 2. For every question the research gap will be first described shortly, then the resulting research question will be presented. Thereafter, the hypothesis for that question will be explained. In paragraph 3.1 the main research question will be discussed, where after in paragraph 3.2 the sub questions will follow.

3.1 Research question

The literature review showed that in the interaction between VRUs and drivers, the drivers' and cyclists' behaviour are important factors. Eye-contact, posture and gesture of the driver could influence among others how the VRUs will behave. With AVs these factors will probably not play a dominant role, as there is no driver, or the driver is not the one in control. So, it is possible that cyclists cannot base their crossing decision on these factors. It is unknown if consequently the interaction between cyclists and AVs will differ from cyclists' interaction with CVs. Furthermore, it is unknown if behavioural adaptation takes place and cyclists adapt their crossing behaviour towards AVs.

Based on the research gaps, the following main research question will be investigated in this study:

"What is the difference in the crossing behaviour of cyclists when interacting with automated vehicles versus conventional vehicles?"

A difference in crossing behaviour of cyclists when interacting with an AV in comparison to a CV is expected, due to a difference in crossing determents. As described in chapter 2, when interacting with AVs it was indicated that the biggest concern was whether they were noticed by the vehicle. Therefore, it is assumed that cyclists adapt their behaviour towards AVs.

3.2 Sub questions

The following sub questions are formulated to help answering the main research question:

Sub question 1: Awareness

When observing differences in crossing behaviour, it is important to know how often people recognized the AVs. It is critical to know whether people are aware of the choices they make in their behaviour towards AVs, or if they make them unwittingly. Therefore, the following sub question is formulated:

"What is the effect of the awareness of the type of vehicle on the crossing behaviour of cyclists when interacting with AVs versus CVs?"

The awareness of the type of vehicle is assumed to be of influence, because it is believed that the behaviour is different towards an AV than towards a CV. If people do not notice that the vehicle is automated, their reaction should not differ from their reaction towards a CV.

Sub question 2: Priority

Thirty percent of the accidents on the road between cyclists and motorized vehicles happened at priority crossings, the literature review showed. That made it the number one accident location on the road. Additionally, cyclists are more often hit on their left side than on their right side, which could indicate that they are easier hit in a situation where they have priority. Furthermore, it is indicated that the crash rates for cyclists are higher when cyclists have priority, than when the vehicle has priority. However, it is unidentified what causes these differences. Perhaps there is a change in cyclists' behaviour, when they know they will have priority, although that has not been researched yet. It is unknown as well if cyclists' behaviour will react in the same way, when they have priority over an AV. So, the sub question is formulated as follows:

"What is the effect of a change in priority on the crossing behaviour of cyclists?"

Participants are predicted to cross more often, when they have priority over the vehicle. On the contrary, when the vehicle has priority over the cyclist, they are expected to cross less.

Sub question 3: Influence variables

Many factors influence crossing behaviour and the eventual decision whether to cross. The factors that influence crossing decisions of cyclists are listed in the literature review. However, it is undiscovered if these factors have the same influence for AVs as they have for CVs. Hence, a sub question is made to determine this:

"What is the effect of a change in the variables speed, gap size and priority on the crossing behaviour of cyclists when interacting with AVs versus CVs?"

It is expected that a change in variables will have a different effect on cyclists in interaction with an AV than a CV, since a difference in crossing behaviour between the vehicles is predicted.

Sub question 4: Level of trust

Not everyone will have the same amount of confidence in the AV technology. The trust people have in AVs can influence how they will behave around these vehicles. If they trust this technology and feel safe around AVs they might perform more risk-taking behaviour, due to behavioural adaptation. If they are cautious about this type of transportation, they could act more hesitant. It is not yet identified how the amount of trust influences the behaviour of cyclists. Thus, to find out how this influences the crossing behaviour, the following sub question is formed:

"How does cyclists' level of trust in AV technology affect their crossing behaviour in front of an AV?"

A higher level of trust in AV technology is believed to increase the number of crossings in front of an AV. If cyclists feel safe around AVs they are more likely to cross in front of them whereas when they do not trust AV technology, they probably act more careful and cross less in front of AVs.

Sub question 5: VR

The use of VR in studies is a new technology and it is not widely used yet for observing crossing behaviour. Therefore, it would be interesting to see how the VR environment performs for this purpose. So, the subsequent sub question is prepared:

"How does the VR environment perform for research purposes?"

The VR environment is expected to work well for research purposes. The crossing environment is thought to be realistic, as seen in previous crossing experiments described in chapter 2. However, not everyone can stand VR environments, so it is expected that for a small share the VR environment will not work, and they need to withdraw.

4. Methodology

The data collection of this research consisted of a virtual reality experiment performed with 50 participants. These participants saw videos where they would drive towards a crossing and needed to decide whether to cross, while a vehicle was moving towards them. In these videos different scenarios were shown which consist of a CV as well as an AV.

The aim of the experiment is to see if participants adapt their crossing behaviour when interacting with an AV versus a CV.

Four experiments are performed for this research, three pilot studies and one final experiment. First a small pilot study was done to see which cycling speed was most realistic in VR to the participants. Secondly, before doing the experiment a second pilot was performed to test the feasibility of the set-up of the experiment. The third pilot study was to test the final videos and to see which AV should be used. The improvements of these pilots could be used for the last step of the data collection, being the final experiment.

The method used by every pilot and the final experiment will first by described. Hereafter, the intent and methods used by the pilot studies will be explained and the results of the pilots will be presented. Furthermore, the lessons learned of this pilot study for the experiment will be explained. Lastly, the final experiment will be specified. The videos used for the final experiment can be found at the repository of the TU Delft via: https://repository.tudelft.nl/islandora/object/uuid:ac45f9ed-347c-4817-8ce4-0b8afe7f0780?collection=education

4.1 Overall method

The method is adapted and improved after every pilot study, however the basis method stayed the same. First the overall method will be defined that has been used for every pilot study. The choice for VR will be explained, even as the method used to establish a cyclist's point of view. Controlling the cycling speed will be described even as the use of different versions. Furthermore, the crossing options will be discussed, as well as the aimed participants.

Virtual reality

To make the experiment as realistic as possible, VR is used. By using VR, the participants can have the realism of being at the crossing, without needing to be at a certain time at a certain place. So, there is no need to close off a road for multiple days and therefore the number of participants can be higher. Besides, it would have been extremely difficult to make the scenarios comparable for all participants, since the gap size between the vehicle and cyclist depends a lot on the cycling speed. Every participant would need to drive at the exact same speed and the reaction time of the driver should always be the same. To make sure the participants would be safe, the gap sizes between the vehicle and cyclist would have to be larger, to make sure the participants were not in danger, even when they would make an unexpected move. In VR there is no safety risk for the participants and small gap sizes can be used.

A VR environment can be created in two ways, namely creating an animated environment or recording a real-life setting. Since the lack of realism is often described as the biggest disadvantage of VR videos (Farooq et al., 2018), the most realistic option has been chosen, being the use of 360 degrees videos. So, participants were in a real-life setting and were not shown animated videos. The downside of the 360 degrees videos is that participants were not able to move around, as would be possible in an animated setting. However, by walking around in an animated setting behavioural adaptation could occur. If participants cross the road multiple times in the animation, they will get feedback on their decisions. When they cross at the last moment before an AV for example, they will see if the AV is going to brake or if it might hit them. This may affect their next decisions and can influence the experiment. In this experiment the recorded video will stop before the cyclist is crossing the street, so the participant can decide whether to cross. This prevents behaviour adaptation taking place and therefore the recorded environment is chosen for this experiment. The videos have been recorded with a 360 degrees camera and shown to the participants using VR glasses. This enables participants to watch around and immerse in the video.

VR makes it possible to create scenarios that are comparable to each other and only differed on the chosen attributes. Every scenario could be recorded multiple times and the best recordings, with the correct gap sizes, were selected. Every participant also saw the exact same videos.

The used camera was a Nikon Keymission 360 action camera. This camera used two lenses and stitched these two recordings together by itself. This made it an easy to use camera and together with the price-quality ratio made us decide to use this type. A similar method has been used by Nuñez Velasco et al. (2018) to study the behaviour of pedestrians (Nuñez Velasco, Farah, Arem, & Hagenzieker, 2018). By using the same method, it might be possible to eventually compare the results and define the differences between cyclists and pedestrians.

Since motion sickness could occur, as described in paragraph 2.4, it is essential to monitor the participants during the experiment and stop it when they experience nausea. Moreover, the use of VR for longer than one hour is not advised (Karner, 2016), thus experiments will not exceed one hour.

Cyclists’ point of view

To give the participants the feeling that they saw the videos through the eyes of the cyclist, it was important to create a good point of view. This point of view was created with the use of a Go Pro mouth mount, which is a mouth piece that can be connected with a converter to fit the Nikon Keymission camera. The camera is then hanging under the mouth mount and the mouth mount was placed in the mouth as can be seen in Figure 2. This made it possible to cycle with both hands on the steer while recording.

Since the camera was recording in 360 degrees, it was important that the construction did not block a large part of the recording. Since the camera was hanging in front of the face, only a small part of the 360 degrees was blocked by the cyclist. Therefore, it was in the videos still possible to look around and see more than 270 degrees. When looking down, it was possible to see the legs pedalling as well. The point of view was found to be realistic by the participants of the pilot study.

Videos made on top of a helmet worn by the cyclist were also tested, however this point of view felt not realistic, because it was too high. An option with a tripod on the bike seat was discussed as well, so it would be possible to place a stabilizer on top of the tripod to make the shots more stable. However, it turned out too costly to create a case which would hold the tripod in its place on the bike seat, which was stable enough to make sure the camera would not drop. To ensure the videos made with the mouth mount were stable, they were stabilized in post-production using Adobe After Effects.

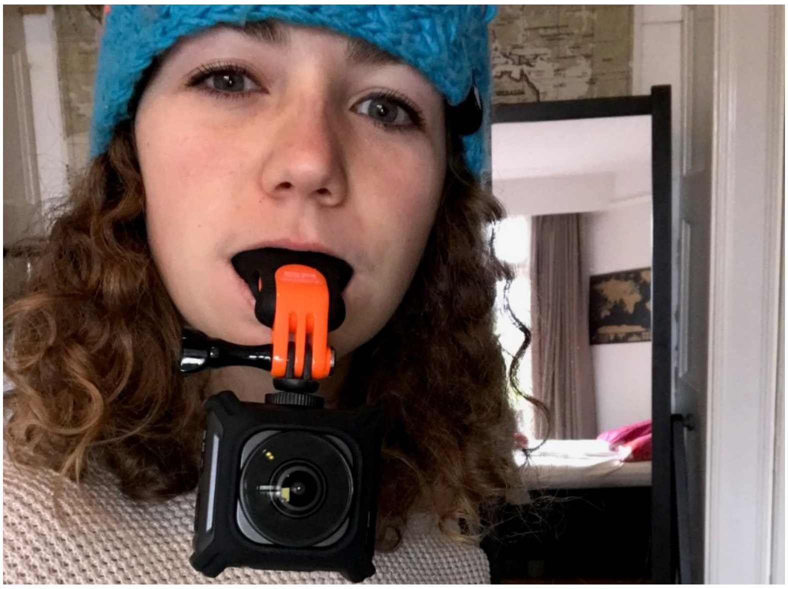

Figure 2 The camera connected to the mouth mount

Cycling speed
The bike was equipped with a bike computer to show the speed to the cyclist, to make it possible to monitor the speed. The cyclist could use it to make sure the right speed was driven, and it could be used to check in the recordings if the speed was correct and constant. The speed was blurred in the videos, to make sure the participants were not distracted or biased by this number.

Versions
The order in which the videos appeared to the participants was randomized. Three versions were made with a rotating order of the videos, to make sure the order was not of influence on the participants' preference. Furthermore, the answers of previous participants could not influence the decision of the participant when multiple participants were in the same room.

Crossing options
For this experiment participants were needed to cooperate. Participants were shown different videos, after which they must decide whether they would cross the road or not. After a video is shown they needed to answer what they would do in this situation, would they either continue cycling, cycle faster or let the vehicle pass first. After each scenario this question popped up in the screen and participants were asked to answer out loud, so their answers could be written down. In comparison to research about the behaviour of pedestrians an extra option was added, namely cycle faster (Nuñez Velasco et al., 2018). When an accepted crossing gap is smaller, pedestrians are seen to speed up their pace (Ishaque & Noland, 2008). It is possible that a similar trend can be seen by cyclists. Because most cyclists try to keep going as much as possible (Plumert et al., 2004), and are able to slow down or speed up to avoid needing to stop, only the options cross or stop was thought to be insufficient. Since the crossing gap before the vehicle will be just enough to cross, only cycle faster and cross before the vehicle is added as an option. Let the vehicle cross first includes slowing down as well as braking.

Participants
Since a bigger group of participants will always improve the significance of the findings, the aim will be to get as many and homogeneous participants. If the participant characteristics differ a lot, differences can be due to other factors such as age. As shown in paragraph 2.3, this factor has a big influence on

crossing behaviour. With a heterogenous group, many participants are needed to get statistically significant results. By choosing a homogenous group, it might be possible to get significant results with a smaller test group. Since the experiment will be performed at the TU Delft, most of the participants will be living around Delft and the age will be between 18-28. The goal is set to get at least 50 participants, given the limited time.

It is important to get as many men as women to participate, since a difference in the amount of accidents can be seen between these groups and therefore it could be that their behaviour differs. It is import that all the participants are from a country where priority-to-the-right applies or that they live long enough in the Netherlands to have adapted to this, otherwise they could misinterpret the priority situation and bias the results (Rodriguez Palmeiro et al., 2017). Furthermore, the participants should have experience with cycling, to be representative for the cycling population in the Netherlands.

4.2 Pilot 1: Identifying the correct cycling speed

A speed had to be chosen for the cyclist to cycle in the experiment. To determine with which speed the cyclist should cycle in the recordings, a pilot was performed, since literature was not unambiguously.

In literature different “average cycling speeds” were found, varying from 12,4 km/h to 17 km/h (KiM, 2016). Since this difference was not neglectable, a pilot was set up to see which cycling speed was found realistic by the participants. Three videos were made in which a cyclist would cycle 12, 15 or 18 km/h. These speeds were chosen since all the found averages in literature would fit in this range. The slowest cycling speed at which it is possible to drive steady is 12 km/h (CROW kennisbank, 2018), therefore this was chosen as the lowest speed. Since the difference in speed should be noticeable steps of 3 km/h were used.

The videos were put behind each other and shown in VR to participants, who had to answer which cycling speed they felt was most realistic.

All participants give 2 points to the speed they found most realistic, 1 point for the second-best scenario and 0 points for their least favourite speed. A total of 16 participants took part in this pilot. The participant characteristics and the answers per participant can be found in Appendix B.

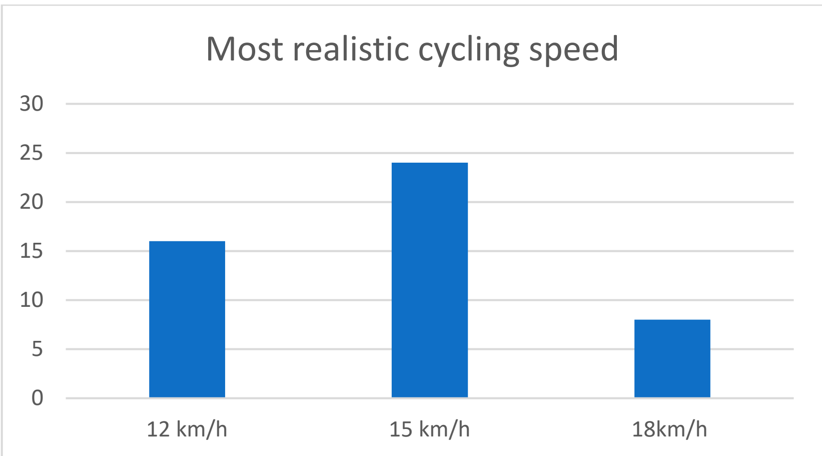

Figure 3 Results most realistic cycling speed

The most realistic cycling speed for the participants was 15 km/h, which is shown in Figure 3. Ten participants gave their highest score to this video. Because the preferred speed of the participants was clear, 15 km/h is used as the cycling speed in all videos of the pilot study and the experiment.

4.3 Pilot 2: Testing methodology

Besides the pilot which cycling speed was most realistic, a pilot study was done to test the experiment set up. Different scenarios were created and recorded on a crossing with a cyclist and an approaching vehicle and shown to participants in VR. The pilot study should determine if the location, gap size, vehicle and stopping point were useful.

Location

The pilot study was performed on the crossing between Cornelis Drebbelweg and Leeghwaterstraat on the TU campus. This crossing was chosen because both cyclist and vehicle would be able to go straight on. Therefore, it was not necessary to make an extra manoeuvre for the cyclist or the driver. Furthermore, this crossing was relatively quiet with other vehicles, so it was possible to record a scene were no other vehicles would influence the decision of the participants.

The crossing had some priority markings to show which direction had priority. It was thought that this was easily removable with video editing. However, the removal could still be seen a bit and therefore it was not deleted when the videos were shown to the test participants. Participants indicated that this influenced their decisions. Therefore, a new requirement was added for the experiment. The crossing needed to be free of priority markings.

While making the recordings it was found that the materials of the road influenced the stabilization of the camera. Asphalt was found to lead to more stable shots than roads with clinkers. Consequently, the cyclist was chosen to use the road of asphalt, while the vehicle would be entering from the road with clinkers.

The first attempt to make the recordings was done on a weekday, but since there were a lot of pedestrians and cyclists in the recordings, it was impossible to make the scenarios comparable with each other. Therefore, a second attempt was done in the weekend. Since it was on university terrain, there was less traffic on the weekends, and it was possible to exclude pedestrians and cyclists in all scenarios.

Speed

The resolution of the camera gives a limitation to the distance someone can see clear. With a speed of 50 km/h, a vehicle can be clearly identified around 2,5 seconds before it passes the participant. This gives a clear sight of around 35 meters, with a lower speed of 30 km/h it takes 4.2 seconds to cross that distance. To make sure the participants have time to recognize the vehicle, the vehicle speed will not exceed 30 km/h in this experiment. This experiment will focus on urban areas, so most of the roads will have a speed limit of 30 km/h. To see what the influence is of speed, a second velocity has been chosen. 20 km/h has been selected, because it differs enough from 30 km/h to be able to spot it and it would still give participants a sense of risk, when they needed to cross in front of the vehicle.

Gap sizes

The average gap sizes in literature were around 3.5 seconds, as seen in paragraph 2.2. It also showed that younger participants accepted smaller gaps. Since the target group was young, the two time gaps were chosen around 3.5 seconds, and somewhat lower. The selected time gaps were 2 seconds and 4 seconds, these gaps varied enough to see a change.

Scenarios

Four different scenarios were recorded where the variable “speed of the vehicle” was either 20 km/h or 30 km/h and “gap size” was variated between 2 seconds and 4 seconds. This resulted in 4 scenarios, as seen in Table 2.

Table 2 Different scenarios planned

	Speed of the vehicle		
Gap size		20 km/h	30 km/h
	2 seconds	20 - 2	30 - 2
	4 seconds	20 - 4	30 - 4

To make sure the gap sizes would be correct a starting point for the vehicle and bicycle was measured and drawn on the road by chalk. The vehicle would start 100 meters from the crossing and it was measured how long it took to get to the 2 seconds and 4 seconds point with a speed of 20 and 30 km/h. This could not be calculated with the average speed since the vehicle was standing still at the starting point and needed to speed up before driving a constant speed. Thereafter, it was calculated what distance the cyclists would cover in this amount of time and that became the starting point for the cyclist. Since it took the cyclist quite a lot of time to get to 15 km/h and the time this took was varying a lot, the cyclist started further away and reached the actual starting point when it was cycling at a steady speed. At this point the driver was instructed to start driving, so they would reach the crossing with the right gap size. The cyclist tried to stay as close as possible to 15 km/h and the speed stayed between 14.5 and 15.5 km/h in all scenarios. Because the cycling speed, vehicle speed and reaction time of the driver could not be controlled, every recording was a bit different. To make sure the gap size was correct every scenario was done five times or over to be able to select the best recording.

The gap sizes were measured from the point where the vehicle and the bicycle would enter the crossing as could be seen in Figure 4.

Figure 4 Crossing Leeghwaterstraat - Drebbelweg gap size measurements

The 4 second gap was later excluded, because it was found that it did not feel like a critical gap. Test participants indicated that they would not stop in this scenario, because the gap was so big. During the recordings the gap size did not feel critical as well. The vehicle could hardly be seen in the video before a decision whether to cross could be made, since the vehicle was still 33.3 meters away. The vehicle was only visible for a few seconds as well, since there was a building blocking the view on the vehicle. Therefore, a new scenario was included, in which the gap was made as small as possible. However, it was still possible for the cyclist to cross before the vehicle. A gap size of 0.5 second enabled the cyclist to cross without the need to speed up or the driver needing to brake. When the gap size would have been smaller than 0.5 seconds, it would be difficult to determine when to brake, so it would not be visible in the recordings, while it was made sure that the cyclist was not hit. To embrace the right level of safety precautions, this is not tested. The four scenarios that were shown to the participants can be seen in Table 3.

Table 3 Different executed scenarios

	Speed of the vehicle		
Gap size		20 km/h	30 km/h
	0.5 seconds	20 – 0.5	30 – 0.5
	2 seconds	20 – 2	30 – 2

Braking behaviour of vehicle

Some recordings have been made to test scenarios with a vehicle that was braking before it entered the crossing. In the recordings this braking behaviour was hard to detect and not always clear. There was a limit to the number of scenarios, since participants could only stay a limited amount of time in the VR environment and the experiment could not take too long. Therefore, other variables that were clearer were preferred to braking behaviour, and this variable was excluded from the scenarios.

Vehicle

For the pilot study a black Renault Twingo was used. This vehicle was chosen because it was always available to make the recordings. So, it was not a problem if the videos had to be re-made or if a different scenario was added. This was very helpful to try out different locations. However, the black colour of the vehicle did not stand out against its background. Consequently, the vehicle was hard to notice from afar. To make the vehicle more visible another colour should be used in the experiment.

Video editing

The videos were edited before shown to the test participants, with Adobe Première Pro and stabilized with Adobe After Effects. To let the test participants decide whether they wanted to cross the road, the video was stopped before the cyclist crossed the road. This stopping point was chosen so that participants would have the feeling that they were still able to stop. However, the point was chosen as late as possible, so the vehicle would be close, and it was clearly visible for the participants. The chosen distance was discussed with the participants and was found realistic.

The videos the participants got to see started with a black screen with “start” at one point, so they would automatically look at the direction of the road when the video started playing. After the video was stopped a question was shown on the screen asking what they would do now: Continue cycling, cycle faster or let the car cross first. This question appeared for 5 seconds to give participants the time to answer. In real life people need to decide quickly and cannot think their decision completely through. So, to make it most realistic, the participants had to answer quickly as well. A decision period of 3 seconds was tested, but this made participants stress out and uncomfortable, so it was decided to extend this to 5 seconds. Hereafter, the next video was shown, and this was repeated for all four scenarios.

Each video took between 10 and 15 seconds. After a few videos, participants could be seen getting a little bored when the videos took too long. Since only the last few seconds are important, and the seconds before that are to get into the situation again, this could be shortened.

Gained insights

Not all participants saw a vehicle in every scenario, so besides the answers “continue cycling” (continue), “speed up” and “let the car cross first” (stop) a fourth option “no car” was included. So, there could be a distinction between the scenarios were participants continued, because they felt safe enough to cross and were they would continue cycling, because they had missed the vehicle.

All scenarios got a variety of answers from the participants, as can be seen in Figure 5. Some participants would continue, some would speed up and in both scenarios with a gap size of 0.5 seconds some would stop. This indicates that the used gap sizes of 0.5 and 2 seconds are both working as critical gap sizes.

Two participants did not see a vehicle in every scenario (participant 1 and 4), so they are excluded from the analyses from here on. Beside those 2 participants, there were 5 cases were “no car” was reported. Three of those happened in the first video. It could be that participants needed to get used to the videos, so it was profitable to rotate the order in which the videos appeared to the participants. Furthermore, three out of five happened in the 30-2 scenario. In this video the vehicle was visible for the shortest amount of time. The speed was higher in this scenario, so the vehicle was further away when the gap was two seconds than it was with 20 km/h. Since there was a building blocking the view, the vehicle was only visible for 1.33 seconds. This turned out to be too short, so for the experiment the vehicle will be visible for a longer period. Therefore, the location will be changed, and the new location should be free of buildings blocking the view. The characteristics of the participants and the given answers per participant can be found in Appendix B.

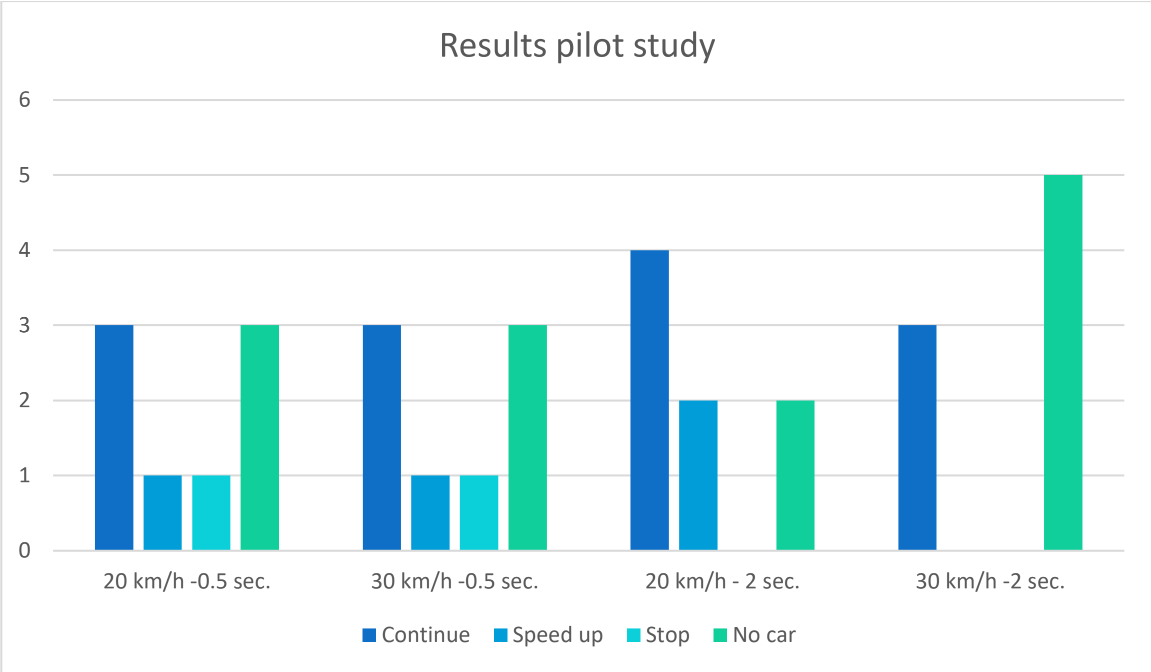

Figure 5 Answers given per scenario in pilot study

Lessons learned

The pilot study resulted in some new insights, which are listed here. These insights were used to add some new criteria and to improve the experiment.

Crossing without priority markings

The priority markings on the crossing were more difficult to delete via video editing than thought beforehand. A bit of the indications stayed visible and therefore the pilot study was done without deleting these priority markings. The participants indicated that the presence of these indications influenced their decision. So therefore, another location will be used for the experiment.

Road with asphalt for the cyclist

It was noticed that there was a difference in stability between recordings made on roads with asphalt and roads with clinkers. So, it was decided that the cyclist should drive on the road with asphalt, and the vehicle on the road with the clinkers, since the cyclist made the recordings. For a new location it is therefore important that the road used by the cyclist is made of asphalt.

Smaller gap sizes

The planned gap sizes were 2 seconds and 4 seconds. However, during the recordings and when testing the videos, the 4 second gap did not feel as a critical gap. No risk was perceived during the pilot and everybody would cross without any hesitation. Since a scenario in which every participant would act exactly the same, will not give any information, this scenario was not used, and a smaller gap size was chosen. A gap of 0.5 seconds was used, and this resulted in a variety of answers from the participants, so this gap size is preferred for the experiment.

Vehicle colour

The black colour of the vehicle did not attract attention against the dark background. For the visibility it would be better to use a different colour vehicle.

Stopping point based on braking distance

The point where the videos were stopped was chosen to represent a distance at which the cyclist would still be able to stop. This point was 2 seconds before the cyclist would enter the crossing, because this was the measured time it took the cyclist to come to a complete stop. A point in the video was chosen to represent this and all the videos were cut at this same point.

Hereafter, a formula and the coefficient of friction for bicycles were found, so it would be better to use the calculated braking distance, than the braking distance of this specific bike and this specific cyclist. For the experiment it is useful to mark this point on the road, so the videos can all be cut at this specific point.

Rotating order of videos

It turned out helpful to rotate the order in which the videos were shown to the participants. The vehicle was more often not seen in the first video, than in the other videos. By rotating the order this did not negatively affect the results of one scenario.

When testing the cycling speed, it could be seen that participants were influenced by answers given by previous participants. They were seen discussing over their conflicting or agreed opinion, when they were shown the videos. Hereafter, when participants in the same room were shown the videos different versions were used and they were informed about this, so that they would not be influenced by others.

No buildings around crossing

In one scenario a lot of participants missed the vehicle. In this scenario the vehicle was the furthest away from all scenarios, because the speed was higher, and the gap was bigger. Furthermore, the vehicle was only visible for a short amount of time, because a building was blocking the view. The results showed that 1.33 seconds was too short for the participants to notice the vehicle. Therefore, new requirements are set for the experiment. There should be free sight in the direction of the vehicle and the vehicle should be visible for a longer amount of time.

4.4 Implemented changes based on pilot 1&2

After the first and second pilot study a few suggestions for improvements were made. With these improvements in mind, new recordings were made and edited. Those general improvements and the new recordings will be described.

Automated vehicle

To compare the CV and AV, an AV needed to be chosen. Since AVs are not commonly used yet, it is difficult to get an AV to use in this research. It was planned to use the WEpod, an Easymile EZ10, to represent an AV. However, that vehicle was moved to Germany and the availability was limited and subject to changes. Furthermore, the speed of the WEpod was limited to 15 km/h and with a cycling speed of 15 km/h as well this might not feel as a risk.

To be able to fit the research in the provided time and to increase the speed it was chosen to create the AV via video editing. This decision made it also easier to create comparable scenarios, since less scenarios had to be recorded and the recordings of the CV could be used. The AV had the same size and speed as the CV because it was placed over the CV and tracked the exact movements of it. The software used to edit this was Adobe Photoshop, Adobe Premiere Pro and Adobe after effects.

New location

A new location was chosen, were the vehicle would be visible from far away. A location without any buildings blocking the view was found in Emmen, on the crossing between the Verlengde Herendijk and the Tweede Boerwijk. This crossing was also free of any priority markings and consisted of a way of asphalt, were the cyclist would be able to cycle steady. Furthermore, the road was quiet with other traffic, so it was possible to make recordings without other traffic driving through the screen. It was necessary to avoid other traffic interfering, to make sure the vehicle and cyclist could drive in a safe way.

New vehicle

Since the black vehicle, did not stood out enough, a new colour vehicle was needed. A colour that would make the vehicle visible from further away. To choose a new colour, some research has been done.

The most visible colour to the human eye is a bright green (Wilson, 2017). It is a mixture of 50% green and 50% yellow. Unfortunately, this is not a popular colour for vehicles, and it was not possible to find a car in this colour. Furthermore, since the location is surrounded by agriculture, this colour will not stand out against the background. Therefore, a complementary colour might be more efficient.

A vehicle that is visible will be noticed better by other road users and might be involved in crashes less often. When looking at crash statistics, it was found that vehicle colour was of influence on the safety (Newstead & D'Elia, 2010). When correcting for model and type of car, a statistical difference could be seen for some colours. Compared to white, there was a statistically significant increase in crash risks for the colours red, silver, blue, green and grey. Some colours had a lower crash risk than white, such as orange, mauve and fawn, but these differences were not statistically significant. Therefore, white could be seen as one of the safest car colours.

However, the colour self does not increase safety, but how much it stands out in the background. Which can be either the environment or other cars (Newstead & D'Elia, 2010). Furthermore, the safety of vehicle colours cannot be added to the effect of the colour alone. Drivers preferences for a car colour play a role as well (Andrews, Nieuwenhuis, & Ewing, 2006). Therefore, it is not possible to rate the safety of a car colour without involving the drivers' characteristics of the drivers who choose that colour.

The chosen vehicle colour would not only be used for the vehicle that would be recorded, but for the AV as well, to make the vehicles the most comparable. Since the most known AVs are white (Google Firefly, Waymo Chrysler), or black (Uber), these colours are associated with AVs.

Since the environment of the location is mostly agriculture and dark colours, a light colour would most stand out. Also, it was reported to be the colour with the lowest crash risk, and the colour is often used for AVs. Therefore, a white vehicle is chosen for the experiment.

The white vehicle that was used in the recordings was a BMW 5-serie. This vehicle was chosen because of its availability for recordings and because it was free to use. It was also free of stickers or advertisement, that could distract the attention. Furthermore, it was comparable in size to the AV.

Stopping point

The stopping point of the videos is chosen at a point where participants were still able to brake and stop before the vehicle would hit them. To determine this point the average braking distance of a bicycle is calculated. The formula for the breaking distance is:

$$S = \frac{V^2}{2A}$$

S= Breaking distance
V= Speed
A= braking deceleration

The speed of the bike is 15 km/h in the experiment and the braking deceleration is 2.6 m/s² for firm braking on a bicycle (CROW kennisbank, 2018). This gives a breaking distance of 3.34 meters. When the bike was 3.34 meters away of the crossing, the video was stopped, and the question showed on the screen.

Scenarios

Four different scenarios have been recorded, in which the vehicle speed and gap size were variated, as shown in Table 4. The two other variables (vehicles and priority) were created via video editing. Video editing was chosen over recording more scenarios, to be able to make consistent scenarios. It would have been difficult to create eight or sixteen comparable scenarios, were the weather and amount of light was the same and the gap sizes were equal. Every scenario is repeated five times or over to make sure the best scenario, with the correct gap size, could be selected.

Table 4 Different scenarios recorded

	20 km/h	30 km/h
0.5 seconds gap	Scenario 1	Scenario 3
2 seconds gap	Scenario 2	Scenario 4

4.5 Pilot 3: Different AVs and priority switches

To make a choice for the AV that should be used in the experiment, a small pilot is performed with some participants. In this pilot the procedure of the experiment and the recordings were also tested, even as two ways of changing priority. The pilot is explained, and the results are reported as well. Finally, the adjustments for the experiment will be described and the experiment procedure will be shown.

Different AVs

To represent an AV a specific vehicle had to be chosen. It was important that there were clear pictures of this vehicle, which could be used. To improve the realism of the AV, only pictures of vehicles were used, and sketched of hypothetical vehicles were excluded. The colour of the vehicle could not be black, since this proved to be unclear in the videos, so the Uber vehicles were excluded. The most known AV that is already driving around and has made the most kilometres on the public road are the vehicles of Waymo (former Google self-driving car project) (Waymo, 2019). Their prototype “Firefly” is a small vehicle, that clearly stands out between other vehicles. Their current vehicle is an adapted

Fiat Chrysler Pacifica Hybrid, were sensors and a camera can be seen on the roof. The vehicles can be seen in Figure 6. Both vehicles only come in white and are thus clearly visible in the environment.

Figure 6 Google Firefly (left) and Waymo Fiat-Chrysler (right) (Kerr, 2017)

To determine which of these vehicles would be best to use a small pilot has been performed.

Different priority markings

Changing the priority between vehicle and cyclist was possible in two different ways. The vehicle could appear from the left (priority to the cyclist) or from the right (priority to the vehicle), since priority to the right applies. It was also possible to switch priority by using priority markings. A scenario without indications and an approaching vehicle from the left would give priority to the cyclist, and a scenario with indications that showed the other road was a priority road, would give priority to the vehicle. Both ways could be applied in post-production, so it was not necessary to make extra recordings. To determine which of these ways worked out best, both were included in the pilot.

Pilot procedure

The pilot was done with six participants, who fitted in the intended participant profile. They were aged 25-28 years and all students or just graduated. Four females and two males took part in this pilot. All participants were shown two series of 12 videos. The first 12 videos showed three different vehicles, the CV, the google Firefly and the Waymo Fiat-Chrysler. All these vehicles appeared in all four scenarios with variating speed and gap size, as shown in Table 5. The vehicles came all from the left in the first session, so the cyclist had priority.

Table 5 Pilot scenarios first session

Variables	**Levels**
Vehicle	Conventional vehicle
	Google Firefly
	Waymo Fiat-Chrysler
Scenario	20 km/h – 0.5 sec.
	20 km/h – 2 sec.
	30 km/h – 0.5 sec.
	30 km/h – 2 sec.

In the second session the priority was switched to the vehicle. In half of the videos this was done by mirroring the scenario, so the vehicle would appear from the right side. In the other six videos, priority markings were added to show that the vehicle had priority. To limit the number of different videos, this was only done for the 2 scenarios were the vehicle was driving 20 km/h. These scenarios can be seen in Table 6.

Table 6 Pilot scenarios second session

Variables	**Levels**
Vehicle	Conventional vehicle
	Google Firefly
	Waymo Fiat-Chrysler
Scenario	20 km/h – 0.5 sec.
	20 km/h – 2 sec.
Priority switch	Mirrored
	Priority markings

After six videos the participants were asked whether they wanted to take a break or continue, to make sure they did not suffer from motion sickness, but all participants chose to continue the experiment. Between the two sessions there was a break of a few minutes for every participant.

Results AVs

One participant did not see a vehicle in all scenarios in the first session, so besides the choices continue cycling, speed up and slow down, the option no car is included. For every vehicle type, the total amount of crossing decisions is calculated and shown in Figure 7. It could be seen that the convention vehicle (CV) and the Waymo Fiat-Chrysler (WC) show comparable results. The Google Firefly (FF) has a different impact on the crossing behaviour and participants are seen speeding up or slowing down more compared to the other vehicles.

Participants indicated that the WC looked realistic and comparable to the CV in size and appearance. However, participants did not see that it was an AV. Some saw it as a police car due to the camera on the roof, which they interpret as a siren. Others thought of a scan car with automated number plate recognition on the roof.

The FF did not look realistic to the participants, and was found bigger than the CV. This was due to the fact that the CV was oblong, and the FF was as high as it was wide. Therefore, it had to be a bit higher to match the length that was necessary to cover up the whole CV. The FF was seen as a toy or electric vehicle and was reported to be clearly fake.

It was found important that the AV should look realistic, so that participants would not act differently because the vehicle was edited. Therefore, it was chosen to use the WC in the experiment. A big concern was whether participants would notice that the vehicle was an AV. To be able to answer the research questions, it is important that at least a share of the participants did notice that the vehicle was an AV. Since there were only 16 scenarios, the total experiment time was less than six minutes, it was possible to extend the experiment. Therefore, it was decided to repeat the whole experiment twice for every participant.

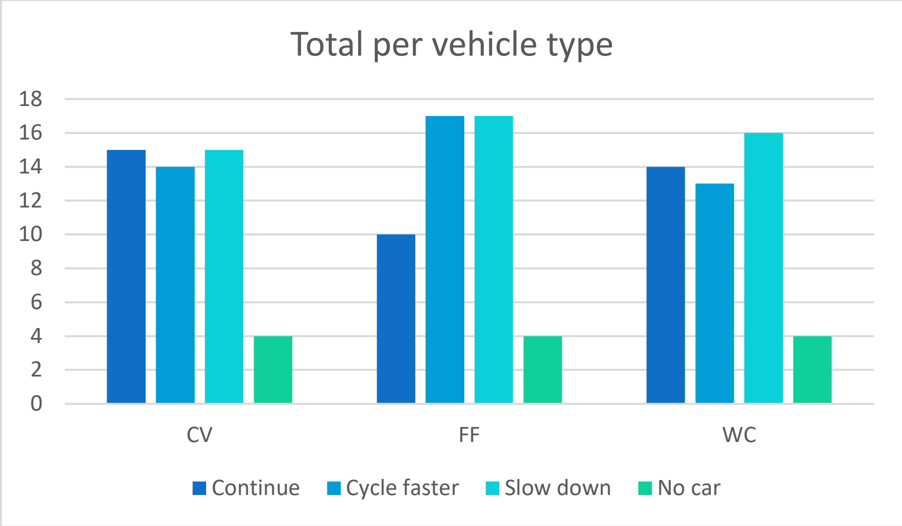

Figure 7 Crossing decisions per vehicle type

In the first session they were not informed about the different vehicles and before the second session they were told which vehicle a CV was, and which an AV. This made it possible to make sure there would be a data set were the participants knew they were interacting with an AV, and a data set where they were not influenced with any information. It also made it possible to compare those with one another.

Results priority switch

The different ways of switching priority from the second session, were compared to the results of the first session, where the cyclist had priority. The combined results of all the scenarios and vehicles can be seen in Figure 8. The priority markings had almost no effect, except one participant missed all the vehicles in the first session and therefore scored 6 times "no car". However, there was a large effect seen when the recording was mirrored, and the vehicle appeared from the right.

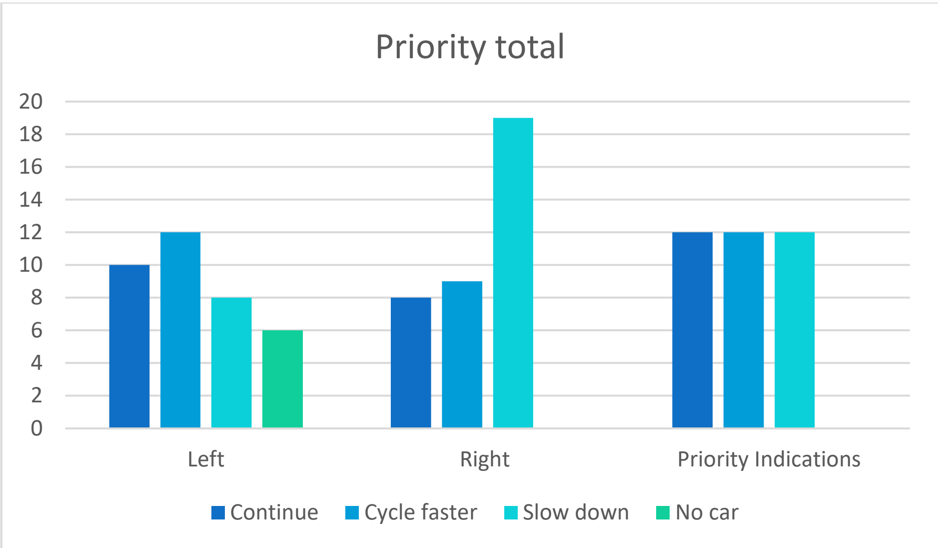

Figure 8 Results priority switch for all scenarios

Four out of six participants indicated that they had not seen the priority markings when asked what they thought about the differences in videos. When the videos were showed to them on a laptop afterwards, they were surprised to see the signs. The two who did see signs indicated that it influenced their decision. It was a concern that participants might found it irritating to search for the vehicle, when the vehicle could appear either left or right, or that participants would miss the vehicle. Interestingly, participants indicated that they found it more interesting and eventful that they did not know where to look. It is decided to use the mirrored scenarios, since this was clear for all the participants and did not show disadvantages.

Results overall experiment

In this pilot the videos and procedures were checked as well. All the scenarios showed expected results, and there were no surprises. After every six videos, there was time for a break, although none of the participants took a break or thought it was necessary. Afterwards some indicated that 12 videos after one another was a bit much, but others were fine with it. To make sure all the participants are satisfied in the experiment, there will be breaks after every set of eight videos.

There were no participants that felt sick during or after the pilot, although one person indicated he was a bit dizzy. For him some extra time was taken during the videos and that was fine. It was noticed that almost all participants were holding the VR glasses in their hands during the videos. The glasses were a bit heavy and leaned on the nose a bit. It was considered to put people on an actual bike, to make their experience even more realistic. Since participants would not see the bike, because of the VR glasses and would not hold the steer, since they were holding the glasses, this plan was skipped. By skipping the bike, it was also simpler to perform the experiment on different locations and this made it easier for people to participate. However, participants were asked to stand up during the experiment, since this resulted in a more active appearance and participants were able to watch around more easily.

In the three crossing options "let the vehicle cross first" is changed for "slow down". This is shorter, and quicker to read, when the question and question options appear on the screen for the participant. Before the videos are shown to the participants the question options are discussed and they are told that slow down means that they will let the vehicle cross first. When they choose to continue cycling or speed up, it means they will cross before the vehicle.

4.6 Final experiment

The final experiment consisted of all the methods described before and their improvements. The experiment consisted of 16 different scenarios. The variables and their levels can be seen in Table 7. Furthermore, the procedure and questionnaires that are used during the experiment will be explained.

Table 7 Experiment variables

Variables	**Levels**
Vehicle	CV
	AV (Waymo Fiat-Chrysler)
Speed	20 km/h
	30 km/h
Gap size	0.5 seconds
	2 seconds
Priority	Vehicle from the left
	Vehicle from the right (mirrored)

Procedure and questionnaires

The people participating in this experiment all followed a similar procedure. First, they were welcomed, informed on the procedures and asked to sign an informed consent. Because motion sickness could be experienced when using VR, participants were extra informed about these symptoms, so they were aware of this and able to tell if it was happening. They were asked to fill in a questionnaire to determine if the participants are a good representation of the population. This included some standard questions, such as age, education and occupation. Furthermore, some questions about the amount of risk-taking behaviour were asked, to see if this influenced their decisions. Since no useful cyclists behaviour questionnaires could be found, an adapted version of the Pedestrian behaviour scale was used (Granié, Pannetier, & Guého, 2013).

Furthermore, a MISC scale was filled in to determine their score previous to the experiment. This took around 10 minutes in total. Thereafter, the participants were asked to stand up and the VR glasses were put on. At first, they saw one test video, to determine if the settings of the glasses were correct for the participant and to let them get used to the VR environment.

In total 32 videos were shown to the participant, in which they were riding towards an intersection where a vehicle is coming from the left or right. Each video showed a different scenario, after which a question popped up on the screen whether they would cross the road or not. The participants answered verbally if they would like to continue cycling, cycle faster or slow down. Each video took around 10 seconds to watch and 5 seconds to answer. After each block of eight videos there was a short break in which the VR glasses could be put off and the participant could sit down. In each brake the MISC questionnaire was filled in once more to monitor the scores and determine if the participant could go on with the experiment. After two blocks of eight scenarios the participant were asked to fill in some questions about the experience so far and what they noticed about the vehicles. Hereafter, it was asked whether they were thinking about AVs and how much they knew about AVs. The level of trust participants have in AV technology was conceived by a survey, using an revised version of the questions used by (Payre, Cestac, & Delhomme, 2016) (Nuñez Velasco et al., 2018). Thereafter, they were informed that there were two different vehicles and that one is automated. The second half of the experiment was answered after this information was given.

After all the videos were watched there will be a debriefing in which all the remaining questions of the participant will be answered, and a final questionnaire will be filled in to determine the immersiveness of the VR environment. The Presence questionnaire was used for this (Jerome, 2009). In total the experiment took around 30 minutes. The complete questionnaire can be found in Appendix H: Complete survey.

The results of the experiment will be discussed in chapter 5, the analysis.

5. Analysis & results

In this chapter the data gained with the experiment will be analysed and the results will be presented. The data set contained in total 1600 crossing decisions, made by 50 participants. Every participant has seen 32 crossing scenarios and had the option to choose either continue cycling, cycle faster or slow down.

To get an idea of the answers given by the participants, the overall crossing decisions are first presented. The option 'continue cycling' was the most popular and it was chosen 42.1% of the time. Cycle faster and slow down were almost equally represented with 29.2% and 28.7%, as shown in Figure 9. In every scenario, all possible crossing options were used at least once by the participants. Furthermore, all participants used every crossing option at least once.

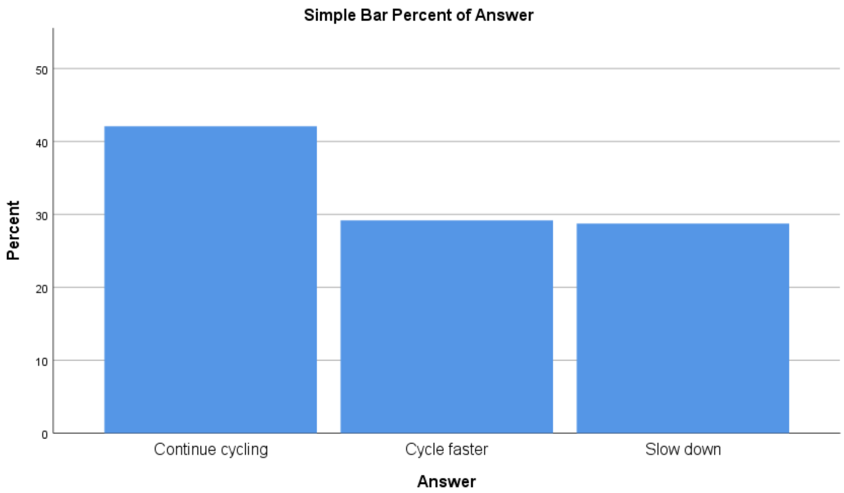

Figure 9 Percentage of appearance for every crossing option

In paragraph 5.1 characteristics of all the participants that have taken part in this research are discussed. All the variables that were created are described in 5.2. In 5.3 the model that has been used is presented and described. The variables that were not implemented in the model but were interesting to discuss can be found in 5.4 and in 5.5 the VR environment is discussed.

5.1 Participant characteristics

First the participants that took part in the experiment will be examined, so it is clear what the target group was and what might have influenced their results. 50 participants took part in the experiment and all participants were able to finish it. The characteristics of these participants will be described in this chapter. Their age and occupation will be discussed, even as their gender and the influence of these statistics on their crossing behaviour. For this experiment a homogenous group is chosen to participate, as explained in paragraph 4.1, so the differences are expected to be low.

Gender

All participants identified themselves as either man or woman, so the category "Other/I prefer not to say" is not used and will therefore not be mentioned in this research. 26 Men and 24 women participated, which led to 52% men and 48% women. The answers per gender can be found in Figure 10. Women tend to slow down more often, and males choose more often to continue or cycle faster. However, a Pearson Chi-Square test indicated that this difference is not significant (P=0.143).

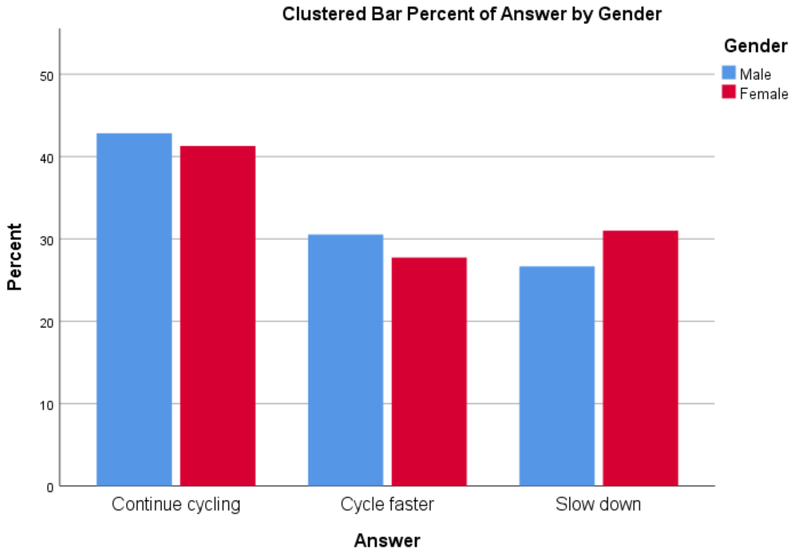

Figure 10 Answers divided by gender

Age

The age of all participants ranged between 19 and 31 years old on the day of the experiment (March 2019). To check if age was of influence on the crossing behaviour, the participants were categorized into three groups. There were only small differences seen between the age groups, as shown in Figure 11. The differences between the groups were too small to be able to draw conclusions and a Pearson Chi-Square test indicated that this difference is not significant (P=0.157).

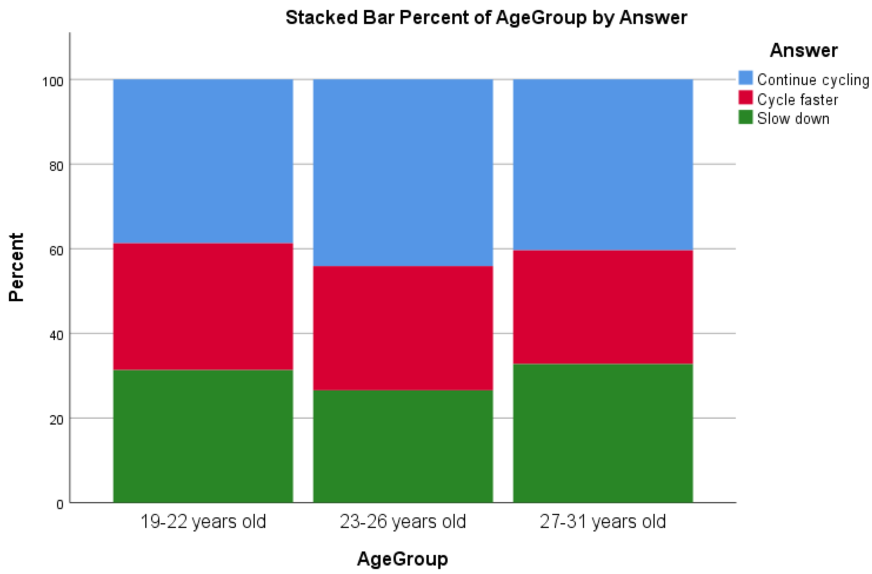

Figure 11 Differences crossing behaviour between age groups

Occupation

Almost all participants were students or recently graduated. In Figure 12 the distribution between occupations is shown. Since the groups were so small, no differences in crossing behaviour based on occupation could be found.

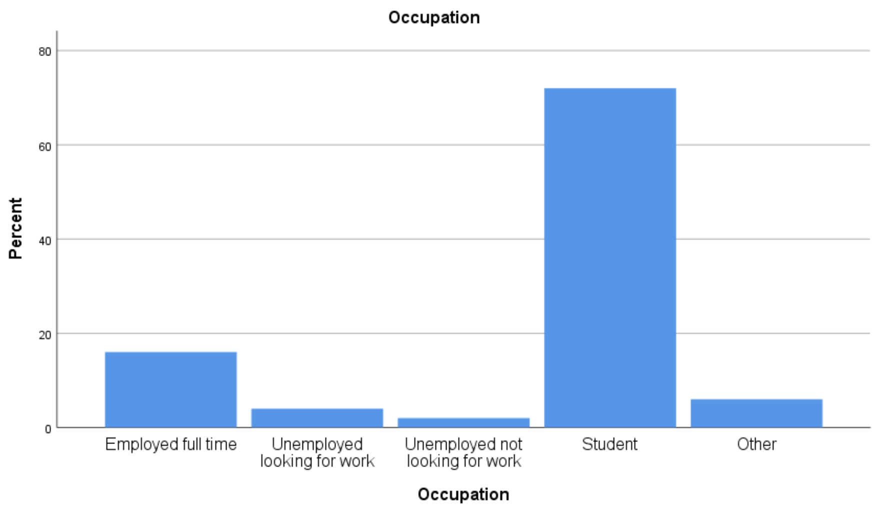

Figure 12 Occupation of the participants

Other characteristics

It was not possible to check differences in nationality, since only 4% of the participants did not originated from the Netherlands. Since only one participant suffered from colour blindness, it was impossible to determine the impact of it on the crossing behaviour as well. However, his answers did not seem to differ from other participants. Furthermore, only 8% of the participants did not have a driver's license, however no difference in crossing behaviour was estimated on the ownership of a license or the amount of time a participant possessed it.

5.2 Created variables

To be able to answer all research questions, some questions from the questionnaires had to be recoded into new variables. It will be described how these variables are constructed.

Risk taking

In the questionnaire 16 questions were asked about risk taking behaviour of the participants. A revised version of the Pedestrian behaviour scale has been used, since there was not a specific cyclists behaviour questionnaire found (Granié et al., 2013). Participants could rate their behaviour on these 16 questions on a scale from 1-5, which were labelled never, rarely, sometimes, often and very often. To get an average risk-taking score per participant their answers have been summed and divided by 16. The distribution of all scores can be seen in Figure 13. The mean score is 2,7 and this number is used to divide the participants in two equal sized groups. The groups were labelled: "low risk takers" and "high risk takers". When the groups were split an extra time, the differences between the groups became too small to see any differences, therefore only two groups were created.

When the crossing behaviour of both groups is compared, as in Figure 14, a clear difference can be seen. The "high risk takers" choose to continue cycling more often, and do not choose the option slow down as much as "low risk takers" do. These results are as expected, since "low risk takers" will probably choose to let the vehicle cross first and slow down earlier and will not take the risk to cross before the vehicle if they think it is not entirely safe.

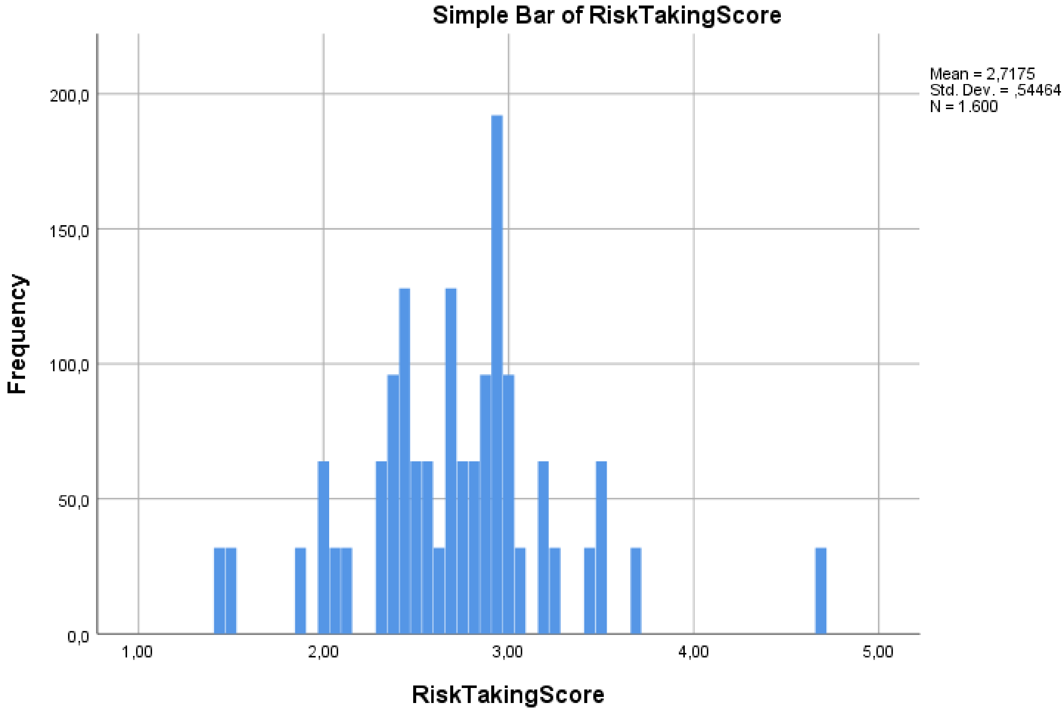

Figure 13 Distribution risk taking score of all participants

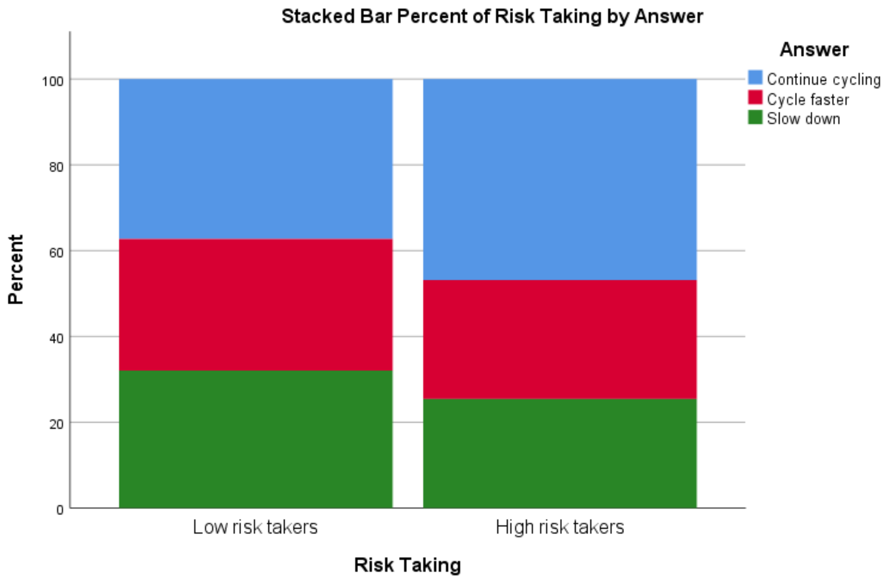

Figure 14 Crossing decisions of participants divided by risk taking behaviour

Trust in AVs

To see how much participants trusted AVs, they have responded to 11 statements which they scored on how much they agreed with that statement. There were 7 answer options varying from strongly disagree (1) to strongly agree (7). The average score was 4.66, which is in between of "neither agree nor disagree" and "somewhat agree". Which is comparable to the scores found using the same questionnaire in earlier studies, namely 4.7 and 5.23 (Nuñez Velasco et al., 2018; Payre et al., 2016). In Figure 15 the distribution of all scores can be seen. Based on these scores the participants are sorted into two groups, the group with a score beneath average is labelled "Low trust", the others are in the group "High trust". When split into four groups, the differences between the groups became too small, so only two groups are used.

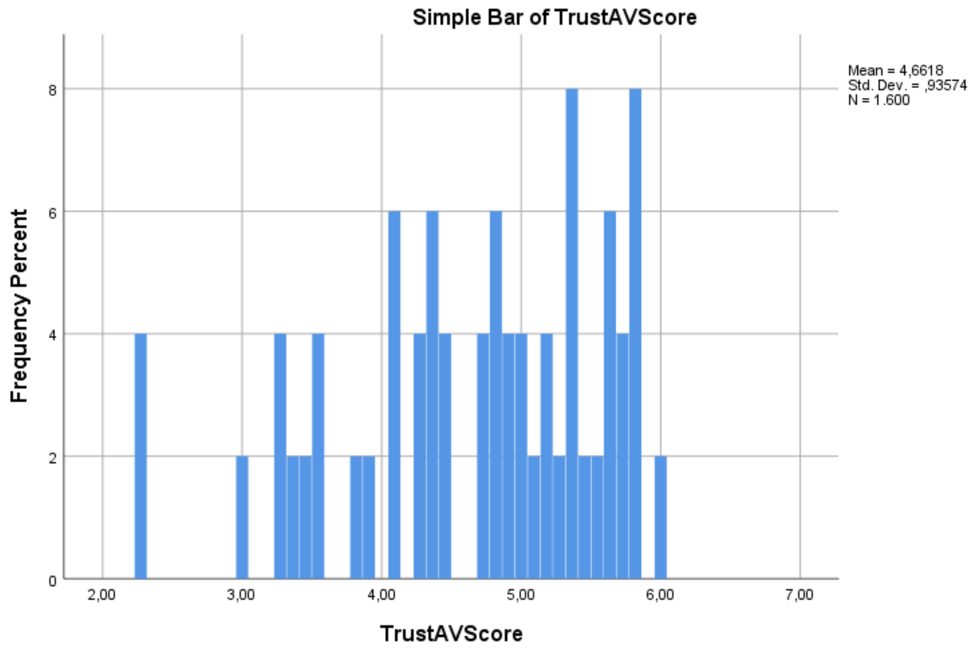

Figure 15 Distribution of trust in AV scores of all participants

When looking at crossing behaviour of the group with low trust in AVs, seen in Figure 16, a difference between CVs and AVs is visible. The ones with low trust in AVs are seen to slow down more in front of AVs than in front of CVs, which could indeed be a sign that they do not trust the AV to cross in front of them. The group with a high trust in AVs reacts almost the same in interaction with an AV as with a CV.

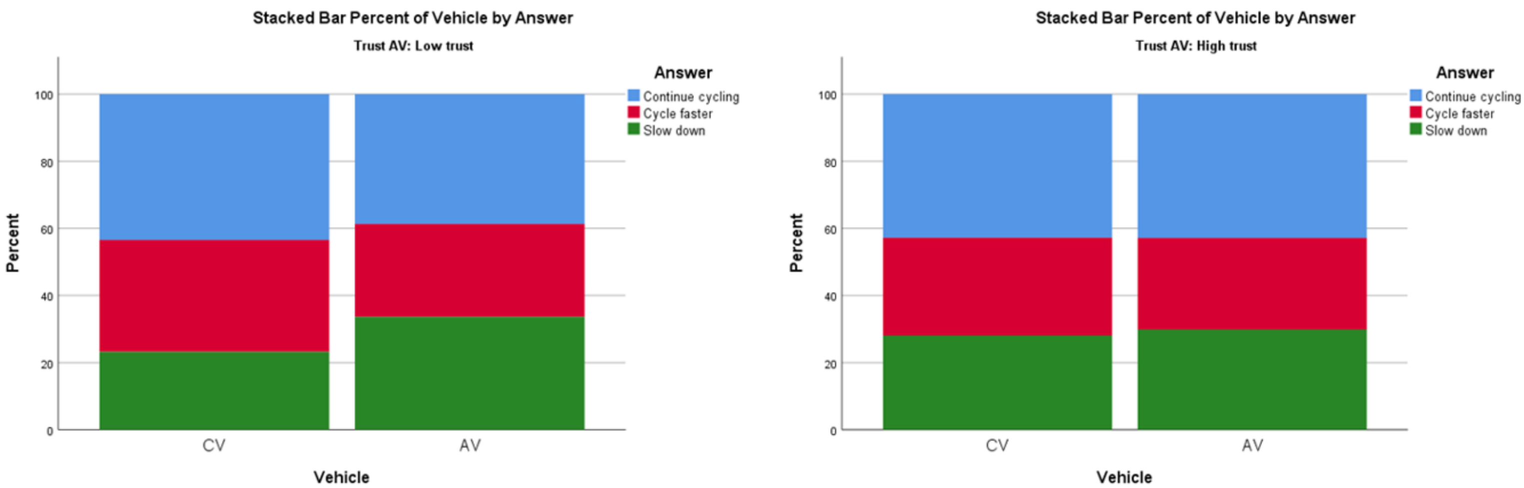

Figure 16 Difference in crossing behaviour between vehicles split based on trust in AVs

The scores of both groups are based on the total amount of scenarios, which includes session 1 and session 2. However, only before session 2 they are told about the different vehicles and that one vehicle is an AV. In session 1 only 14% was thinking about AVs, so a large majority did not notice this difference. However, when the results are split by session, as seen in Figure 17 and Figure 18, it is noticed that the information about the AV almost did not have an effect on the crossing behaviour.

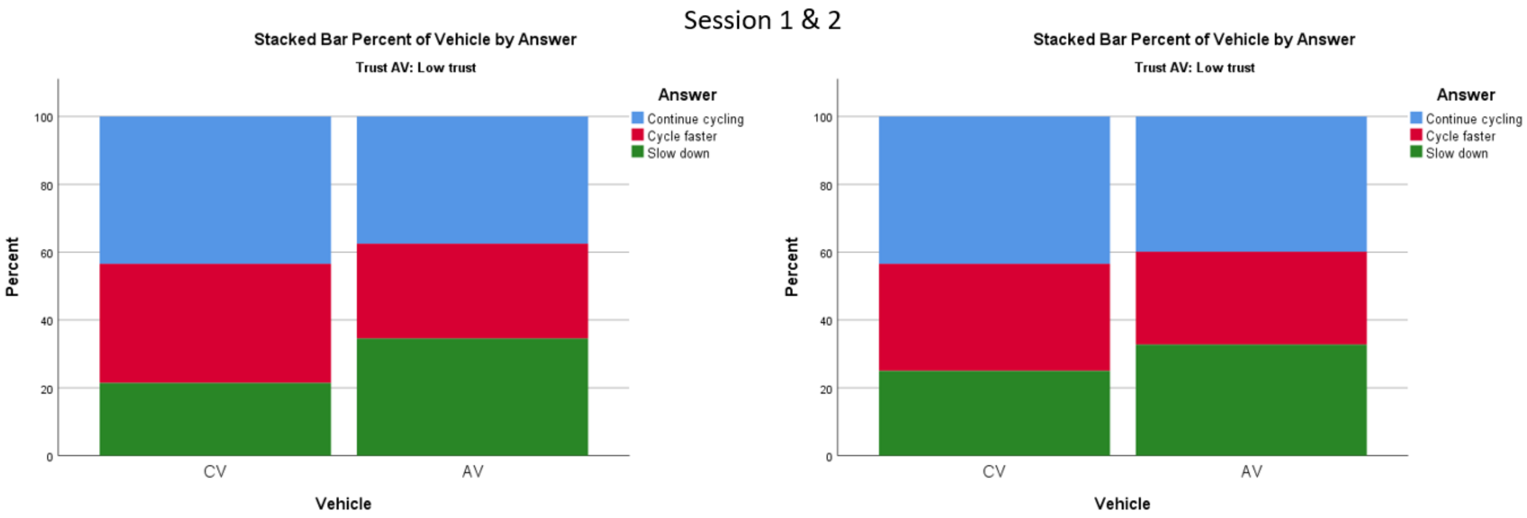

Figure 17 Difference in crossing behaviour between vehicles split by session for "Low trust" group

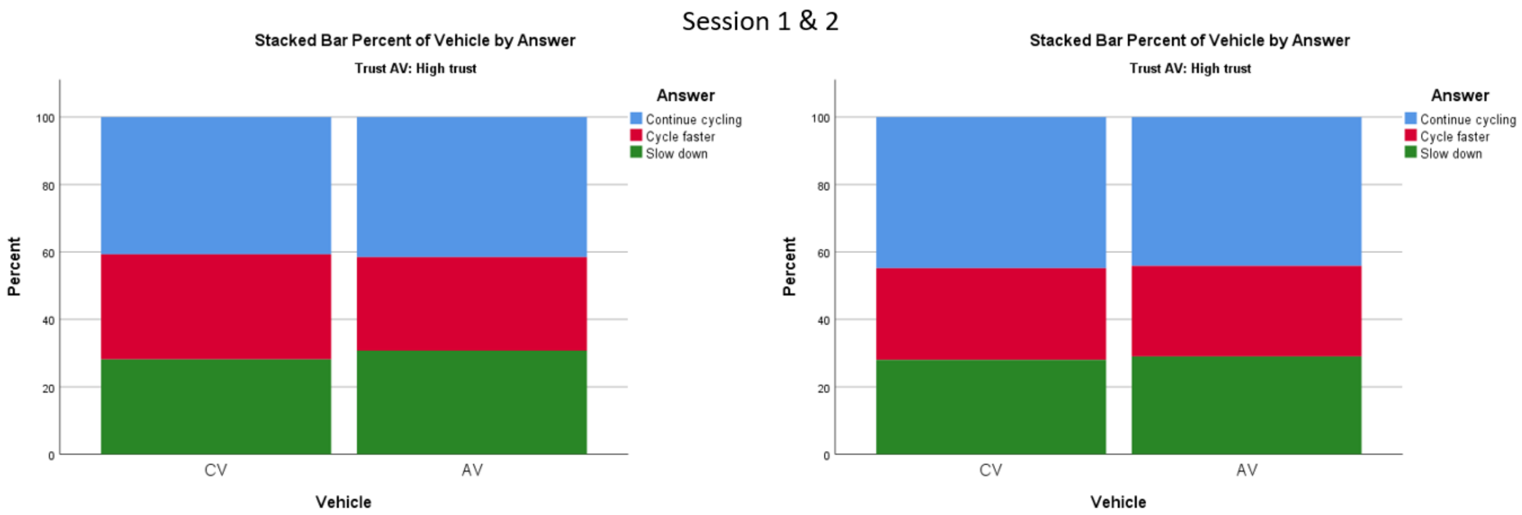

Figure 18 Difference in crossing behaviour between vehicles split by session for "High trust" group

Stated trust

To see how participants stated that they would react on AVs, a new variable labelled "Stated trust" was created. To check how participants thought about AVs compared to CVs they were asked: "Did you feel different about the vehicles once you knew one was automated and the other was not?". If they choose yes or maybe, they were asked in what way they felt different. Based on these answers three categories were created, as can be seen in Table 8. The participants were divided in groups that stated they trusted AVs more than CVs (14%), participants that thought they reacted the same (58%) and participants that trusted AVs less than CVs (28%).

Table 8 Categorizing participants based on stated trust in AVs

Answer did you feel different?	Answer in what way?	Category Stated Trust
Yes	Trusted AV more	More trust in AV
Yes	Trusted AV less	Less trust in AV
Maybe	Trusted AV more	More trust in AV
Maybe	Trusted AV less	Less trust in AV
No		No difference

The crossing behaviour of all groups has been checked for differences between vehicles and between sessions, since at session 1 it was for the majority not clear that one of the vehicles was an AV. The results can be seen in Figure 19.

The group that had more trust in AV, choose less often to slow down in front of an AV than in front of a CV. In session 2 the difference between the vehicles became even bigger. They choose to continue cycling >15% more often and they choose slow down even less than before.

The ones that stated that there was no difference in their behaviour towards AVs and CVs, show indeed almost no difference between the two types of vehicles. In session 1 they choose a bit more to slow down in front of an AV, perhaps because they do notice a difference between the vehicles but are not aware of the specific difference. In session 2 the differences between the vehicles are almost gone.

An increase in slow down can be seen when interacting with an AV, for the group that trusts AVs less than CVs. They feel less comfortable to cross in front of AVs and choose more often to let the AV cross first. In session 2 the differences between the vehicles grow even bigger. At the crossing with an AV they choose to continue 20% less than at a crossing with a CV.

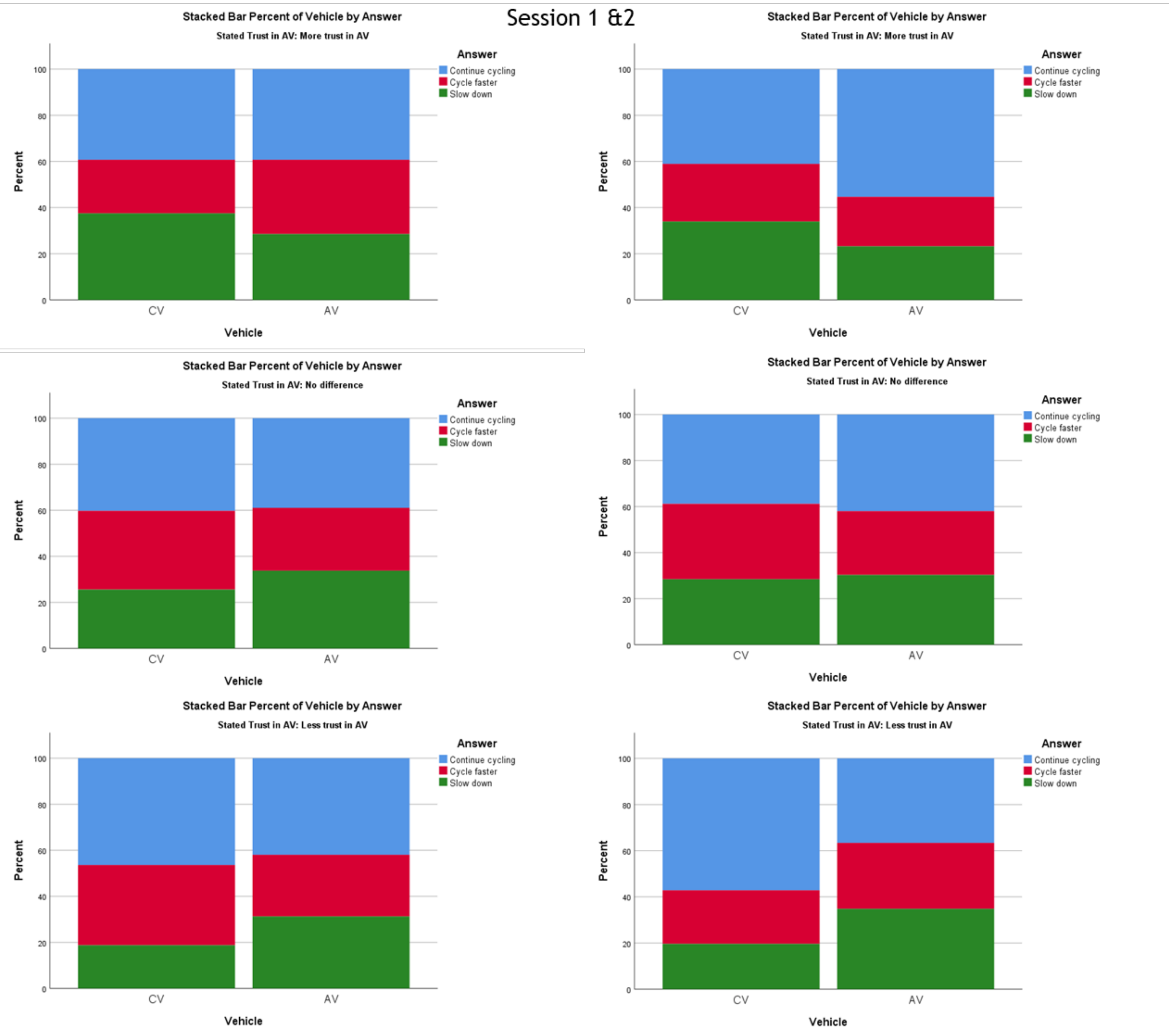

Figure 19 Differences in crossing behaviour between vehicles for all groups based on their stated trust for session 1 (left) and session 2 (right)

Gap distance

One of the rotating variables in the different crossing scenarios, besides vehicle, speed and priority, was gap size. The gap size was measured in time, so in every crossing scenario there was either a gap size of 0.5 seconds or 2 seconds. Since the gap size was dependent on the time, it was also dependent on the speed of the vehicle. People select a gap mostly based on gap distance, and less on the gap in time (Oxley, Ihsen, Fildes, Charlton, & Day, 2005). Since there were two different speeds, there were four different gap sizes when measured in distance. To capture all four distances a new variable is created labelled gap distance. The different distances for all scenarios are shown in Table 9. Gap distance cannot be used together in the model with gap size, because it measures the same difference.

Table 9 Gap distance for all scenarios

		Gap size	
Speed		0.5 seconds	2 seconds
	20 km/h	2.778 meter	11.111 meter
	30 km/h	4.167 meter	16.667 meter

5.3 Model

To analyse which factors influenced participants' crossing decision, a choice model has been created. A choice model tries to predict the decision of a participant based on variables of that situation and the characteristics of the participants. So, for a change in the level of the variables in Table 7, the model would predict a different outcome. Variables were only added to the model if they improved the predictive power of the model and were significant.

Each of the 50 participants watched 32 videos and made just as much crossing decisions. Therefore, the data set consisted of 1600 choices. In three occasions a participant missed the vehicle in the video and could therefore not answer, these choices were eliminated, and the total data set contained 1597 decisions.

However, these 1597 choices cannot be seen as individual choices, since the answers given by the same participant in different scenarios are correlated, because every participant has their own preferences (Lund Research Ltd, 2018). Therefore, a mixed model with repeated measures is used, which accounts for multiple responses per participant. To include individual differences, a random intercept was added to the model. An unstructured covariance matrix has been used for the model, since the error structure was unknown (Kincaid, 2005; Singer, 1998).

The mixed model with repeated measures was made in SPSS, a software package for statistical analysis. The results of the model can be found in Table 13. The participants were given three options in the experiment: *continue cycling*, *cycle faster* and *slow down*. The model can only compare 2 answers to each other, so both *slow down* and *cycle faster* are being compared to *continue cycling*.

The crossing decision is based on multiple variables, so the model also tries to gather all the important variables. The value of these variables represents their impact on the outcome, if the value is larger, the effect of this variable on the outcome is larger as well. Negative values show that *continue cycling* was chosen more often and positive values indicate that *slow down* or *cycle faster* were more popular. For every variable one of the levels is set to 0, as this is the reference level.

For example, the value -0.245 of CV (at *slow down)* indicates that participants slowed down less in front of a CV instead of an AV compared to *continue cycling*.

First the model characteristics will be presented, to see the performance of the model. Thereafter, a covariance check is shown, to see if all variables can be combined in the model. Then all variables included in the model are discussed separately; vehicle, gap distance, priority, risk taking, stated trust and the interaction variable vehicle*stated trust. Furthermore, the influence of the variable "session" is examined.

Model characteristics

The mixed model tries to predict the outcome of the choice the participants make. The predicted outcome is based on the variables that are used for that specific crossing decision, such as vehicle, gap distance and priority, and personal characteristics like risk taking and stated trust. The predicted outcomes were compared to the real answers of the participants, to see what the predictive power of the model is. The final model was able to predict 63.3% of these crossing decisions correct, as seen in Table 10.

Table 10 Model summary

Model summary	**Value**
Classification Overall Percent Correct	63.3%
Akaike Corrected	13118.350
Bayesian	13129.067
2 Log likelihood	13114.343

Covariance

To make sure the used variables were not interfering with each other, a covariance check has been done. This check is done before the model was made, to prevent variables being in- or excluded for wrong reasons. It is possible for multiple variables to have a high covariance with each other. This could be an indication that both variables predict an identical effect. When two variables explain the same effect, they cannot be put together in one model.

Gap distance has a strong covariance with gap size, as expected, as can be seen in Table 11. Gap distance is made out of the gap size and they can therefore not be used together. Speed also shows a high covariance with gap distance, which is logical since gap distance was created to show the difference in speed in the gap sizes. So, gap distance will not be used together with speed or gap size.

Table 11 Covariance gap distance with speed and gap size

		Speed	**Gap size**
Gap distance	Pearson correlation	0.447**	0.894**
	Covariance	0.250	0.500

** Correlation is significant at the 0.01 level (2-tailed)

Stated trust has an interaction with risk taking and trust in AVs. The covariance with risk taking is very low, as seen in Table 12, so this will not cause any problems. The covariance of stated trust and trust in AVs is somewhat higher, although it is still within margins, so it is still possible to use both together in a model.

Table 12 Covariance stated trust with risk taking and trust in AVs

		Risk taking	**Trust in AVs**
Stated trust	Pearson correlation	-0.055*	-0.154**
	Covariance	-0.020	-0.055

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

Table 13 Fixed coefficients of final mixed model

Answer	Model Term		Coefficient	Std. Error	t	Sig.
Slow down	Intercept		-1.128	.3702	-3.047	.002
	Vehicle	CV	-.245	.2011	-1.216	.224
		AV	0^b	.	.	.
	GapDistance	2.778 m	2.806	.2426	11.567	.000
		4.167 m	2.865	.2398	11.947	.000
		11.111 m	.130	.2529	.514	.607
		16.667 m	0^b	.	.	.
	Priority	Priority to cyclist	-2.425	.1693	-14.324	.000
		Priority to vehicle	0^b	.	.	.
	RiskTaking	Low risk takers	.847	.3895	2.175	.030
		High risk takers	0^b	.	.	.
	StatedTrust	More trust in AV	-.457	.6124	-.746	.456
		Less trust in AV	-.104	.4709	-.220	.826
		No difference	0^b	.	.	.
	[Vehicle]*[StatedTrust]	CV * More trust in AVs	1.031	.4499	2.292	.022
		CV * Less trust in AVs	-1.046	.3604	-2.902	.004
		CV * No difference	0^b	.	.	.
		AV * More trust in AVs	0^b	.	.	.
		AV * Less trust in AVs	0^b	.	.	.
		AV * No difference	0^b	.	.	.
Cycle faster	Intercept		-.278	.2646	-1.051	.293
	Vehicle	CV	.211	.1714	1.231	.219
		AV	0^b	.	.	.
	GapDistance	2.778 m	1.079	.1863	5.793	.000
		4.167 m	.412	.1954	2.108	.035
		11.111 m	.040	.1676	.241	.810
		16.667 m	0^b	.	.	.
	Priority	Priority to cyclist	-.985	.1347	-7.310	.000
		Priority to vehicle	0^b	.	.	.
	RiskTaking	Low risk takers	.438	.2737	1.598	.110
		High risk takers	0^b	.	.	.
	StatedTrust	More trust in AV	-.202	.4448	-.453	.650
		Less trust in AV	-.023	.3464	-.065	.948
		No difference	0^b	.	.	.
	[Vehicle]*[StatedTrust]	CV * More trust in AVs	-.070	.3938	-.178	.859
		CV * Less trust in AVs	-.579	.2948	-1.964	.050
		CV * No difference	0^b	.	.	.
		AV * More trust in AVs	0^b	.	.	.
		AV * Less trust in AVs	0^b	.	.	.
		AV * No difference	0^b	.	.	.

b. This coefficient is set to zero because it is redundant.

Risk taking and trust in AVs also show some correlations, as seen in Table 14. The covariance is however low, so it is not a problem to include both variables in the same model.

Table 14 Covariance risk taking and trust in AVs

		Trust in AVs
Risk taking	Pearson correlation	0.122**
	Covariance	0.030

** Correlation is significant at the 0.01 level (2-tailed)

The values presented in Table 13 will be discussed per variable below. The presented values of *slow down* and *cycle faster* are compared to the reference category *continue cycling*. In green and red is indicated if the effect is statistically significant or not, assuming significance at the 0.05 level.

Vehicle

The AV is the reference category and has a value of 0. Slowdown has a small negative coefficient of -.245 compared to continue, when interacting with a CV rather than an AV. When interacting with an AV participants therefore choose a bit more often to slow down. Cycle faster was chosen a bit more often than continue cycling (coefficient of 0.211), when participants interacted with a CV compared to an AV. Thus, when interacting with an AV, participants choose more often to slow down. When they were facing a CV, they choose more often to continue or cycle faster, as shown in Figure 20. However, these effects were not statistically significant.

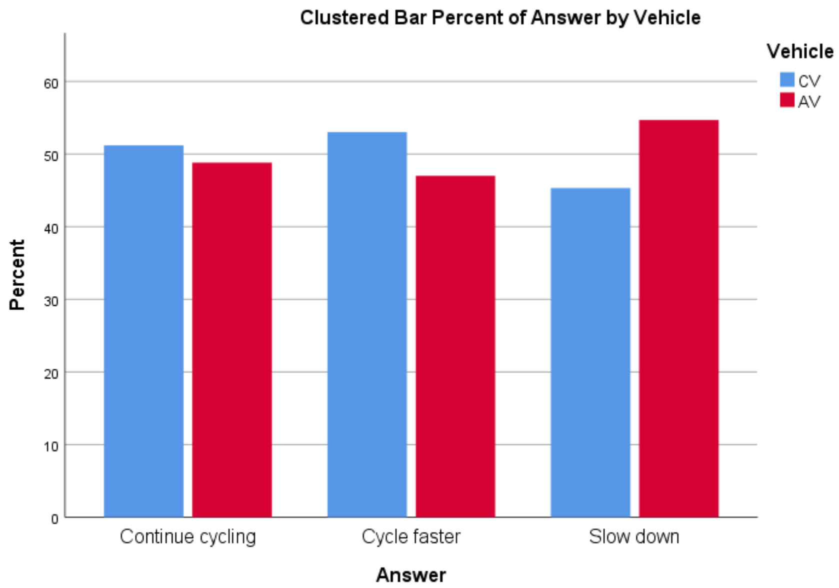

Figure 20 Crossing choices when interacting with CVs or AVs

Gap distance

When the gap distance is smaller, the vehicle is closer to the participant. The largest gap distance, 16.667 meter is the reference category. When the gap distance becomes smaller, more participants are seen to be slowing down than continuing. The smaller the gap gets, the more slowing down is chosen over continuing, however the highest change at slowdown is seen at a gap distance of 4.167, as can be seen in Figure 21. With a gap of only 2.778 meters slowing down has a 2.806 higher change of being chosen, compared to a gap of 16.667 meters. The effect is similar for cycle faster, although the values are somewhat lower. The smaller the gap gets, the higher the changes get that cycle faster is chosen over continue cycling. Cycle faster is chosen with a factor 1.079 more at the smallest gap, then at the highest gap. The two smallest gaps are statistically significant, however the gap distance of 11.111 is not statistically different from the reference gap of 16.667. Since this gap distance is closest to the reference, this is not surprising.

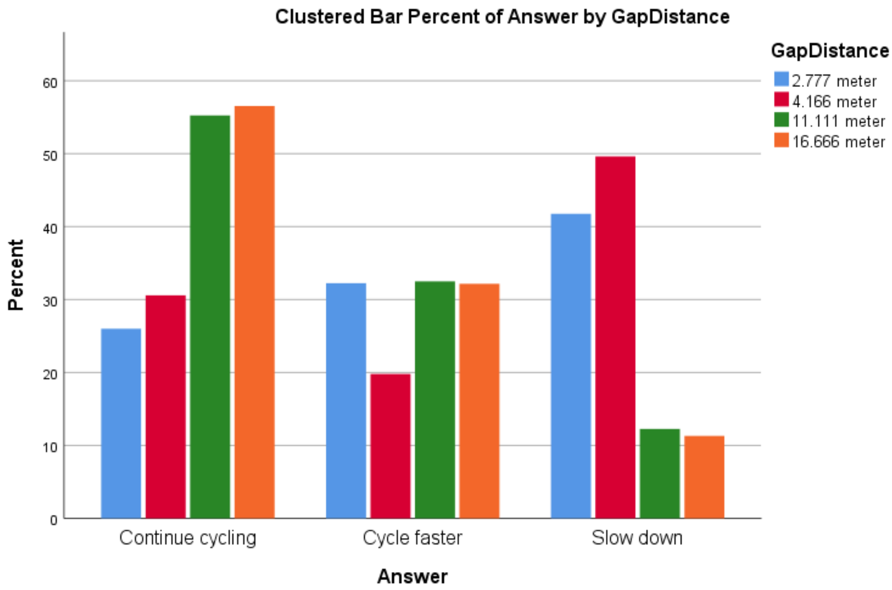

Figure 21 Crossing choices per gap distance

Priority

A switch in priority had a large effect on the crossing behaviour of the participants. Priority to the vehicle was the reference category, in these scenarios the vehicle was approaching from the right. When the cyclist had priority over the vehicle, slowdown had a large negative coefficient of -2.425 and was chosen less often. Cycle faster was also chosen less, although the effect was smaller with a coefficient of -.985. So, participants choose more often to continue, when they had priority, as visualized in Figure 22. Both values were significant and showed a strong reaction of the participants.

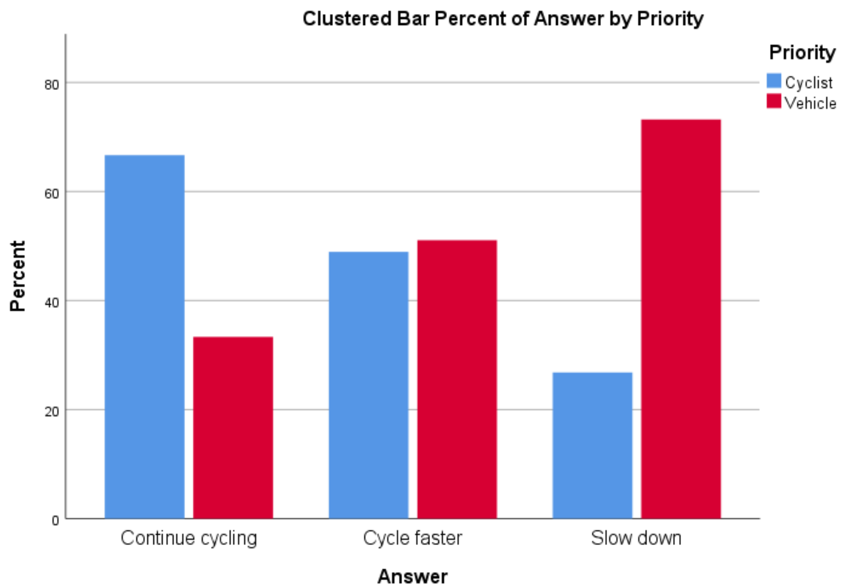

Figure 22 Crossing choices per priority situation

Risk Taking

Participants who are low risk takers, have a higher chance of choosing slow down and cycle faster compared to high risk takers. High risk takers are the reference category and have a value of 0. Slowdown has a coefficient of 0.847 and this means participant who are in the low risk takers group, are more likely to choose slow down than the high-risk takers. Low risk takers also choose more often to cycle faster, than high risk takers, shows the coefficient of 0.438, although for cycle faster this is not a significant effect. The differences can also be perceived in Figure 23.

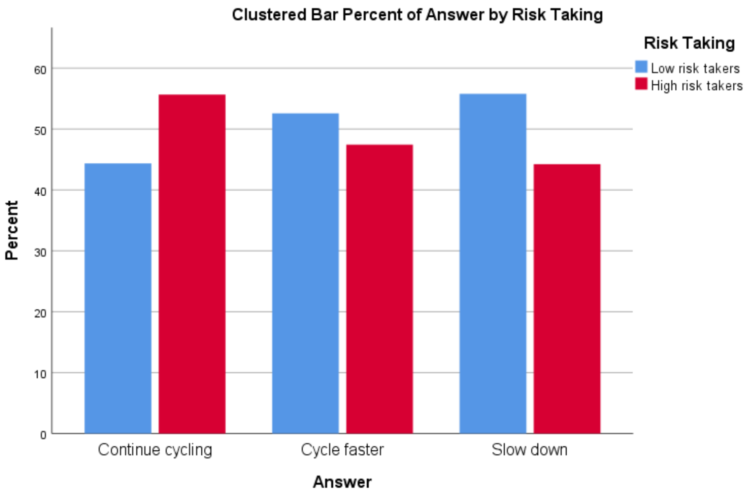

Figure 23 Crossing choices per risk taking category

Stated Trust

The amount of trust participants have in AVs does not have a significant effect on the crossing behaviour of participants in general.

Vehicle * Stated Trust

The effect of stated trust in AVs does influence the crossing behaviour when CVs and AVs are being compared. By including the interaction variable vehicle times stated trust, both the variables vehicle as well as the variable stated trust have to be included in the model as well, even if they are not statistically significant themselves. When AVs are stated to be trusted more than CVs, it is more likely that participants slow down less often in front of AVs than in front of CVs. Since they trust AVs more, they are more comfortable to cross in front of AVs than in front of CVs. Since AVs as well as "No difference in stated trust" are both reference categories, most of the values are set to 0. The values of each category are therefore calculated in Table 15, by summing the three values of vehicle, stated trust and vehicle*stated trust.

Table 15 Calculated values of Vehicle * Stated trust

Vehicle * Stated Trust	**Slow down**	**Cycle faster**
*CV * More trust in AVs*	0.329	-0.061
*CV * Less trust in AVs*	-1.395	-0.391
*CV * No difference*	-0.245	0.211
*AV * More trust in AVs*	-0.457	-0.202
*AV * Less trust in AVs*	-0.104	-0.023
*AV * No difference*	0	0

More trust in AVs

When AVs are trusted more than CVs, and participants are interacting with a CV, an increase in slowing down of 0.329 can be seen. It is logical to see an increase in slowing down behaviour when they are interacting with the vehicle they trust less. When they are interacting with AVs, a decrease in slowing down behaviour of -0.457 can be seen, so they choose to continue more.

The difference in cycle faster and continuing is small for interactions with CVs. For AVs a decrease is seen in the amount of choices for cycle faster of -0.202. So, participants felt safe enough to continue their pace, without hurrying. In Figure 24 these numbers are visualized and the percentages CVs and AVs for each crossing option are shown.

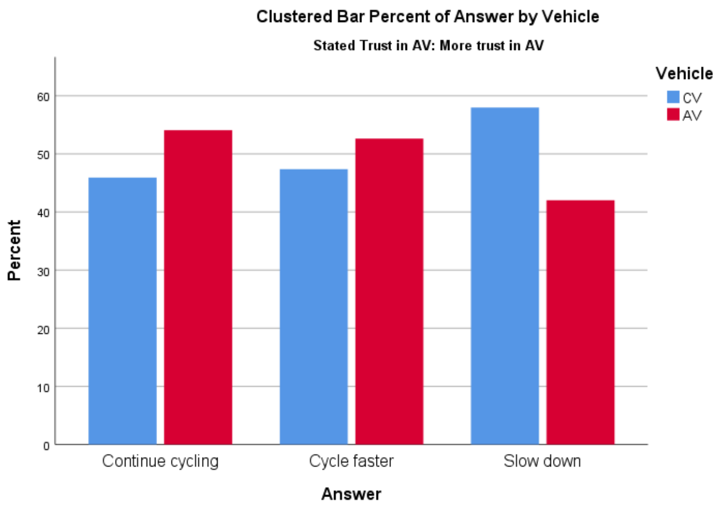

Figure 24 Crossing behaviour of group with more trust in AVs than CVs, when CVs and AVs are compared

Less trust in AVs

When the group with less trust in AVs interacted with CVs, they showed a strong preference of -1.395 to slow down less. They were interacting with the vehicle they trusted more, and thus choose to continue cycling. When they were on the crossing with an AV, they choose to slow down less than continue, although this was only -0.104. A positive value was expected, since they were interacting with a vehicle they trusted less. However, when compared to interacting with a CV, this value is a lot higher. Besides, continue cycling is overall the most chosen answer.

A similar trend can be seen for cycling faster. When interacting with CVs, there is a strong decrease in cycling faster, of -0.391, since they trust CVs and choose to continue. For AVs a really small decrease of -0.023 is seen, so they choose to continue a bit more. Figure 25 shows the differences in the crossing options between vehicles. Since the bars are set to percentages of the total x-as category, the figure shows a large increase in slowing down when interacting with AVs, even though the model displayed a negative value of -0.104. When the amount of choices for each crossing decision are considered, as shown in Figure 26, the decrease of slowing down is visible.

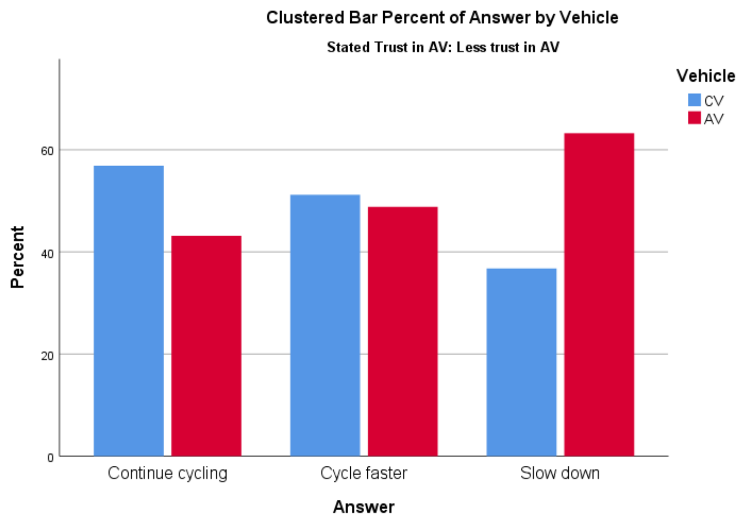

Figure 25 Crossing behaviour of group with less trust in AVs than CVs, when CVs and AVs are compared

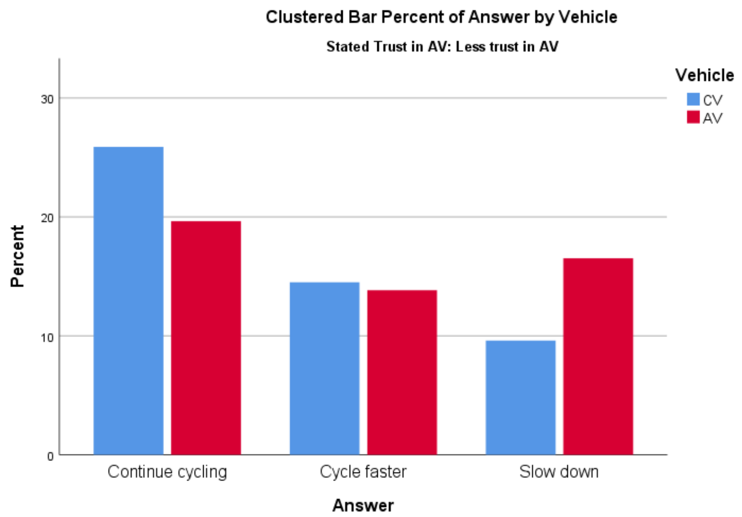

Figure 26 Crossing behaviour of group with less trust in AVs than CVs, when CVs and AVs are compared, showing how often each crossing option has been chosen

No difference between vehicles

The group who said there was no difference in their behaviour was seen slowing down less in front of CVs, which does show a difference. However, their preference to slow down less of -0.245 and choose cycle faster more of 0.211 almost even out each other, so they choose to continue cycling an equal amount of times. "AV * No difference" was set as the reference category, and therefore had a value of 0. In Figure 27 the differences between vehicles for all crossing options are shown.

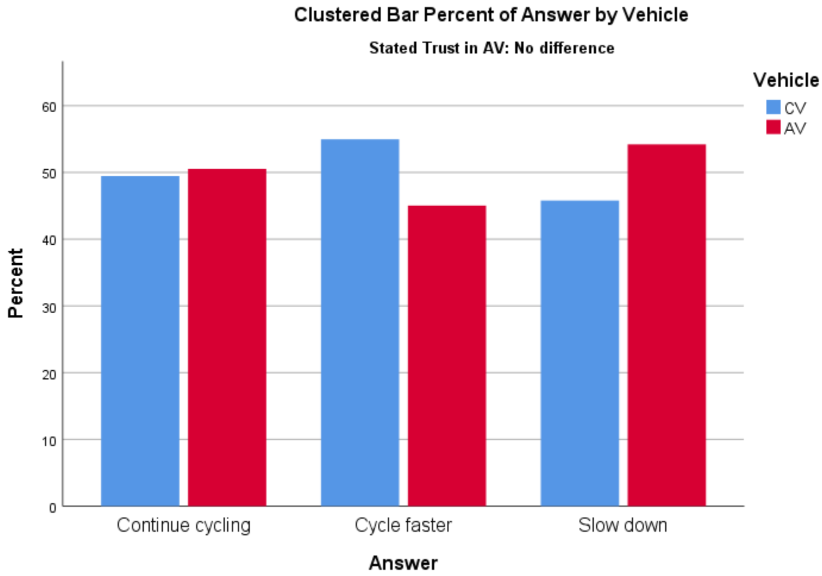

Figure 27 Crossing behaviour of group with no difference in trust between vehicles, when CVs and AVs are compared

Sessions

Halfway through the experiment, the participants were told about the different vehicles. After the first part 75% saw a difference between vehicles, however only 14% thought they saw AVs in the experiment. Since 86% of the participants did not knew they were interacting with AVs in half of the experiment, it is interesting to see if their behaviour changed, when they did know.

Adding session as a variable to the model is difficult, since it influences the interaction effect “vehicle*stated trust”. To analyse the effect of session a three-way variable, “vehicle*stated trust*session”, had to be created and this did not improve the model and was difficult to analyse, so it was not added as a variable in the model. To see which changes occur, two new models have been made, with the same variables as the previous model. One with only the data of session 1 and one model with only the data of session 2. The complete results of these models can be found in Appendix E: Model session 1 and 2 compared.

As seen in Table 16, both models, and especially session 2, were able to predict more choices correct than the overall model, which improved the power of the model. So, these models were better in predicting the choices of the participants. The values for Akaike corrected, Bayesian and 2 log likelihood increased as well in session 2 compared to session 1, which decreased the power of the model a bit. The scores of session 1 and 2 only are hard to compare to the total model, since they consisted of half of the data.

Table 16 Model summaries of the total model and session 1 and 2 only

Model summary	**Total model**	**Session 1 only**	**Session 2 only**
Classification Overall Percent Correct	63.3%	63.4%	65.6%
Akaike Corrected	13118.350	6300.210	6600.738
Bayesian	13129.067	6309.503	6610.079
2 Log likelihood	13114.343	6296.195	6596.768

The largest differences between the models can be seen in “vehicle*stated trust”, which have been calculated in Table 17. Especially the values for interaction with AVs change heavily and the interaction with CVs between cycle faster and continue. In paragraph 5.2, the differences can be seen in bar charts.

When participants have more trust in AVs, and are interacting with an AV, they choose ‘continue cycling’ more in the second session. When they do not trust AVs, they can be seen slowing down and speeding up more, in contact with an AV. The differences between session 1 and 2 are quite big and they even changed directions. When interacting with CVs, participants who trusted AVs less, choose to cycle faster less and continue more. The ones who trusted AVs more and the ones who said there was no difference both also choose to cycle faster less, which is surprising.

Table 17 Values for vehicle*stated trust, model of session 1 and 2 compared

Vehicle * Stated Trust	**Session 1 Slow down**	**Session 1 Cycle faster**	**Session 2 Slow down**	**Session 2 Cycle faster**
*CV * More trust in AVs*	0.308	-0.092	0.384	-0.543
*CV * Less trust in AVs*	-1.291	-0.048	-1.319	-1.263
*CV * No difference*	-0.48	0.163	0.02	-0.275
*AV * More trust in AVs*	-0.14	0.209	-0.712	-0.611
*AV * Less trust in AVs*	-0.39	-0.165	0.315	0.176
*AV * No difference*	0	0	0	0

Overall, the differences between the groups becomes bigger. This is a logical finding, since only a small part knew they were interacting with an AV in session 1.

5.4 Versions

Not all variables are included into the model, since they were not statistically different. However, the variable “version” is worth mentioning since it does show a difference.

Version

A difference in crossing behaviour per version is noticed. In version A participants tend to continue cycling a bit more and in version C they choose slow down more often, as displayed in Figure 28. The participants were assigned to a version in the order of testing. The first participant got version A, the second version B, the third got version C and the forth got version A again and so on. The participants got not assigned to a group based on their characteristics. Since there were 50 participants, version A and B are used 17 times and C is used 16 times.

It is interesting to see that the differences display a difference per vehicle type. When only CVs are compared, version A shows a larger amount of continue, than the other two, as seen in Figure 29. Version C shows a higher amount of slow down when interacting with an AV than the other two, which can be seen in Figure 30. The difference in stated trust could therefore be important. The amount of risk-taking behaviour of the participants can play a role in these differences as well, since version C has a lot of low risk takers, who choose more to slow down.

There is not a single variable that can explain the difference in versions exactly, so it is probably a combination of different variables. Also, the first vehicle that appeared in the experiment can also be of influence, since that was a CV for version A and an AV for version C (and version B as well).

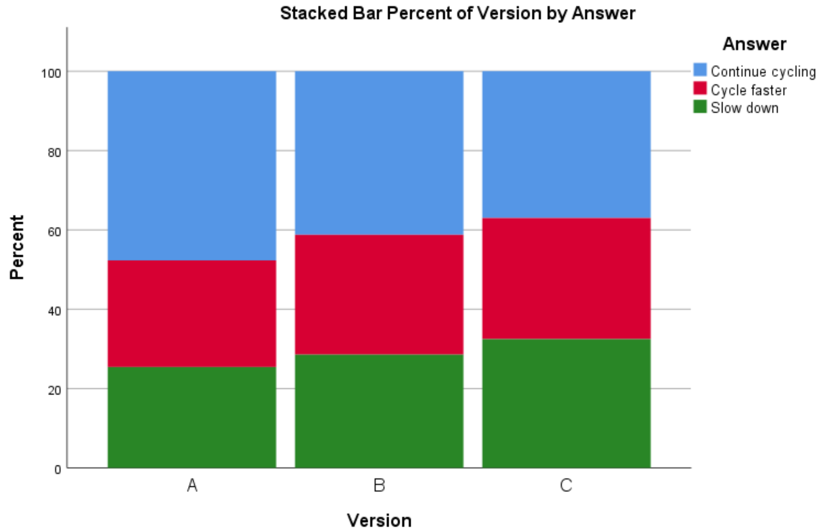

Figure 28 Difference in crossing behaviour between versions

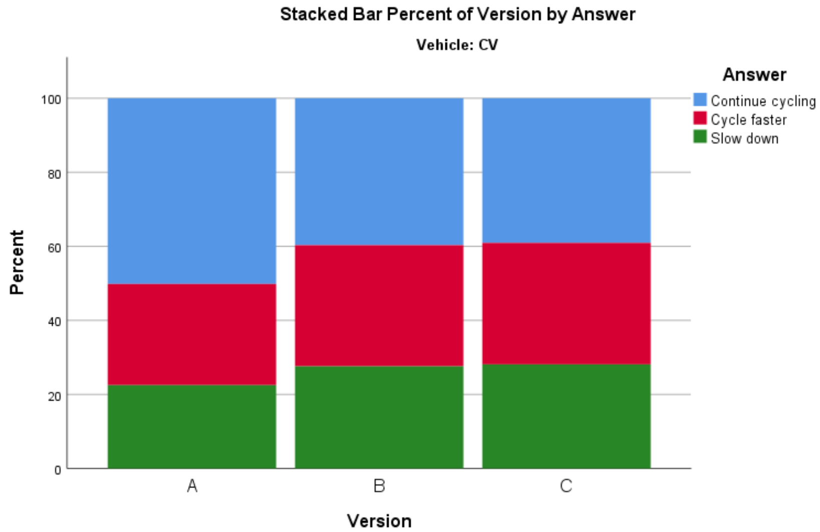

Figure 29 Crossing behaviour per version for CVs

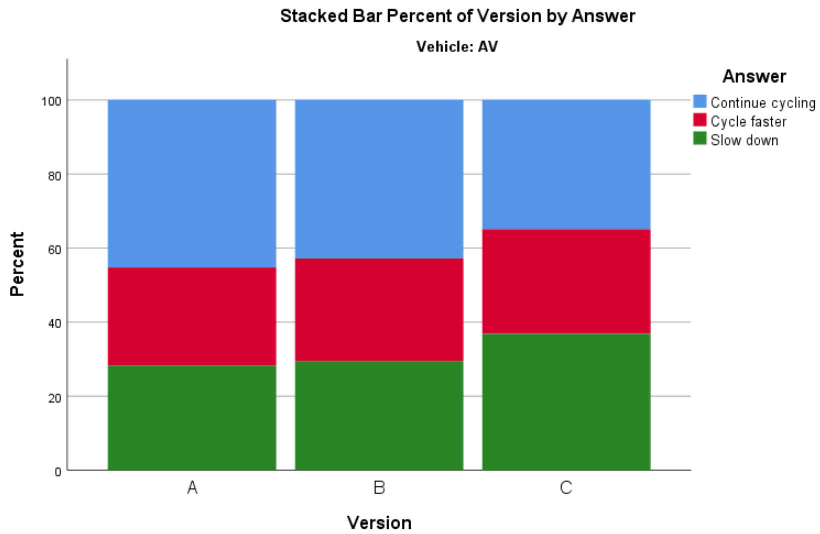

Figure 30 Crossing behaviour per version for AVs

5.5 VR

This experiment is performed with VR, a method that is not yet used often in these kind of researches. Therefore, it is important to see if the VR environment leads to the same conclusions as real-life experiments do. The participants are asked how they felt about the VR environment in the questionnaire and their answers will be discussed.

Participants

Of all participants, 80% thought that crossing in VR differed from crossing in real life. Their reasons why varied a lot; however, they listed the absence of eye-contact, not being able to control the speed of the bike, the absence of any consequences of their decision and the decision moment. When asked how safe they felt during the experiment compared to real life, their answers varied as well. Around 26% felt slightly unsafe, 14% said they did not experience a difference and 60% felt slightly safer or safer, as seen in Figure 31.

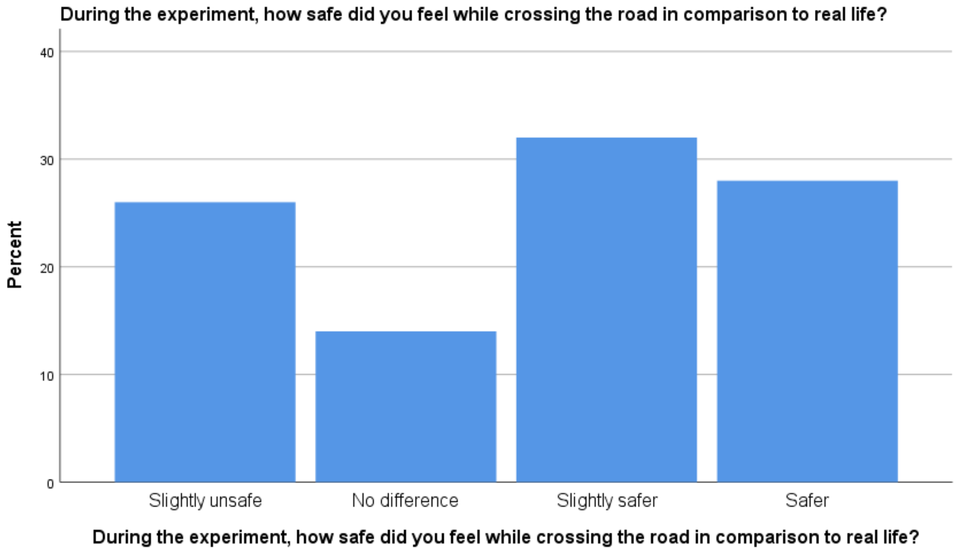

Figure 31 Answers on feeling safe during the experiment compared to real life

To check how immersive the environment felt to the participants 16 questions were asked about how they experienced the VR environment. For these questions the Presence questionnaire has been used (Jerome, 2009). The participants could give a score from 1(not at all) – 7(very), 4 points was labelled as moderately. The total score of these questions was calculated and divided by 16, to get an idea of the answers. Some questions were recoded, because a high score did not mean a positive score for all questions. The distribution of all participants total scores can be seen in Figure 32. The mean score is 4.93 on a scale from 1-7, so participants gave the immersiveness of the environment on average a high score.

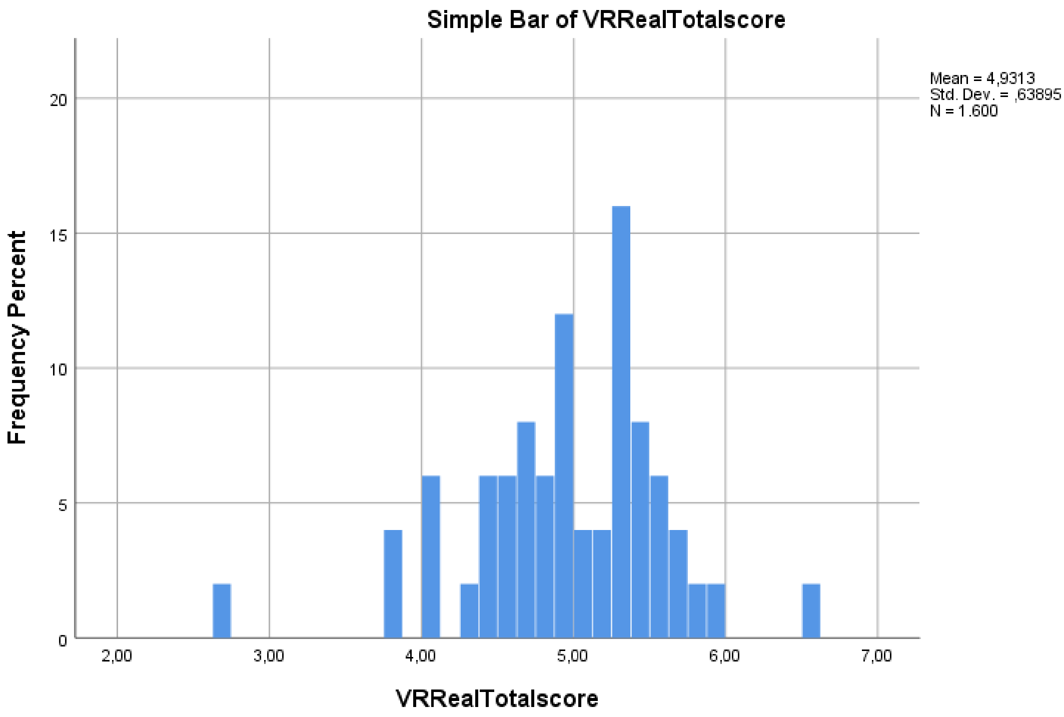

Figure 32 Distribution of total score on VR immersiveness

MISC scores

To check if participants felt fine during the experiment and did not suffer from motion sickness, the MISC scale was filled in by them before, during and after the experiment (Van Emmerik, De Vries, & Bos, 2011). In total it was filled in 5 times per participant, since the experiment took place in 2 sessions and in the middle of each session was a small break. As seen in Figure 33 the MISC scores do increase a bit over time. The average scores do not increase so much, but the scores become more scattered. The high scoring participants (participant number 4, 6 and 7) already did not feel optimal when starting the experiment and their scores were not caused by the experiment. All participants were able to finish the experiment, and none had to stop due to motion sickness. However, since there is clearly an effect, it is not advised to use VR for experiments that take much longer.

One outlier, who scored a 10 on MISC4 is deleted, because the score was incorrect. The participant had rated his misery between 1 and 2 during the whole experiment and felt fine afterwards. When checked he indicated that the score was indeed false and that he had felt fine.

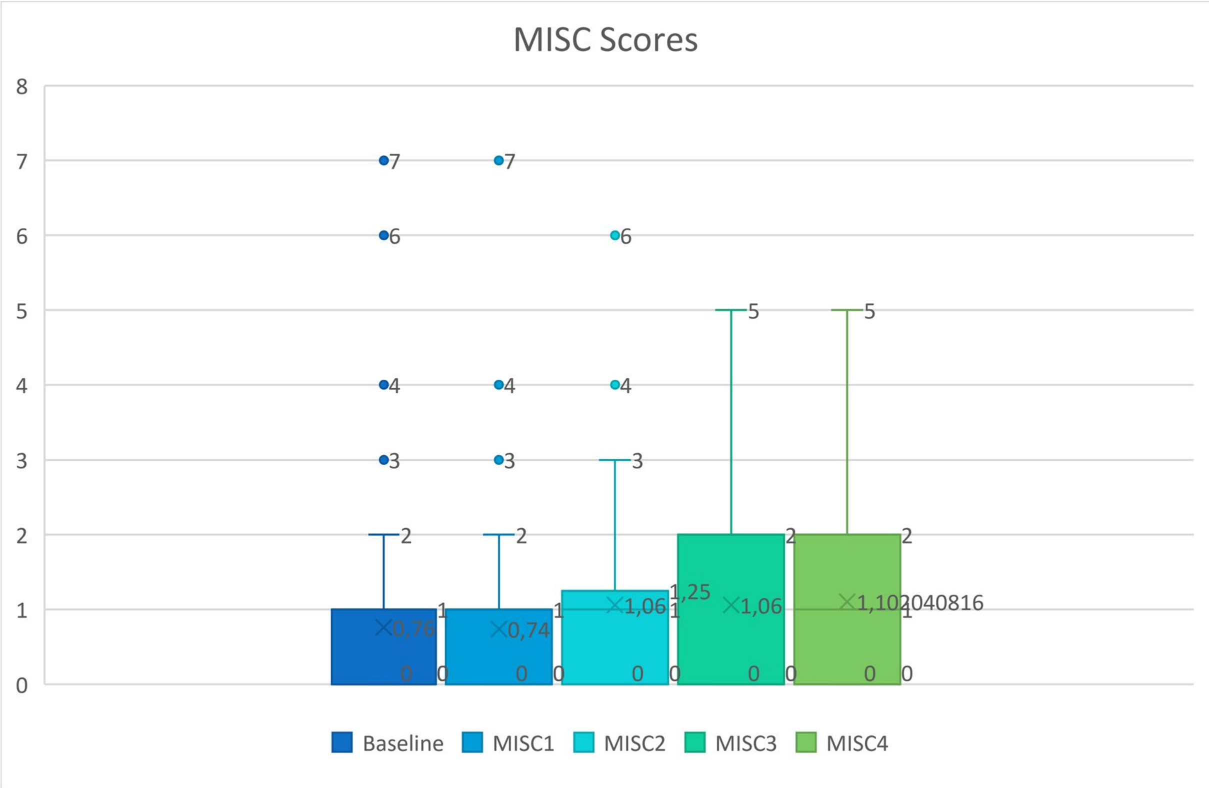

Figure 33 MISC scores over time

6. Discussion

The goal of this research was to determine the differences in crossing behaviour of cyclists interacting with AVs compared to CVs. The results show that the behaviour of cyclists in interaction with AVs was affected by their amount of trust in AVs. If they had more trust in AVs, they crossed more often, and choose to slow down less. When AVs were not trusted, the amount of choices for slow down had increased and the number of crossings went down. This study shows that there is no difference in crossing behaviour towards CVs and AVs as a group average. Since participants show contradicting behaviour, some cross more and some less, differences cancel each other out when observing the group as a whole. Therefore, it is important to include the amount of trust in AVs in future research about road user interactions with AVs.

In this chapter, the research results are explained and the research questions will be answered. Furthermore, the limitations of this research are discussed and suggestions are done for future work.

6.1 Research questions

In this paragraph, the main conclusions from this research will be discussed. The main research question will be answered, and an answer will be given to the sub questions. To answer these questions, the results of the experiment are used, which have been described in the analysis and results in chapter 5. The most interesting findings will be discussed first.

Difference between vehicles (main research question)

The main research question will be answered first. The difference in behaviour of cyclists between vehicles is quite small when the participants in total are observed. Participants are seen to slow down less and choose ‘cycle faster’ more, when interacting with CVs. The coefficients of the model can be seen in Table 18. The effects of slow down and ‘cycle faster’ almost equal out the difference, so there is no difference for both vehicles for ‘continue cycling’. The lack of difference in vehicle type is in accordance with a number of other studies (Rodriguez Palmeiro et al., 2017; Rothenbucher, Li, Sirkin, Mok, & Ju, 2016).

Table 18 Coefficients of model compared to 'continue cycling'

	Vehicle	Coefficient
Slow down	CV	-0.245
	AV	0
Cycle faster	CV	0.211
	AV	0

The slight negative coefficient of slow down, shows that participants generally slowdown less for CVs than for AVs. Therefore, their general trust in CVs is a bit higher. An explanation could be found when looking at the stated trust of participants. As seen in Figure 34, most participants indicate that the type of vehicle is not of influence on their decision. However, the group that trusts AVs less is bigger than the group that stated they trust AVs more. So overall, the general opinion is to trust AVs less, and this would result in more slowing down in front of AVs, and thus less slowing down in front of CVs.

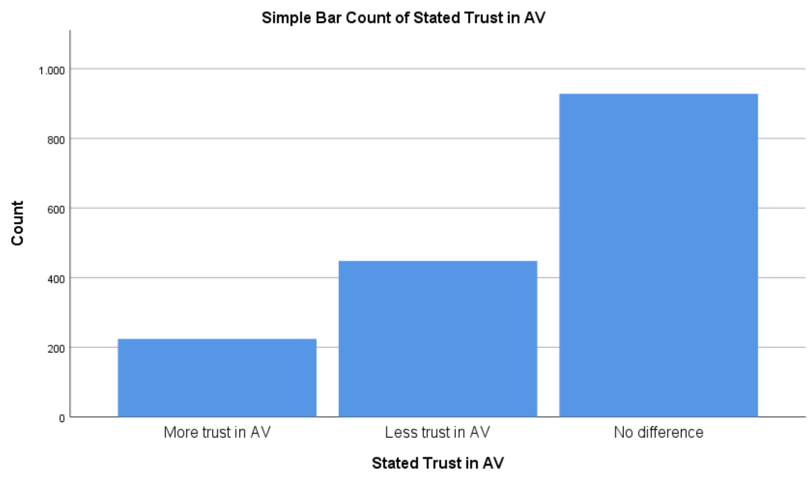

Figure 34 Shares of each group for stated trust in AVs

However, when trust in AVs is considered, a difference in crossing behaviour can be observed.

Level of trust in AVs (sub question 4)

The most important finding of this study is that the level of trust in AV technology was a clear indicator for crossing behaviour in front of AVs. When participants stated they trusted AVs more, they could be seen continuing more in front of AVs and slow down more in front of CVs. For the ones who trusted AVs less, a strong reaction could be seen in front of CVs, they slowed down way less. In front of AVs, they also slowed down a bit less than they continued. However, when compared to CVs, the coefficient was very small and higher than CVs. So, they slowed down a bit more than continued, but compared to CVs their slow down behaviour was much higher. Hence, in front of the vehicle the participants stated they trusted more, they were more comfortable to cross, and could be seen to cross more often in this experiment.

The group that stated there was no difference in vehicles, showed only a small difference in crossing behaviour. In front of CVs, they slowed down less, and choose cycle faster more. These differences could be caused by small variances between the vehicles. The vehicles are chosen to be similar in colour and appearance, but they still vary a bit and influence the participants unwittingly.

Creating groups based on trust AVs

The stated trust of participants seems a good indicator for their observed behaviour towards AVs. In this research, two different methods were used to determine the amount of trust participants had in AVs. For the variable “Trust in AVs”, a summation of 11 questions has been made at which participants had scored their trust in AVs in specific situations on a score from 1-7. Two groups were created by dividing the participants in half. The lowest half become the low trust group and the highest half was sorted into the high trust group. The variable “Stated trust” was created by asking the participants if they thought they reacted differently to AVs than to CVs. The ones who did, were asked how they thought their behaviour differed. Based on their answers, 3 groups were created. The ones that trusted AVs more than CVs, the group that trusted them less and the group who said there was no difference. The stated trust variable proved to be a better predictor of crossing behaviour than estimated trust in AVs was. This can be explained by the fact that stated trust asked how much they trusted the AV compared to the CV, where trust in AVs only asked about situations with an AV. In the model, the two vehicles are compared to each other, and the values indicate the crossing decisions of one vehicle related to the other. When participants trust AVs a lot, but still less than CVs, their results in the model will show less crossings compared to CVs.

This shows that participants' own estimates were a better predictor of their behaviour in this case. It is unknown if stated trust is the optimal way of dividing participants into these groups. When participants would have been asked to state which vehicle they trust more in different situations, perhaps a better indicator could have been created. It was not possible to test this, since the questionnaires had already been filled in, when this difference appeared in the results.

Awareness type of vehicle (sub question 1)

Another important finding is the effect of the awareness. Since participants were only told before session 2 that one of the vehicles was an AV, and only 14% noticed it in the first session, it was possible to determine the difference. A clear difference was seen in crossing behaviour between the first and second session, based on their stated trust in AVs.

So, the effect awareness had on the crossing behaviour depended on their stated trust. It made their preference for a specific vehicle stronger. The ones who trusted AVs more, had an even stronger preference for AVs and the ones who trusted AVs less, had a stronger preference for CVs. Even in session 1, a difference between the three groups was visible. This could be due to the small percentage that already noticed one of the vehicles was an AV. It is also possible that the differences in session 1 are caused by other factors, such as differences in the appearance of the vehicles.

Adding session as a variable to the model did not add value to the predictions of the model. The average crossing behaviour of all participants did not change when they knew one vehicle was an AV. In the interaction between vehicle and session, there was not a difference found as well. Since there are different groups, who reacted inversely to this news, it is consistent that there is no overall effect. However, within those groups a reaction could be observed, as presented in Figure 20. To capture this effect in the mixed model, a three-way effect had to be added, which did not improve the power of the model. Nevertheless, when the model was split in session 1 and session 2, a clear difference could be seen between the sessions in the reaction of the stated trust groups on the vehicles.

Awareness of different vehicles

It was striking to see that 25% of the participants had not seen any difference between the vehicles halfway through the experiment. At that point they had seen 16 different scenarios with 8 CVs and as many AVs. When looking at their crossing behaviour, a major difference was seen compared to the group that did noticed a difference. The ones who did not, continued 13% more often and choose slow down 9% less, as seen in Figure 35. No variables were able to explain this change. However, an explanation could be that participants who did not see a difference, did not pay close attention and therefore observed less risks and continued more often anyway.

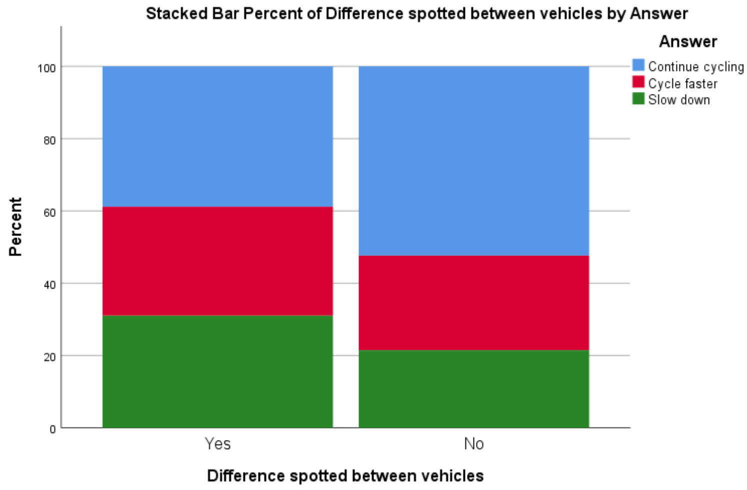

Figure 35 Crossing behaviour of the ones who did and did not notice a difference between the vehicles

Effect priority (sub question 2)

There was a strong reaction visible on a change in priority between cyclists and vehicles. When cyclists had priority, they continued more often and slowed down less. Next to gap distance, the strongest reaction was seen by a change in priority. Even though a number of participants indicated, after the experiment, that they did not thought about the priority rules, a strong reaction can be seen. It is possible that priority to the right is so common to the participants, that they were not even aware of acting upon it.

Effect change in variables (sub question 3)

Speed was not an addition that improved the model. The literature in paragraph 2.2 already showed that people were better in estimating distance than speed, so that was expected. Furthermore, research with pedestrians found that speed did not determine the crossing decision of younger pedestrians (20-30 years old) (Lobjois & Cavallo, 2007). Since the participants of this study also fell in this age category, it is possible that they are therefore not influenced by speed as well. Also, cross effects of vehicle with the variables: speed, gap distance or priority did not improve the model. So, a change within these variables did not affect the interaction with the vehicles. Therefore, the hypotheses that there would be an effect on the crossing behaviour towards AVs and CVs is incorrect. Participants did not change their behaviour towards AVs when speed, gap distance or priority changed.

To see the effect of speed, gap distance or priority per vehicle type, the figures in "Appendix G: Effect of speed, gap distance or priority on the type of vehicle" can be studied. Here the effect of the three variables on vehicles is divided by the three stated trust groups, to make sure there are not different effects that cancel each other out. However, no effect of the variables on the type of vehicle is seen.

VR method (sub question 5)

The two biggest concerns about the VR environment were the absence of consequences of participants' decisions and whether they would experience motion sickness. The absence of consequences was expected to increase the number of crossings of participants. However, the results show that for every scenario participants debated whether to cross. Every participant used all his crossing options at least once, so nobody crossed anyways due to the absence of consequences.

Most participants did indicate that they felt safer to cross in VR, than in real life, so it is possible that a higher number of crossings is observed than would have been in real life. However, this study observes differences between the variables and trade-offs are still made, so the observed differences within variables are still visible.

It was unexpected that a share of 26% of the participants felt slightly more unsafe than they felt in real life. Their main reason to feel unsafe was a lack of control. They did not have an influence on the speed of the bike or the decision moment. For some participants the decision moment felt too late, and they would have acted earlier on themselves. However, these reasons are not per se an effect of VR, but of it being a controlled experiment. In the experiment the cycling speed and decision moment are standardized, to be able to compare all participants. For cycling speed, the main preference of all test participants has been chosen, and this is not the favourite of all cyclists. Therefore, in a real life experiment these comments would still be mentioned.

MISC

The second concern was if participants would experience motion sickness and if this influenced their decisions. It is hard to say if the motion sickness influenced the crossing behaviour, since only a few scored a three or higher on the misery scale (MISC) . MISC question 3 and 4 were asked at ¾ of the experiment and at the end, and the highest scores were given at these moments. How often each score was given, can be seen in Table 19. The MISC scores 4 and 5 are based on answers of 3 participants or less, so they are not considered.

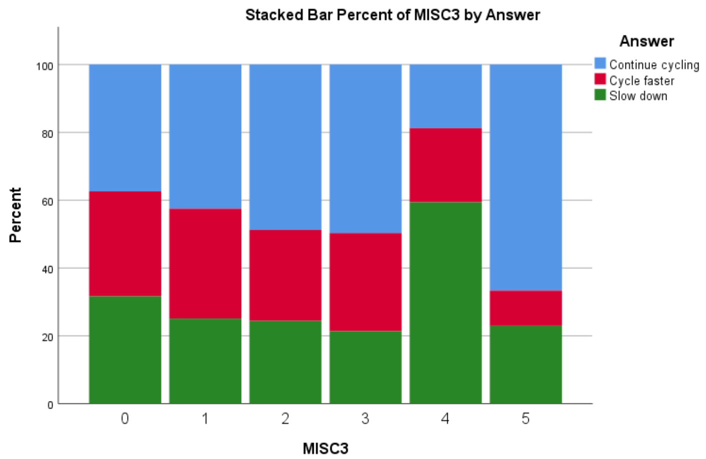

Figure 36 Crossing behaviour divided by MISC scores at ¾ of the experiment

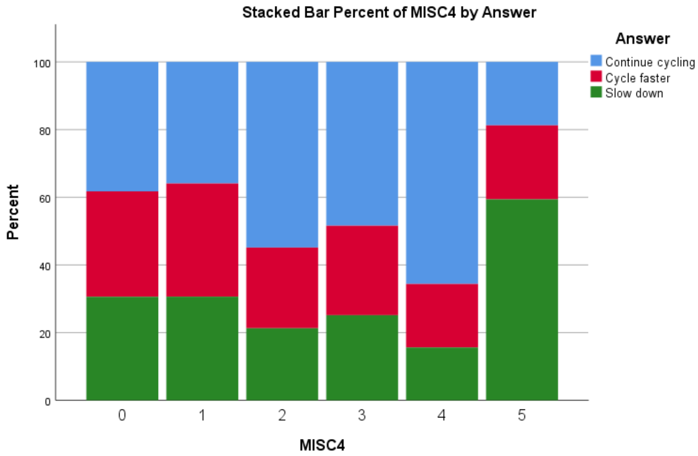

Figure 37 Crossing behaviour divided by MISC scores at the end of the experiment

The overall trend, is that participants who gave higher MISC scores, more often choose to continue and slowed down less, as shown in Figure 36 and Figure 37. However, adding this to the model did not improve its performance and the differences are small. An explanation could be that participants who did not feel optimal, were more in a hurry to finish the experiment and choose to continue more. Even though their choice was not of influence on the duration of the experiment.

Table 19 Percentage of participants that gave that MISC score, MISC 3 was at ¾ of the experiment, MISC 4 was given at the end.

Score	**0**	**1**	**2**	**3**	**4**	**5**
MISC 3	54%	18%	10%	10%	2%	6%
MISC 4	44%	20%	20%	10%	2%	2%

The percentage that scored higher than a 3 on the MISC scale, was relatively low. Even though participants were placed in a VR environment where they saw recordings made from a moving bicycle, while standing still in real life, their MISC scores were relatively low. The low MISC scores and the limited effect of the absence of consequences, makes VR a useful and safe tool for research.

Some participants scored relatively high on the MISC scores before the VR experiments started. To create a baseline, every participant was asked beforehand how they felt. Since the MISC scores 2-5 were categorized to describe dizziness and 6-9 was labelled as nausea, everyone who felt a bit nauseous, even without being dizzy, scored disproportionally high. This may distort the interpretation of the high MISC scores.

Takeaways for VR research

A quiet road was chosen to be able to create comparable scenarios, where in every scenario only one vehicle was visible. Multiple participants indicated that they were not used to such quiet roads in rural areas, since all participants lived in either Delft or The Hague, two crowded cities. In this research, the comparability of the scenarios was thought to be more important, but in future work, more traffic might increase the realism of the experiment.

The recording method with the camera hanging underneath the mouth mount was successfully reviewed. The point of view was found realistic by the participants and they were able to look around them. A small part of the view was blocked, were the cyclist was, but since this part was behind the participants, and they were looking in front of them to see the traffic, this was not a limitation. The recordings were stabilized with Adobe After Effects and reviewed as comfortable to watch.

Participant felt a bit limited in their view and had to turn their heads more to look to the left and right, than they would have in real life. Due to the way the VR glasses work, the video is more in front of them and it limited their field of view. In real life, people can see a broader field of view and even watch left and right with their eyes without moving their heads. The VR glasses only showed a new side when the head was actively turned in that direction. In this experiment the vehicle came either from the left or the right, so participants only had to watch in one direction, therefore it did not affect their decision. However, the somewhat limit field of view needs to be considered, when one wants to create a scenario with multiple vehicles coming from more than one direction.

The camera was found easy to use, considering it stitched the recordings together by itself, to create a 360 degrees video. The quality of the camera was sufficient for this experiment, however with a higher quality camera, it might be possible to record vehicles from further away and therefore it becomes possible to record vehicles with a higher speed. For the same safety gap in time, a bigger gap in distance is necessary when the vehicle drives at a higher speed. If the gap distance between the vehicle and the cyclists became larger, the quality was too low to clearly identify the vehicle.

6.2 Limitations

Research limitations

Due to limited time and finances, the sample size of this research consisted of 50 participants. Since the sample size was relatively small and differences in location and age showed alterations in crossing behaviour, a homogenous group of participants has been chosen. A limitation of this choice is that the results only fit a small part of the population. The sample size consisted mostly of participants aged 20-28 from around Delft, studying or graduated at the Delft University of Technology. Their background could have influenced them in the amount of knowledge about or trust in AVs they have. Although, these participant did not show a relation between their amount of trust in AVs and their self-rated knowledge about AVs, as can be seen in Figure 38.

Figure 38 Trust in AVs (scores 1-7) in comparison with knowledge about AVs (scores 1-6)

In this experiment, a vehicle needed to be chosen to represent an AV and a CV. Two vehicles comparable in size, colour and vehicle type were chosen and by telling the participants halfway through the experiment that one vehicle was a CV and one was an AV, it was made sure that participants were aware of the difference. However, it is possible that another vehicle will produce different results in crossing behaviour. Some participants indicated that they thought the CV looked like a sportscar, while the AV looked more like a family car to them. It is possible that their behaviour was adjusted by small differences in appearance like this. Nonetheless, the differences in appearance were present in both sessions, and a difference between the sessions can be seen. This indicates that the reaction in session 2 was a result of the knowledge that one vehicle was an AV, and not just the difference in appearance. Despite this, it is possible that different vehicles will produce differences in crossing behaviour.

In this research, different scenarios were included, however all the scenarios were recorded on the same crossing. For the case of this research, identifying differences between levels of variables, that was sufficient. A few participants indicated that they did not think the rural environment in the recordings was representative for their daily cycling trip though, since they live and cycle in a city. To generalize the results of this research, it is important to investigate the effect of different crossings and different crossing manoeuvres, for example turning left or right on a crossing.

VR limitations

This experiment is performed in VR to make it possible to observe crossing behaviour with small and constant gap sizes and to interact with an AV. VR is not yet widely used for these type of experiments, so it is not confirmed if VR shows the same results as real-life experiments. 80% of the participants thought that crossing in VR differed from real-life. Some of the examples they used, such as not being able to control the speed of the bike and the decision moment, were the effect of it being a controlled experiment and not per se a VR experiment. The absence of any consequences of their decisions, and the absence of eye-contact on the other hand, were effects of the VR experiment. The absence of consequences could have made the participants feel safer, as 60% felt safer crossing in VR than real life. When participants felt safer, they could have chosen more often to continue, than they would do in real life. 26% felt less safe crossing in VR, which could be caused by a lack of control, since they were not able to control the speed of the bike or the decision moment.

Due to the quality of the camera, the VR environment and the distance between the vehicle and cyclist, it is not possible to see a driver in the recordings. So, for the CV as well as for the AV, it is not possible to make eye-contact. Since eye-contact is an important feature in crossing behaviour, and it is absent with AVs, it is a disappointment that this difference could not be included in the experiment (Guéguen et al., 2015; Malmsten Lundgren et al., 2015). Nevertheless, eye-contact is not the only factor participants base their decision on, and eye-contact is not possible in every situation.

6.3 Recommendations

Recommendations for further research

This research shows how participants react on differences in vehicles at this moment. AVs are not widely used, and participants are not familiar with how they will react. Their trust is based on information they have heard or read about AVs, and not on their own experiences. A strong learning effect is expected, when participants start to encounter AVs more often. It would be interesting to see what the effect on their crossing behaviour will be and how it will influence their trust.

Furthermore, this research focussed on a specific sample group, in future research it would be interesting to compare these results with other groups of different age groups and locations. It would also be interesting to compare the behaviour of cyclists to other VRU's, such as pedestrians. Cyclists account for a large share of the traffic in the Netherlands, but are less represented in other countries.

To see how VR relates to real life crossing behaviour, a study could be performed to see how participants estimate distance and speed in VR compared to real life. This can contribute to the usage of VR as a research tool.

Recommendations for policy

The scale of this research is too small to base policy recommendations on. Further research is necessary, especially with a wider ranch of participants, before a policy can be formulated. However, this study can give some food for thought for future work.

Since so many participants did not think about AVs during the first half of the experiment, it raises the question whether participants will recognize AVs when they encounter them in real life. 92% of the participants knew what an AV was, so although AVs are not seen on the streets yet, participants were familiar with them. In the future, AVs will probably appear more, and people will familiarize with them. However, every vehicle brand will produce their own, so there will not be a standard AV appearance.

So, the question raises if we want people to know they are interacting with an AV. This research shows participants are adjusting their behaviour, when they know they are interacting with an AV. The AV technology is mainly focused on detecting cyclists and pedestrians, and it is complex to correctly predict cyclists' and pedestrians' behaviour and intentions (Vissers et al., 2016). Perhaps this would even be complicated if people altered their behaviour based on the vehicle being an AV or not. Besides, the appearance of the vehicle is not the only factor. The changing behaviour of the driver or the one in the drivers' seat can influence the cyclists as well, for example when he is noticeably distracted. Additional research is necessary to be able to answer this question.

If it would be preferred to inform people about the type of vehicle, the right way to do so should also be explored. It could be possible to apply a sign on the roof, just as with cars used for drivers' lessons or cabs, or a sticker could be applied to the vehicle. A way to interact with pedestrians and cyclists is also being explored, such as projecting something in front of the cyclists or show traffic signs on the vehicle (Fridman et al., 2017), and could also be part of the solution.

7. Conclusion

In this chapter the main conclusions of the research are explained.

The main research question of this study is: “What is the difference in the crossing behaviour of cyclists when interacting with AVs compared to CVs?”. Based on the mixed model results it was found that participants choose to slow down less and choose more to cycle faster when they were interacting with a CV, compared to an AV. So, when they interact with a CV they are more often hurried to reach the other side of the roads, while with an AV they more often let the vehicle cross first. The amount of times the cyclists decided to continue cycling was almost equal for both types of vehicles. However, these effects were small and not statistically significant. So, when the effect of AVs on the average crossing behaviour of the total group of participants is studied, there is no significant difference between the crossing behaviour in front of the two types of vehicles.

However, when participants are divided into groups based on their stated trust in AVs, differences in crossing behaviour between the vehicles can be seen. The participants were divided into 3 groups, the ones who trusted AVs more than CVs, the ones who trusted AVs less than CVs and the ones who said there is no difference in the trust level.

The group who stated they trusted AVs more than CVs, can be seen to slow down less in front of AVs and more in front of CVs. By choosing to continue more instead of slowing down, they show their trust in AVs. The group who trusted AVs less than CVs, can be seen continuing way more than slowing down in interaction with a CV. They trust AVs less, and choose to continue less in interaction with an AV and choose more often to slow down than they do in front of CVs. The ones who said it made no difference for them, choose an equal amount of continue in interaction with both vehicles. However, they can be seen speeding up a bit more in front of CVs and slowing down some more in front of AVs. So, the difference in crossing behaviour between the vehicles is based on which vehicle the participants state they trust more. For the vehicle they trust more, they choose more often to continue cycling and cycle faster and in interaction with the vehicle they trust less, they choose more often to slow down.

The differences in the crossing behaviour in front of the two vehicles are not only due to changes in appearance. Variation can be seen when comparing session 1, when participants did not know they were interacting with an AV and session 2, when they were informed. The differences between the groups who trusted AVs more than CVs, the ones who trusted them less and the ones who said there is no difference in the trust level, increased. So, knowing one vehicle was automated strongly influenced the crossing behaviour of the participants.

Other variables that influenced the crossing behaviour were gap distance, priority and risk taking. When the gap distance became smaller, participants more often slowed down and choose less often to continue. Next to gap distance, the biggest influence on crossing behaviour was the priority situation. When participants had priority, they continued more often and when the vehicle had priority they slowed down more often. Another factor that influenced the crossing behaviour was the amount of risk participants take. High risk takers continued more often, and low risk takers slowed down more often. There was no significant interaction effect of vehicles in combination with these or other variables, beside stated trust.

The VR method was useful as a research method. None of the participants suffered from motion sickness and everyone was able to finish the experiment. Even though 60% of the participants indicated they felt safer in VR than in real life, their crossing decisions still showed a trade-off, and nobody crossed in all scenarios. The way of recording was found suitable as well, since the point of view was found very realistic by the participants and, after stabilizing, the recordings were steady and comfortable to watch.

This study shows that cyclists adapt their behaviour when interacting with AVs, based on their amount of trust in AV technology. These findings are important to reminisce for the continuous developing of AV technology. Furthermore, additional research can build upon this study to formulate a policy on AVs. To see how the behaviour of cyclists will evolve in the future, more research about the learning effects of interacting with AVs is necessary.

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Appendix A: Paper

A STUDY ON CYCLISTS' CROSSING BEHAVIOUR WHEN INTERACTING WITH AUTOMATED VEHICLES USING VIRTUAL REALITY

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***Abstract* – With the introduction of Automated vehicles (AVs), new potential traffic situations could emerge. The interactions of cyclists with AVs versus Conventional Vehicles (CVs), or the amount of trust in AVs versus in CVs, can be different. An experiment in virtual reality has been performed to study crossing decisions of participants when interacting with both AVs and CVs. A choice model was estimated to identify which variables influence participants' crossing decisions. This study shows that cyclists adapt their crossing behaviour when interacting with AVs, based on their amount of trust in AV technology. However, to see how the behaviour of cyclists will evolve in the future, more research about the learning effects of interacting with AVs is necessary.**

Keywords: automated vehicles, cyclists, crossing behaviour, interactions, virtual reality

1. INTRODUCTION

Vehicles are becoming more and more automated: bicycles turn into e-bikes and cars come with all sorts of automation (NHTSA, 2017). Furthermore, pilot studies are being conducted with fully automated vehicles (DAVI, 2018; Waymo, 2018). Automated vehicles (AVs) need to detect and recognize other road users, both motorized vehicles and vulnerable road users (VRUs), to interact with them. In a collision between VRUs and non-VRUs, VRUs have a 30 times higher fatality and severe injury rate than non-VRUs (SWOV, 2012). Therefore, safe interaction with VRUs is literally vital.

A report of the WHO shows that in 2016 pedestrians and cyclists made up for respectively 22% and 5% of all the fatalities split to transport mode worldwide (Toroyan, 2015). How many of these fatalities happened due to human errors, is a wildly discussed subject. Some say over 90% of the crashes is believed to be due to errors by the driver, such as recognition errors (41%), decision errors (34%), performance errors (10%) and non-performance errors (7%) (NHTSA, 2008). Others state that 40% of all fatal motor vehicle crashes in the U.S., involved some combination of alcohol, drugs, distraction and/or fatigue. If these human related factors could be eliminated, the amount of accidents would decrease and, in the end, lives could be spared. Factors such as alcohol, drugs, distraction or fatigue would not bother an AV, which could potentially decrease the fatality rate if the automation does not endure malfunctions and when no side-effects occur (Fagnant & Kockelman, 2015). Therefore, as AVs could possibly reduce the amount of accidents and victims, it would be worth to investigate the AV technology.

Multiple studies have been performed on recognizing other road users from the point of view of AVs (Keller & Gavrila, 2014; Li et al., 2017; Schmidt & Färber, 2009). Research focusses on technical requirements and recognizing and predicting the path of these road users. If human factors are included, the factors that are normally sought are: driver experience and comfort or value for money (Stam et al., 2015), while there is less emphasis on how these AVs will interact and communicate with other road users, such as manually driven cars and VRUs (Merat et al., 2018).

At the same time, the other road users need to interact with these AVs as well. They need to adapt to a changing road traffic system and to a different type of road user (Vissers et al., 2016).

An important factor in the interaction between VRUs and CVs is the drivers' behaviour, such as postures, gestures and eye-contact (Guéguen et al., 2015; Malmsten Lundgren et al., 2015). However, such driver interactions are not possible for an AV, as there is no physical driver present or the person in the driver seat is not in control. As a result, interaction with an AV could possibly differ from the interaction with a CV. Furthermore, the behaviour of VRUs can be influenced by the amount of trust they have in AV technology (Vissers et al., 2016). If VRUs trust AVs to always be able to stop, they might be tempted to take more risks. On the other side, if they do not trust AVs they could be acting more carefully.

Due to the high fatality and injury rates, the large amount of cyclists in the Netherlands and studies on the interaction of cyclists are still rare, the present research will focus on cyclists (CBS, 2017; Korving et al., 2016; Twisk et al., 2013). Most accidents between cyclists and motorized vehicles happen at intersections and during crossing manoeuvres (Reurings et al., 2012; SWOV, 2010). Therefore, this research will focus on intersections, to analyse how cyclists interact in these situations. This study aims to gain insights in crossing behaviour of cyclists while interacting with AVs, which will hopefully lead to safer road interactions.

For this purpose, Virtual Reality (VR) technology has been used. VR can be used to let participants immerse in the VR environment, and to study cyclist interaction this type of environment may be used instead of real life experiments that are expensive, difficult or dangerous to do in real life (Deb et al., 2017). VR might be a useful tool for studies due to the increased realism and the absence of physical danger (Simpson et al., 2003).

Despite the advantages of VR, its use in scientific research is relatively scarce. Nevertheless, studies on the behaviour of pedestrians at crossings show that VR experiments are able to display differences in crossing behaviour (Clancy et al., 2006). The participants did not show reckless behaviour and they adopted behaviour that is common in real-life (Plumert et al., 2004; Simpson et al., 2003) and VR can be seen as a valid way to capture this (Deb et al., 2017). Furthermore, participants have more understanding of the scenarios when using VR and the results are more consistent (Farooq et al., 2018).

In short, the three main contributions of this study are:

- Cyclists adapt their crossing behaviour when interacting with AVs, based on their amount of trust in AV technology.
- Cyclists adapt their behaviour towards AVs, when they are aware they are interacting with an AV.
- This research is, to the best of our knowledge, the first VR experiment on crossing behaviour of cyclists, recorded in a moving real-life environment.

In the remainder of this paper we will describe the methodology (section 2), results (section 3). In sections 4 and 5 the conclusions and recommendations are discussed.

2. METHODOLOGY

In this section, the methodology used for the experiment will be described. The data collection of this research consisted of a virtual reality experiment performed with 50 participants. These participants watched videos where they would drive towards a crossing and were asked to decide whether to *continue cycling*, *cycle faster* or *slow down*, while a vehicle was moving towards them. In these videos different scenarios were shown including either a CV or an AV. The aim of the experiment is to analyse whether participants adapt their crossing behaviour when interacting with an AV compared to a CV.

VR SET-UP

By using VR, it was possible to create comparable and safe scenarios for every participant. Since lack of realism is often described as the biggest disadvantage of VR videos (Farooq et al., 2018), the most realistic option has been chosen, being the use of a real life recordings, instead of an animated VR environment. The used camera was a Nikon Keymission 360 action camera. To establish a cyclists' point of view a GoPro mouth mount has been used, which could be placed in the mouth, with the camera hanging underneath. Through pilot studies it was found to be the best point of view and it was possible to record with both hands on the steer and the pedalling legs beneath.

SCENARIOS

Every participant watched 16 different scenarios, each created with a random set of the variables shown in Table 20. In the videos, the cyclist was cycling at a speed of 15 km/h, since this speed was found most realistic by the participants in a pilot study.

Table 20 Experiment variables

Variables	**Levels**
Vehicle	CV
	AV
Speed	20 km/h
	30 km/h
Gap size	0.5 seconds
	2 seconds
Priority	Vehicle from the left
	Vehicle from the right

Each video stopped just before the cyclist entered the crossing, so participants could make the decision to: *continue cycling*, *cycle faster* or *slow down*. This stopping point was based on the braking distance for cyclists, so participants would still be able to stop (CROW kennisbank, 2018). Since participants did not get feedback on their decisions, they could not be influenced for future decisions and there was no behavioural adaptation.

LOCATION

The chosen location was the crossing between 'Verlengde Herendijk' and 'Tweede Boerwijk' in Emmen, because it was a crossing where both the vehicle and the cyclist could go straight on, without making any manoeuvres and there was little traffic. Furthermore, there were no priority markings on the road, or buildings blocking the view.

VEHICLE

Figure 39 Appearance of CV (top) and AV (bottom) in the videos

The vehicle used in the recordings was a white BMW 5-series, since it was comparable in size to the AV, the colour was clearly visible, and it was often available (which was practical for conducting the study). Since AVs are not widely used yet, they are difficult to get. Due to limited time and resources, the AV was created via video editing. By using video editing, it was ensured that the AV had the same size and speed as the CV, because it was placed over the CV and tracked to its exact movements. Figure 39 shows the appearance of both vehicles in the videos. The software used to edit this was Adobe Photoshop, Adobe Premiere Pro and Adobe After Effects. During a pilot, the Waymo Fiat Chrysler turned out to be the most realistic AV and was therefore used in the experiment.

SESSIONS

A big concern was whether participants would notice that the vehicle was an AV. Therefore, it was decided to repeat the whole experiment twice for every participant. In the first session they were not informed about the different vehicles. Before the second session they were told which vehicle a CV was and which an AV. That ensured there was a data set were the participants knew they were interacting with an AV, and a data set where they were not influenced with any information. It also enabled the possibility to compare those with each other.

PARTICIPANTS

To collect the data, 50 participants took part in the experiment. Since the experiment was conducted at the TU Delft, most of the participants were (former) students from a variety of faculties and were not financially compensated for their participation. As age is of influence on crossing behaviour and the set of participants was relatively small, a homogenous age was chosen for all participants, so their differences in behaviour were not due to changes in age (Bernhoft & Carstensen, 2008; Demiroz et al., 2015).

QUESTIONNAIRES

All participants filled in a questionnaire before, during and after the experiment. Questions included participant characteristics and an adapted version of pedestrian behaviour scale to determine participants' risk taking behaviour in traffic (Granié et al., 2013). Furthermore, the level of trust in AVs was measured per participant (Nuñez Velasco et al., 2018; Payre et al., 2016). To determine how the participants experienced the VR environment, the 'Presence Questionnaire' has been used (Jerome, 2009).

A side-effect of using VR is that participants may get sick due to visually induced motion sickness. In VR, ones' eyes will see a moving vision, while the body notices that it is standing still, and this can cause conflicting signals (Bos et al., 2008; Lubeck et al., 2015). Although most people do not endure this, it is shown that not everybody can tolerate the virtual environment (Deb et al., 2017). To ensure participants did not suffer from motion sickness, they filled in a misery scale before, during and at the end of the experiment (Van Emmerik et al., 2011). If their scores increased significantly during the experiment, the experiment stopped.

MODEL

Each of the 50 participants watched 32 videos and made just as many crossing decisions. Therefore, the data set consisted of 1600 choices. In three occasions a participant missed the vehicle in the video and could therefore not answer, these choices were eliminated, so that the total data set contained 1597 decisions.

To analyse which factors influenced participants' crossing decision, a choice model has been created. A choice model tries to predict the decision of a participant based on variables of that situation and the characteristics of the participants. So, for a change in the level of the variables in Table 20, the model would predict a different outcome. Variables were only added to the model if they improved the predictive power of the model and were significant. However, these 1597 choices cannot be seen as individual choices, since the answers given by the same participant in different scenarios are correlated, because every participant has their own preferences (Lund Research Ltd, 2018). Therefore, a mixed model with repeated measures is used, which accounts for multiple responses per participant. To include individual differences, a random intercept was added to the model. An unstructured covariance matrix has been used for the model, since the error structure was unknown (Kincaid, 2005; Singer, 1998).

3. RESULTS

The mixed model with repeated measures was made in SPSS, a software package for statistical analysis. The results of the model can be found in Table 21. The participants were given three options in the experiment: *continue cycling*, *cycle faster* and *slow down*. The model can only compare 2 answers to each other, so both *slow down* and *cycle faster* are being compared to *continue cycling*.

Table 21 Fixed coefficients of model

	Variable	Levels	Coefficient	Std. Error	t	Sig.
Slowdown	Intercept		-1.128	.370	-3.047	.002
	Vehicle	CV	-.245	.201	-1.216	.224
		AV	0^b	.	.	.
	Gap-distance	2.778 m	2.806	.242	11.567	.000
		4.167 m	2.865	.239	11.947	.000
		11.111 m	.130	.252	.514	.607
		16.667 m	0^b	.	.	.
	Priority	Priority to cyclist	-2.425	.169	-14.324	.000
		Priority to vehicle	0^b	.	.	.
	Risk-Taking	Low risk takers	.847	.389	2.175	.030
		High risk takers	0^b	.	.	.
	Stated-Trust	More trust in AV	-.457	.612	-.746	.456
		Less trust in AV	-.104	.470	-.220	.826
		No difference	0^b	.	.	.
	[Vehicle] *[Stated Trust]	CV * More trust	1.031	.449	2.292	.022
		CV * Less trust	-1.046	.360	-2.902	.004
		CV * No difference	0^b	.	.	.
		AV * More trust	0^b	.	.	.
		AV * Less trust	0^b	.	.	.
		AV * No difference	0^b	.	.	.
Cyclefaster	Intercept		-.278	.264	-1.051	.293
	Vehicle	CV	.211	.171	1.231	.219
		AV	0^b	.	.	.
	Gap-distance	2.778 m	1.079	.186	5.793	.000
		4.167 m	.412	.195	2.108	.035
		11.111 m	.040	.167	.241	.810
		16.667 m	0^b	.	.	.
	Priority	Priority to cyclist	-.985	.134	-7.310	.000
		Priority to vehicle	0^b	.	.	.
	Risk-Taking	Low risk takers	.438	.273	1.598	.110
		High risk takers	0^b	.	.	.
	StatedTrust	More trust in AV	-.202	.444	-.453	.650
		Less trust in AV	-.023	.346	-.065	.948
		No difference	0^b	.	.	.
	[Vehicle] *[Stated Trust]	CV * More trust	-.070	.393	-.178	.859
		CV * Less trust	-.579	.294	-1.964	.050
		CV * No difference	0^b	.	.	.
		AV * More trust	0^b	.	.	.
		AV * Less trust	0^b	.	.	.
		AV * No difference	0^b	.	.	.

b. This coefficient is set to zero because it is redundant.

The crossing decision is based on multiple variables, so the model also tries to gather all the important variables. The value of these variables represents their impact on the outcome, if the value is larger, the effect of this variable on the outcome is larger as well. Negative values show that *continue cycling* was chosen more often and positive values indicate that *slow down* or *cycle faster* were more popular. For every variable one of the levels is set to 0, as this is the reference level.

For example, the value -0.245 of CV (at *slow down)* indicates that participants slowed down less in front of a CV instead of an AV compared to *continue cycling*.

VEHICLE

The main research question is: “What is the difference in the crossing behaviour of cyclists when interacting with AVs compared to CVs?”. As shown in Table 21, participants have chosen to slow down less and have chosen to cycle faster more when they were interacting with a CV, compared to an AV. So, in interaction with a CV they hurried to the other side of the road more often, while with an AV they let the vehicle cross first. The number of times *continue cycling* was chosen was almost equal. However, these effects were small and not statistically significant. So, when the effect of AVs on the average crossing behaviour of the total group of participants is studied, there is not a significant difference between the vehicles.

However, when participants are divided into groups based on their stated trust in AVs, significant differences in crossing behaviour between the vehicles can be observed. The participants were divided into three groups, the ones who stated they trusted AVs more than CVs, the ones who trusted AVs less than CVs and the ones who said there was no difference for them.

Because of the presence of interaction effects, where levels ‘AVs’ as well as ‘No difference in stated trust' are both reference categories, most of the values are set to 0. The values of each category are therefore calculated in Table 22, by summing the three values of vehicle, stated trust and the interaction effect vehicle*stated trust.

Table 22 Calculated values of Vehicle * Stated trust

Vehicle * Stated Trust	**Slow down**	**Cycle faster**
*CV * More trust in AVs*	0.329	-0.061
*CV * Less trust in AVs*	-1.395	-0.391
*CV * No difference*	-0.245	0.211
*AV * More trust in AVs*	-0.457	-0.202
*AV * Less trust in AVs*	-0.104	-0.023
*AV * No difference*	0	0

The group who stated they trusted AVs more than CVs slowed down less in front of AVs and more in front of CVs. By choosing to continue more instead of slowing down, they show their trust in AVs. The group who trusted AVs less than CVs, continued cycling way more than slowing down in interaction with a CV. They trust AVs less, and choose to continue cycling less in interaction with an AV and choose more often to slow down than they do in front of CVs. The ones who said it made no difference for them, choose an equal amount of *continue cycling* in interaction with both vehicles. However, they can be seen speeding up a bit more in front of CVs and slowing down some more in front of AVs. So, the difference in crossing behaviour between the vehicles is based on which vehicle the participants state they trust more. For the vehicle they trust more, they choose more often to continue cycling and cycle faster, while in interaction with the vehicle they trust less, they choose more often to slow down.

SESSION

Only 14% thought they had seen an AV in the first session, so it is interesting to analyse the differences between the sessions before and after participants were told one vehicle was an AV. Adding session as a variable to the model is difficult, since it influences vehicle*stated trust. To analyse the effect of session a three-way variable had to be created and this did not improve the model and was difficult to analyse. Therefore, two separate models were created based on the data of only session 1 or 2. As seen in Table 23, both models, and especially session 2, were able to predict more choices correct than the overall model, which improved the power of the model. The model score values of session 2 increased as well compared to session 1, which decreased the power a bit. However, the scores of sessions 1 and 2 only are hard to compare to the total model, since they consisted of half the data.

Table 23 Model summaries of the total model and session 1 and 2 only

Model summary	**Total model**	**Session 1 only**	**Session 2 only**
Classification Percent Correct	63.3%	63.4%	65.6%
Akaike Corrected	13118.350	6300.210	6600.738
Bayesian	13129.067	6309.503	6610.079
2 Log likelihood	13114.343	6296.195	6596.768

The biggest difference between the models can be seen for the values of vehicle*stated trust, which can be found in Table 24. When participants have more trust in AVs, and are interacting with an AV, they choose to *continue cycling* more in the second session. When they do not trust AVs, they are slowing down and speeding up more when in contact with an AV. The differences between session 1 and 2 are noticeably large and they even changed directions. When interacting with CVs, participants who trusted AVs less, choose to cycle faster less often and continue cycling more often. The ones who trusted AVs more and the ones who said there was no difference both also choose to cycle faster less often, which is surprising.

Overall, the differences between the groups become bigger. This is a logical finding, since only a small part knew they were interacting with an AV in session 1.

Table 24 Values for vehicle*stated trust, model of session 1 and 2 compared

Vehicle * Stated Trust	Session 1		Session 2	
	Slow down	Cycle faster	Slow down	Cycle faster
*CV * More trust in AVs*	0.308	-0.092	0.384	-0.543
*CV * Less trust in AVs*	-1.291	-0.048	-1.319	-1.263
*CV * No difference*	-0.48	0.163	0.02	-0.275
*AV * More trust in AVs*	-0.14	0.209	-0.712	-0.611
*AV * Less trust in AVs*	-0.39	-0.165	0.315	0.176
*AV * No difference*	0	0	0	0

GAP DISTANCE, PRIORITY & RISK TAKING

Other variables that influenced the crossing behaviour were gap distance, priority and risk taking. The variable gap size was converted to gap distance, since people select a gap mostly based on distance, instead of a gap in time (Oxley et al., 2005). When the gap distance decreased, participants more often slowed down and choose less often to continue. Next to gap distance, the biggest influence on crossing behaviour was the priority situation. When participants had priority over the vehicle, they continued cycling more often and when the vehicle had priority they slowed down more often. Another factor that influenced the crossing behaviour was the amount of risk participants take. High risk takers continued cycling more often and low risk takers slowed down more. There was not a significant interaction effect of vehicles in combination with these or other variables, beside stated trust.

DISCUSSION ON THE VIRTUAL REALITY METHOD

VR is not widely used to observe crossing behaviour and therefore its performance was reviewed. Since it is known that not everyone can handle the VR environment and participants might got sick, they were asked to rate how they felt on a misery scale from 0-10 before, during and after the experiment. The scores were slightly increasing over time, as can be seen in Figure 40. However, every participant was able to finish the experiment. Some participants already scored high on the baseline, before the experiment, as the way of scoring categorized a bit nausea as a 6 or over. Since everyone was able to finish and the MISC scores did barely increase for most participants, the research method worked better than expected based on literature. Although it needs to be considered that participants got brakes often and had only short video sessions of approximately 3 minutes. It is not advised to use VR for long periods of time, since an increase in the MISC scores can be observed.

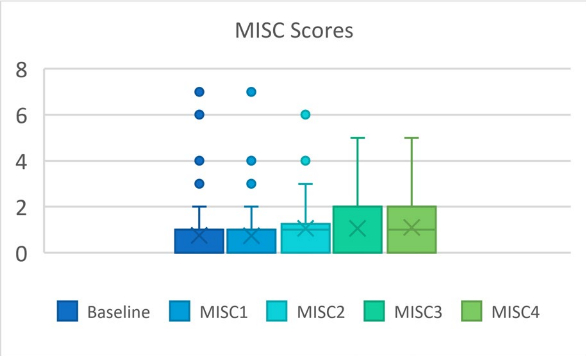

Figure 40 MISC scores participants over time

4. CONCLUSIONS

The goal of this research was to determine what the differences are in crossing behaviour of cyclists in interaction with AVs compared to CVs. To this end AVs were simulated in the present experiment. The results show that the behaviour of cyclists in interaction with these AVs are affected by their amount of trust in AVs. If participants had more trust in AVs, they crossed more often, and choose to slow down less, since they were more comfortable to cross in front of AVs than in front of CVs. When AVs were not trusted, the amount of choices for slow down increased and the number of crossings went down. This study shows there is no difference in behaviour towards CVs and AVs as a group average. Since participants show contradicting behaviour, some cross more and some less, differences cancel each other out when observing the group as a whole. Therefore, it is useful to include the amount of trust in AVs in future research on road user interactions with AVs to get a complete picture.

The differences between the vehicles are not only due to changes in appearance. Variation can be seen when comparing session 1, when participants did not know they were interacting with an AV and session 2, when they were informed. The differences between the stated trust groups increased. So, knowing one vehicle was automated strongly influenced the crossing behaviour of the participants.

The VR method was useful as a research method. Participants did not suffer from motion sickness and everyone was able to finish the experiment. Even though 60% of the participants indicated they felt safer in VR than in real life, their crossing decisions still showed a trade-off, and nobody crossed in all scenarios. The way of recording the scenarios was found suitable as well. The recording angle of the videos, from the viewing perspective of the cyclist was found very realistic by the participants and (after stabilizing in Adobe After Effects) the recordings were steady and comfortable to watch.

5. FUTURE RESEARCH

This study shows how participants react on differences in (the appearance and assumed behaviours of) AVs as compared to CVs at this moment. However, AVs are not widely used, and participants are not familiar with how they will react in real life. Their trust is based on information they have heard or read about AVs, and not on own experiences. A strong learning effect is expected, when participants start to encounter AVs more often. It would be interesting to see what this effect on their crossing behaviour will be and how it will influence their trust.

Furthermore, this research focussed on a specific sample group, in future research it would be interesting to compare these results with other groups of different age groups and locations. It would also be interesting to compare the behaviour of cyclists to other VRU's, such as pedestrians. Cyclists account for a large share of the traffic movements in the Netherlands but are less represented in other countries.

To see how VR relates to real life crossing behaviour, a study could be performed to see how participants estimate distance and speed in VR compared to real life. This can contribute to the usage and validity of VR as a research tool.

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Appendix B: Participants' pilot results

Cycling speed

For this pilot 16 people participated and rated the realism of the cycling speed. The most realistic speed scored 2 points, the one thereafter 1 and the least realistic scored 0 points. Three versions were made, in which the order of the videos rotated, these orders can be seen in Table 25. The answers given per participant per scenario can be seen in Table 26.

Table 25 Order of videos per version in cycling speed pilot

Version	Video 1	Video 2	Video 3
A	12 km/h	15 km/h	18 km/h
B	15 km/h	18 km/h	12 km/h
C	18 km/h	12 km/h	15 km/h

Table 26 Answers cycling speed given per test participants per scenario

Participant number	Version	Age	Male/Female	12 km/h	15 km/h	18 km/h
1	C	51	f	1	2	0
2	A	55	m	1	2	0
3	B	51	m	2	0	1
4	C	55	f	0	2	1
5	A	23	m	0	2	1
6	B	22	f	1	0	2
7	C	27	f	0	2	1
8	A	24	f	2	1	0
9	A	23	f	2	1	0
10	A	24	f	2	1	0
11	B	25	f	1	2	0
12	B	24	m	1	2	0
13	B	23	m	0	2	1
14	C	22	f	1	2	0
15	C	21	f	0	2	1
16	C	19	f	2	1	0
Total				**16**	**24**	**8**

The participants were shown one out of three versions (A, B and C). Therefore, the results are shown in the order that the participants saw them in Table 27. The first, second and third video all scored between 15 – 17 points, so there was no preference based on the order.

Table 27 Answers cycling speed given per test participants in shown order

Participant number	Version	Age	Male/Female	Video 1	Video 2	Video 3
1	C	51	f	0	1	2
2	A	55	m	1	2	0
3	B	51	m	0	1	2
4	C	55	f	1	0	2
5	A	23	m	0	2	1
6	B	22	f	0	2	1
7	C	27	f	1	0	2
8	A	24	f	2	1	0
9	A	23	f	2	1	0
10	A	24	f	2	1	0
11	B	25	f	2	0	1
12	B	24	m	2	0	1
13	B	23	m	2	1	0
14	C	22	f	0	1	2
15	C	21	f	1	0	2
16	C	19	f	0	2	1
Total				**16**	**15**	**17**

In Figure 41 the split in gender can be seen. Every participant identified themselves as either man or woman, so in these results only those two groups are shown, and a third group x is not used. Around 2/3 of the participants was women, thus to check if there are differences between the gender the total amount of points per gender for every speed was divided by the amount of men or women. In Figure 42 can be seen that women had a small preference for 12 km/h and men had a small preference for 18 km/h compared to women. However, 15 km/h was still the most realistic for both groups.

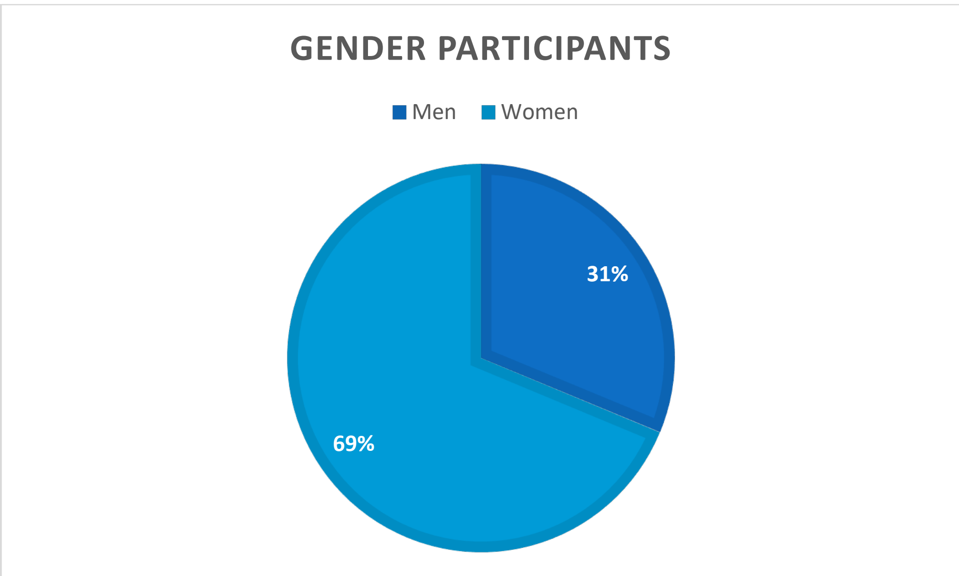


Figure 41 Gender test participants cycling speed

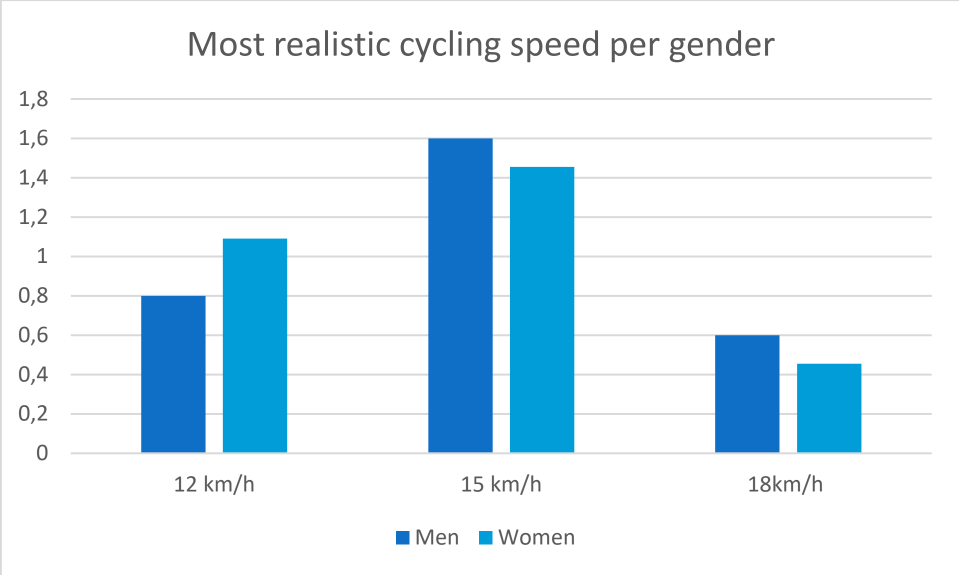


Figure 42 Most realistic cycling speed per gender

The participants were split in different age groups. In Figure 43 it can be seen that most of the participants were between 21-25 years old. Two participants were a bit older or younger than this group and formed their own group. Furthermore, four participants were between 51-55 years old. Since these groups were not the same size, the results per group were added and divided by the number of group members. To check if there were differences in age group, they were compared in Figure 44. The age groups 16-20 and 26-30 only consisted of one participant each, so they are combined with 21-25 year olds. The results are equal for both age groups, so there was no difference noticed.

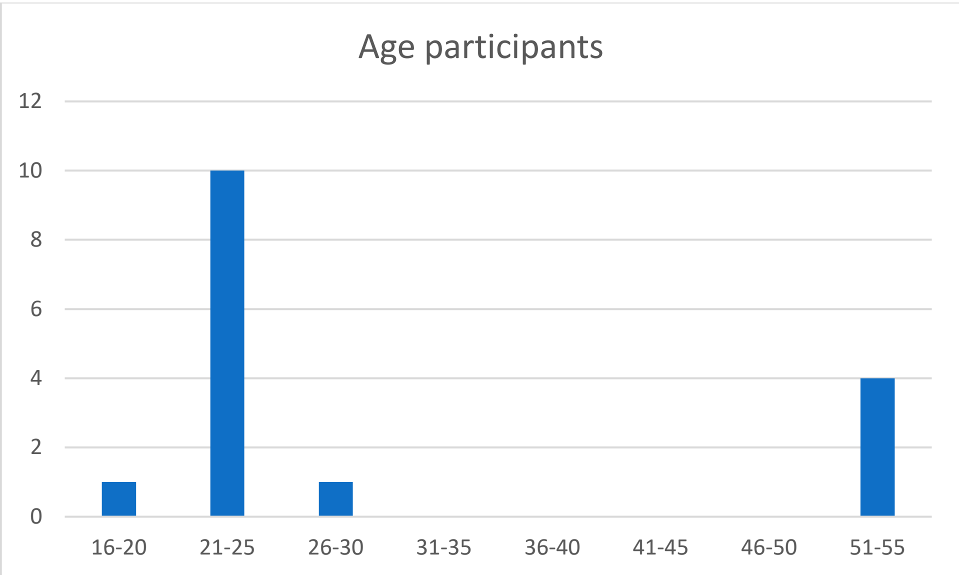


Figure 43 Age distribution test participants cycling speed

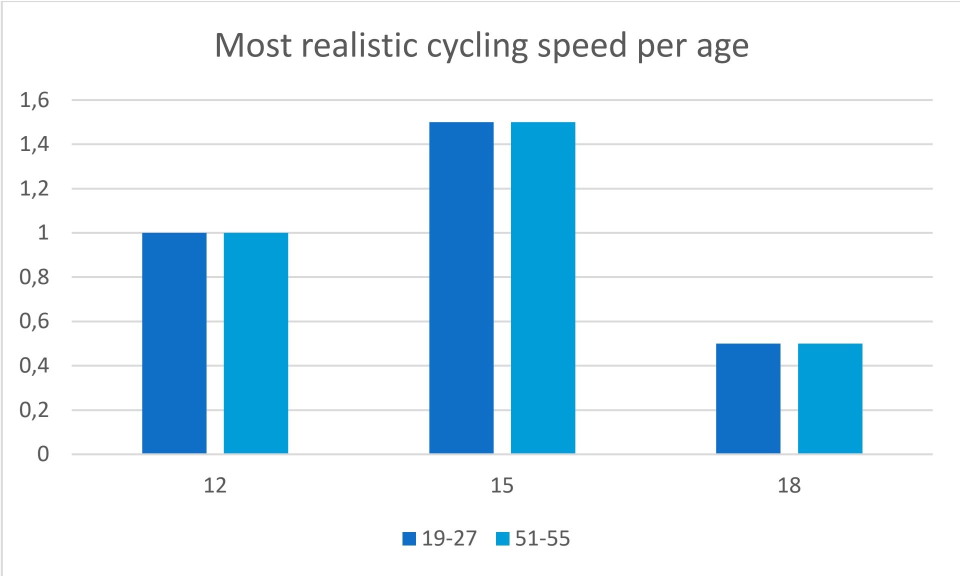


Figure 44 Most realistic cycling speed per age group

Appendix C: Participant results of the pilot study

Crossing scenarios

Characteristics test participants

For this pilot study the videos were shown to eight participants. For this pilot study there were 3 different versions made, which can be seen in Table 28. The answers given by each participant per scenario can be seen in Table 29. In Table 30 the answers per participant are shown in the order they were given, to see if the order mattered. It was noted that the vehicle in the first video was more often missed.

Table 28 Order of scenarios per version

	Order of scenarios			
Version A	20-0.5	30-0.5	20-2	30-2
Version B	30-0.5	30-2	20-0.5	20-2
Version C	30-2	20-0.5	20-2	30-0.5

Table 29 Answers given per test participants per scenario

Participant number	**Version**	**Age**	**Male/ female**	**20-0.5**	**30-0.5**	**20-2**	**30-2**
1	C	51	f	No car	No car	No car	No car
2	A	55	m	Stop	Stop	Speed up	Continue
3	B	51	m	Continue	Continue	Continue	No car
4	C	55	f	No car	No car	No car	No car
5	A	23	m	No car	Speed up	Speed up	No car
6	B	22	f	Speed up	No car	Continue	Continue
7	C	27	f	Continue	Continue	Continue	No car
8	A	24	f	Continue	Continue	Continue	Continue

Table 30 Answers given per test participants in shown order

Participant number	**Version**	**Age**	**Male/ female**	**Answer video 1**	**Answer video 2**	**Answer video 3**	**Answer video 4**
1	C	51	f	No car	No car	No car	No car
2	A	55	m	Stop	Stop	Speed up	Continue
3	B	51	m	Continue	No car	Continue	Continue
4	C	55	f	No car	No car	No car	No car
5	A	23	m	No car	Speed up	Speed up	No car
6	B	22	f	No car	Continue	Speed up	Continue
7	C	27	f	No car	Continue	Continue	Continue
8	A	24	f	Continue	Continue	Continue	Continue

How the gender of the participants was distributed can be seen in Figure 45. Since there were only 5 women and 3 men, the samples of both groups are too small to make a valid check for differences in gender. Especially since two women did not once see a vehicle. Therefore, no remarks can be made on the differences between Figure 46 and Figure 47.

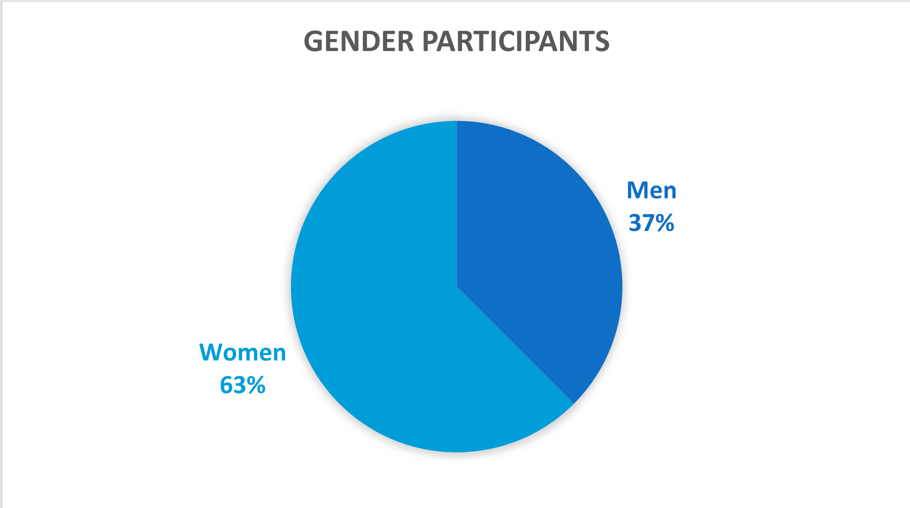


Figure 45 Gender participants of pilot study

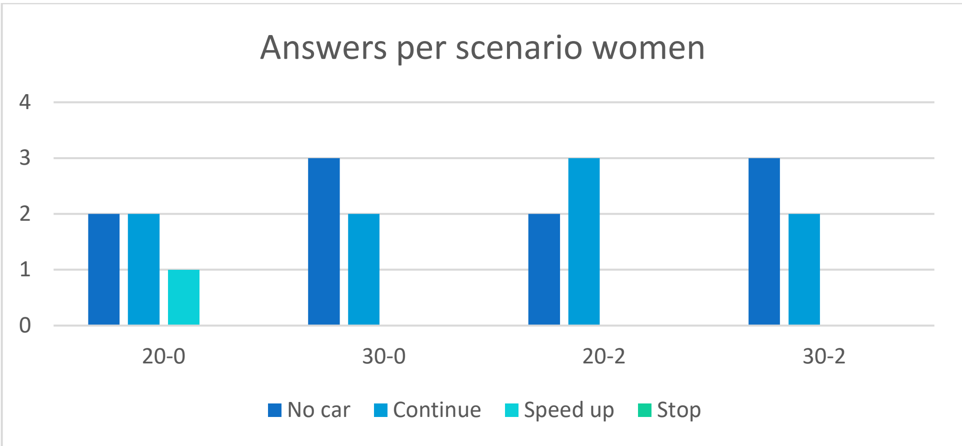


Figure 46 Answers per scenario given by women

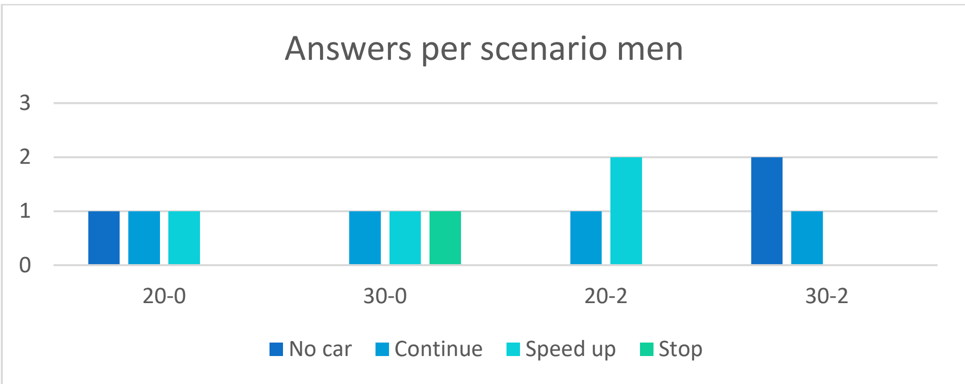


Figure 47 Answers per scenario given by men

For the age distribution roughly two age groups can be made, as shown in Figure 48. The biggest group is 51-55 year olds, three participants fitted in the 21-25 group and one participant was 27 years old. The 21-25 and 26-30 groups were merged, so two equal groups were created. However, it is difficult to compare, since both groups are quite small and the two participants who did not notice a vehicle are in the same group. The comparison of the two age groups can be seen between Figure 49 and Figure 50, but it was not possible to withdraw conclusions from this.

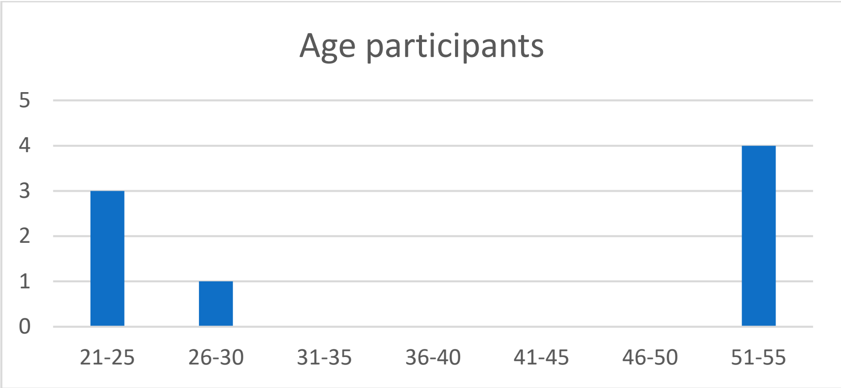


Figure 48 Age participants of pilot study

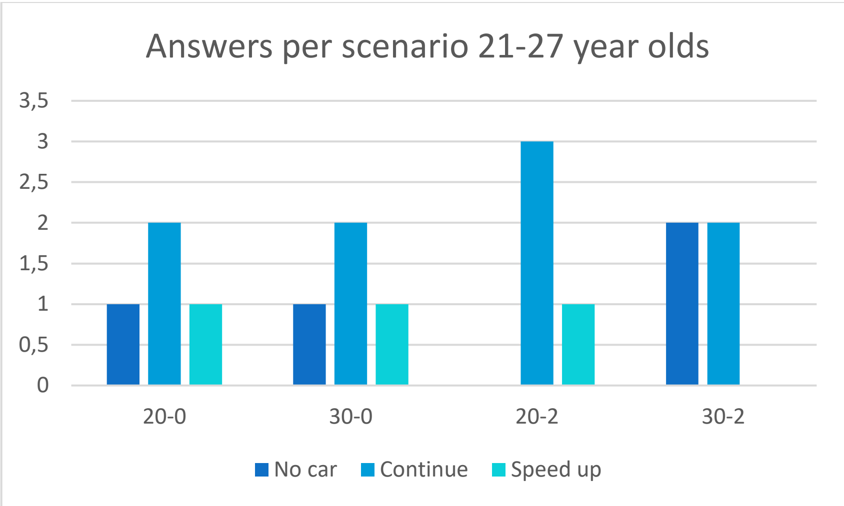


Figure 49 Answers given per scenario for age group 21-27

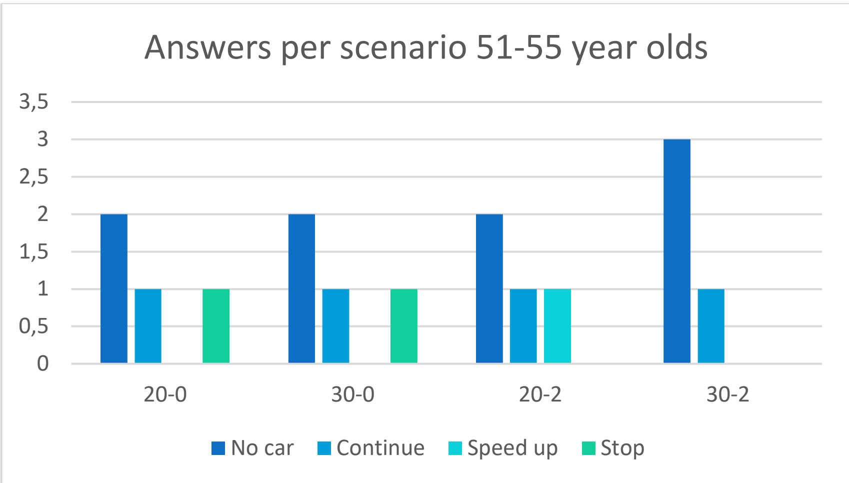


Figure 50 Answers given per scenario for age group 51-55

Appendix D: Covariance matrix

Correlations

		Session	Vehicle	Speed	GapSize	GapDistance	Priority	Risk Taking	Trust AV	Stated Trust in AV
Session	Pearson Correlation	1	,000	,000	,000	,000	,000	,000	,000	,000
	Sig. (2-tailed)		1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
	Sum of Squares and Cross-products	400,000	,000	,000	,000	,000	,000	,000	,000	,000
	Covariance	,250	,000	,000	,000	,000	,000	,000	,000	,000
	N	1600	1600	1600	1600	1600	1600	1600	1600	1600
Vehicle	Pearson Correlation	,000	1	,000	,000	,000	,000	,000	,000	,000
	Sig. (2-tailed)	1,000		1,000	1,000	1,000	1,000	1,000	1,000	1,000
	Sum of Squares and Cross-products	,000	400,000	,000	,000	,000	,000	,000	,000	,000
	Covariance	,000	,250	,000	,000	,000	,000	,000	,000	,000
	N	1600	1600	1600	1600	1600	1600	1600	1600	1600
Speed	Pearson Correlation	,000	,000	1	,000	,447**	,000	,000	,000	,000
	Sig. (2-tailed)	1,000	1,000		1,000	,000	1,000	1,000	1,000	1,000
	Sum of Squares and Cross-products	,000	,000	400,000	,000	400,000	,000	,000	,000	,000
	Covariance	,000	,000	,250	,000	,250	,000	,000	,000	,000
	N	1600	1600	1600	1600	1600	1600	1600	1600	1600
GapSize	Pearson Correlation	,000	,000	,000	1	,894**	,000	,000	,000	,000
	Sig. (2-tailed)	1,000	1,000	1,000		,000	1,000	1,000	1,000	1,000
	Sum of Squares and Cross-products	,000	,000	,000	400,000	800,000	,000	,000	,000	,000
	Covariance	,000	,000	,000	,250	,500	,000	,000	,000	,000
	N	1600	1600	1600	1600	1600	1600	1600	1600	1600
GapDistance	Pearson Correlation	,000	,000	,447**	,894**	1	,000	,000	,000	,000
	Sig. (2-tailed)	1,000	1,000	,000	,000		1,000	1,000	1,000	1,000

	Sum of Squares and Cross-products	,000	,000	400,000	800,000	2000,000	,000	,000	,000	,000
	Covariance	,000	,000	,250	,500	1,251	,000	,000	,000	,000
	N	1600	1600	1600	1600	1600	1600	1600	1600	1600
Priority	Pearson Correlation	,000	,000	,000	,000	,000	1	,000	,000	,000
	Sig. (2-tailed)	1,000	1,000	1,000	1,000	1,000		1,000	1,000	1,000
	Sum of Squares and Cross-products	,000	,000	,000	,000	,000	400,000	,000	,000	,000
	Covariance	,000	,000	,000	,000	,000	,250	,000	,000	,000
	N	1600	1600	1600	1600	1600	1600	1600	1600	1600
Risk Taking	Pearson Correlation	,000	,000	,000	,000	,000	,000	1	,122**	-,055*
	Sig. (2-tailed)	1,000	1,000	1,000	1,000	1,000	1,000		,000	,027
	Sum of Squares and Cross-products	,000	,000	,000	,000	,000	,000	400,000	48,000	-32,000
	Covariance	,000	,000	,000	,000	,000	,000	,250	,030	-,020
	N	1600	1600	1600	1600	1600	1600	1600	1600	1600
Trust AV	Pearson Correlation	,000	,000	,000	,000	,000	,000	,122**	1	-,154**
	Sig. (2-tailed)	1,000	1,000	1,000	1,000	1,000	1,000	,000		,000
	Sum of Squares and Cross-products	,000	,000	,000	,000	,000	,000	48,000	389,760	-88,320
	Covariance	,000	,000	,000	,000	,000	,000	,030	,244	-,055
	N	1600	1600	1600	1600	1600	1600	1600	1600	1600
Stated Trust in AV	Pearson Correlation	,000	,000	,000	,000	,000	,000	-,055*	-,154**	1
	Sig. (2-tailed)	1,000	1,000	1,000	1,000	1,000	1,000	,027	,000	
	Sum of Squares and Cross-products	,000	,000	,000	,000	,000	,000	-32,000	-88,320	842,240
	Covariance	,000	,000	,000	,000	,000	,000	-,020	-,055	,527
	N	1600	1600	1600	1600	1600	1600	1600	1600	1600

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix E: Model session 1 and 2 compared

Table 31 Fixed coefficients of final Mixed Model (Session 1 only)

Answer	**Model Term**		**Coefficient**	**Std. Error**	**t**	**Sig.**
Slow down	Intercept		-0.965	0.3936	-2.452	0.014
	Vehicle	CV	-0.480	0.2717	-1.766	0.078
		AV	0^b			
	GapDistance	2.778 m	2.344	0.3235	7.247	0.000
		4.167 m	2.500	0.3221	7.762	0.000
		11.111 m	0.130	0.3452	0.378	0.706
		16.667 m	0^b			
	Priority	Priority to cyclist	-2.086	0.2222	-9.388	0.000
		Priority to vehicle	0^b			
	RiskTaking	Low risk takers	0.833	0.3558	2.340	0.020
		High risk takers	0^b			
	StatedTrust	More trust in AV	-0.140	0.6023	-0.233	0.816
		Less trust in AV	-0.390	0.4599	-0.848	0.397
		No difference	0^b			
	[Vehicle]*[Stated Trust]	CV * More trust in AVs	0.928	0.6072	1.529	0.127
		CV * Less trust in AVs	-0.421	0.4884	-0.861	0.389
		CV * No difference	0^b			
		AV * More trust in AVs	0^b			
		AV * Less trust in AVs	0^b			
		AV * No difference	0^b			
Cycle faster	Intercept		-0.127	0.2859	-0.445	0.657
	Vehicle	CV	0.163	0.2330	0.699	0.485
		AV	0^b			
	GapDistance	2.778 m	0.488	0.2506	1.948	0.052
		4.167 m	0.121	0.2622	0.460	0.646
		11.111 m	-0.041	0.2260	-0.183	0.855
		16.667 m	0^b			
	Priority	Priority to cyclist	-0.795	0.1802	-4.413	0.000

	Priority to vehicle	0^b			
RiskTaking	Low risk takers	0.322	0.2527	1.274	0.203
	High risk takers	0^b			
StatedTrust	More trust in AV	0.209	0.4512	0.463	0.643
	Less trust in AV	-0.165	0.3580	-0.462	0.644
	No difference	0^b			
[Vehicle]*[Stated Trust]	CV * More trust in AVs	-0.464	0.5380	-0.862	0.389
	CV * Less trust in AVs	-0.046	0.3994	-0.114	0.909
	CV * No difference	0^b			
	AV * More trust in AVs	0^b			
	AV * Less trust in AVs	0^b			
	AV * No difference	0^b			

Table 32 Fixed coefficients of final Mixed Model (Session 2 only)

Answer	**Model Term**		**Coefficient**	**Std. Error**	**t**	**Sig.**
Slow down	Intercept		-1.291	0.4265	-3.028	0.003
	Vehicle	CV	0.020	0.2867	0.070	0.945
		AV	0^b			
	GapDistance	2.778 m	3.110	0.3497	8.894	0.000
		4.167 m	3.053	0.3411	8.953	0.000
		11.111 m	0.118	0.3603	0.327	0.744
		16.667 m	0^b			
	Priority	Priority to cyclist	-2.602	0.2447	-10.634	0.000
		Priority to vehicle	0^b			
	RiskTaking	Low risk takers	0.776	0.4000	1.940	0.053
		High risk takers	0^b			
	StatedTrust	More trust in AV	-0.712	0.6715	-1.060	0.289
		Less trust in AV	0.315	0.5112	0.616	0.538
		No difference	0^b			

	[Vehicle]*[Stated Trust]	CV * More trust in AVs	1.076	0.6448	1.669	0.096
		CV * Less trust in AVs	-1.654	0.5131	-3.222	0.001
		CV * No difference	0^b			
		AV * More trust in AVs	0^b			
		AV * Less trust in AVs	0^b			
		AV * No difference	0^b			
Cycle faster	Intercept		-0.533	0.3175	-1.679	0.094
	Vehicle	CV	0.275	0.2425	1.133	0.257
		AV	0^b			
	GapDistance	2.778 m	1.580	0.2714	5.822	0.000
		4.167 m	0.603	0.2836	2.125	0.034
		11.111 m	0.130	0.2420	0.538	0.591
		16.667 m	0^b			
	Priority	Priority to cyclist	-1.074	0.1953	-5.501	0.000
		Priority to vehicle	0^b			
	RiskTaking	Low risk takers	0.547	0.2977	1.838	0.066
		High risk takers	0^b			
	StatedTrust	More trust in AV	-0.611	0.5283	-1.156	0.248
		Less trust in AV	0.176	0.4016	0.437	0.662
		No difference	0^b			
	[Vehicle]*[Stated Trust]	CV * More trust in AVs	0.343	0.5725	0.598	0.550
		CV * Less trust in AVs	-1.164	0.4303	-2.706	0.007
		CV * No difference	0^b			
		AV * More trust in AVs	0^b			
		AV * Less trust in AVs	0^b			
		AV * No difference	0^b			

Appendix F: VR Environment questions

	Not at all			Moderately			Very
How much were you able to control events?	○	○	○	○	○	○	○
How responsive was the environment to actions you initiated (or performed)?	○	○	○	○	○	○	○
How natural did your interactions with the environment seem?	○	○	○	○	○	○	○
How much did the visual aspects of the environment involve you?	○	○	○	○	○	○	○
How natural was the mechanism (e.g. VR glasses) which controlled movement through the environment?	○	○	○	○	○	○	○
How compelling was your sense of objects moving through space?	○	○	○	○	○	○	○
How much did your experiences in the virtual environment seem consistent with your real world experiences?	○	○	○	○	○	○	○
How compelling was your sense of moving around inside the virtual environment?	○	○	○	○	○	○	○
How much delay did you experience between your actions (e.g. turning your head) and expected outcomes?	○	○	○	○	○	○	○
How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	○	○	○	○	○	○	○
How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?	○	○	○	○	○	○	○
How much did the VR glasses interfere with the performance of assigned	○	○	○	○	○	○	○

	Not at all			Moderately			Very
tasks or with other activities?							
How well could you concentrate on the assigned tasks or with other activities?	○	○	○	○	○	○	○
How completely were your senses engaged in this experience?	○	○	○	○	○	○	○
Were there moments during the virtual experience when you felt completely focused on the task or environment?	○	○	○	○	○	○	○
How easily did you adjust to the VR glasses used to interact with the virtual environment?							

Appendix G: Effect of speed, gap distance or priority on the type of vehicle

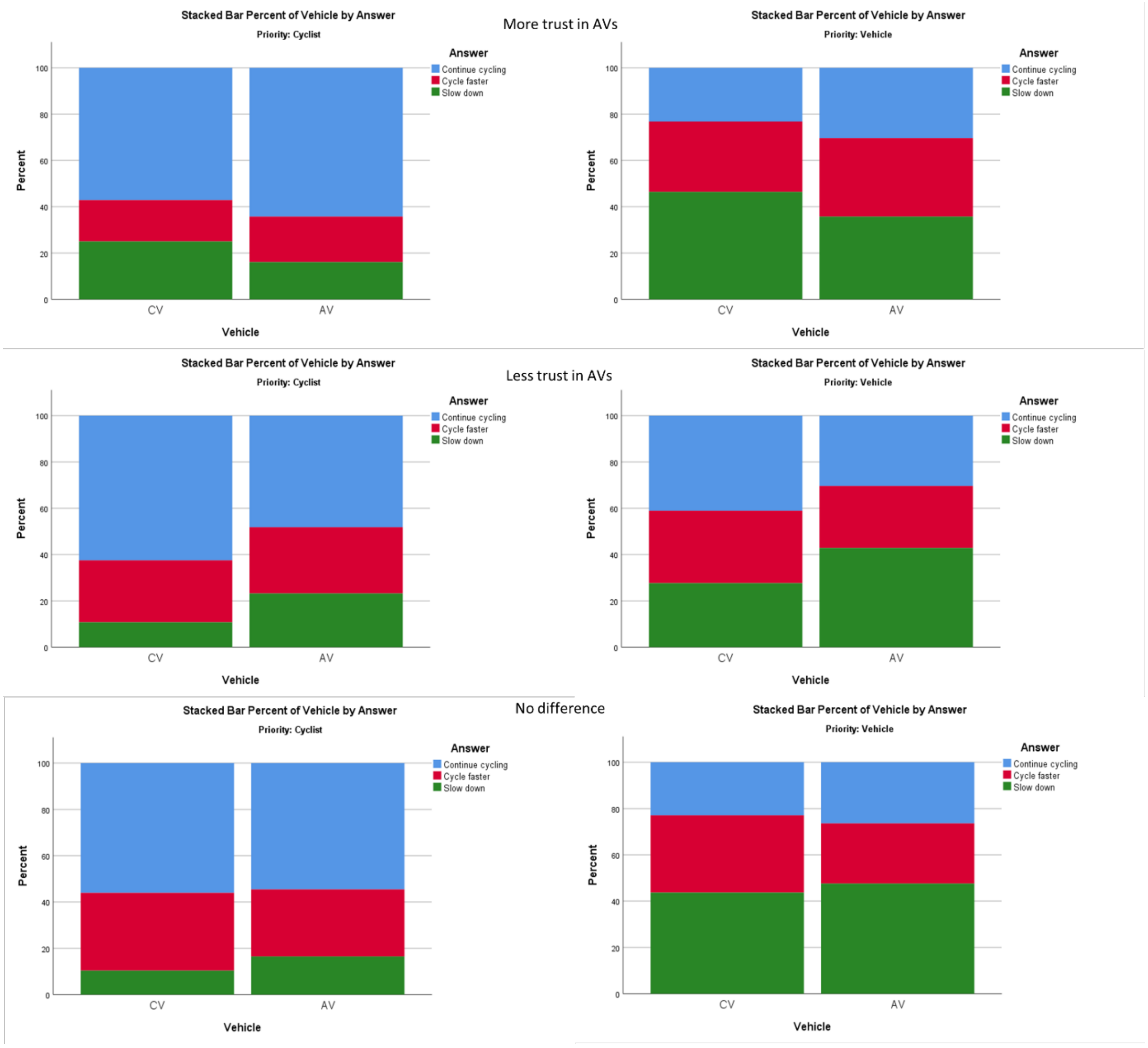


Figure 51 Effect of a switch in priority per vehicle divided by stated trust

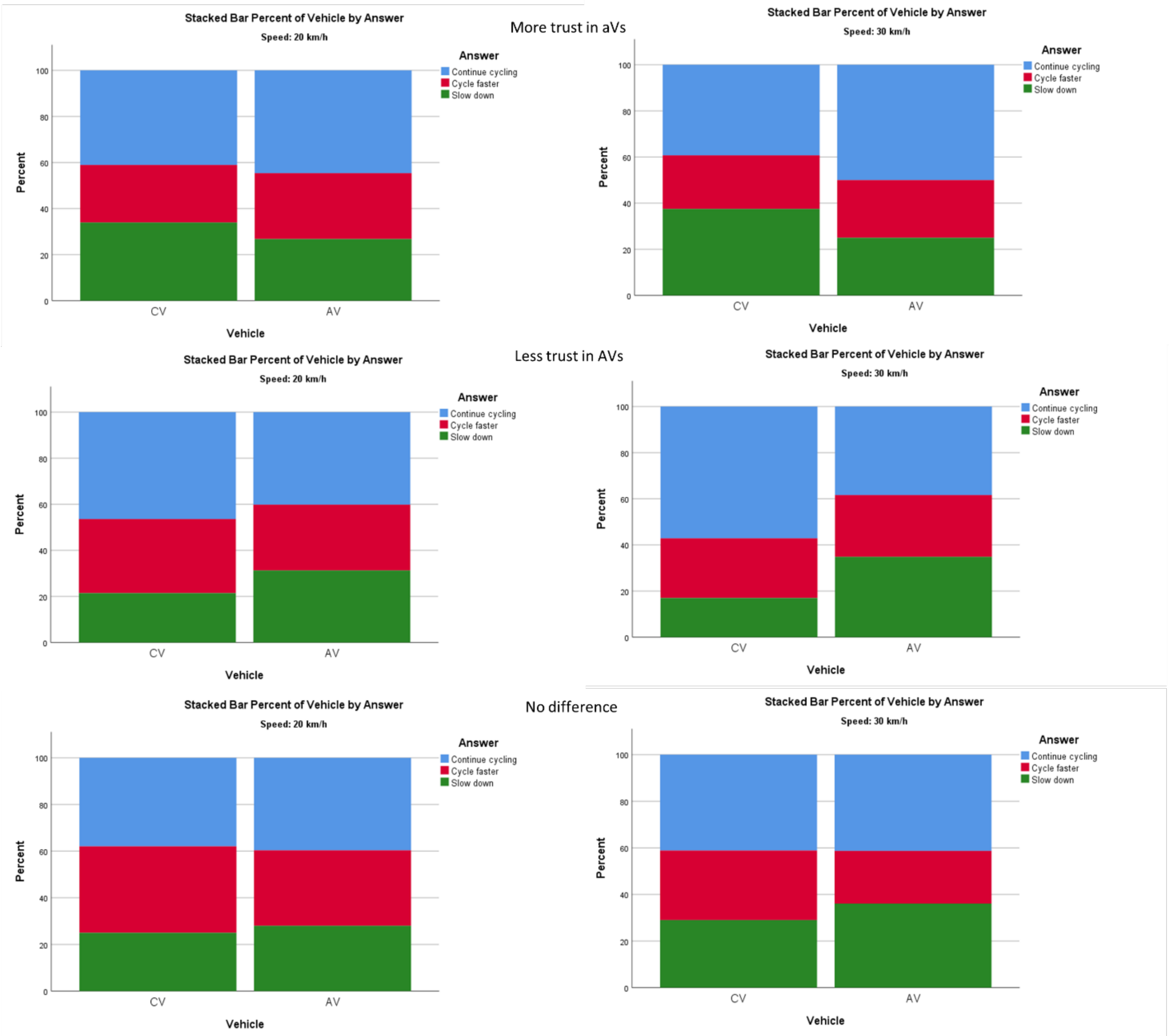


Figure 52 Effect of a switch in speed per vehicle divided by stated trust

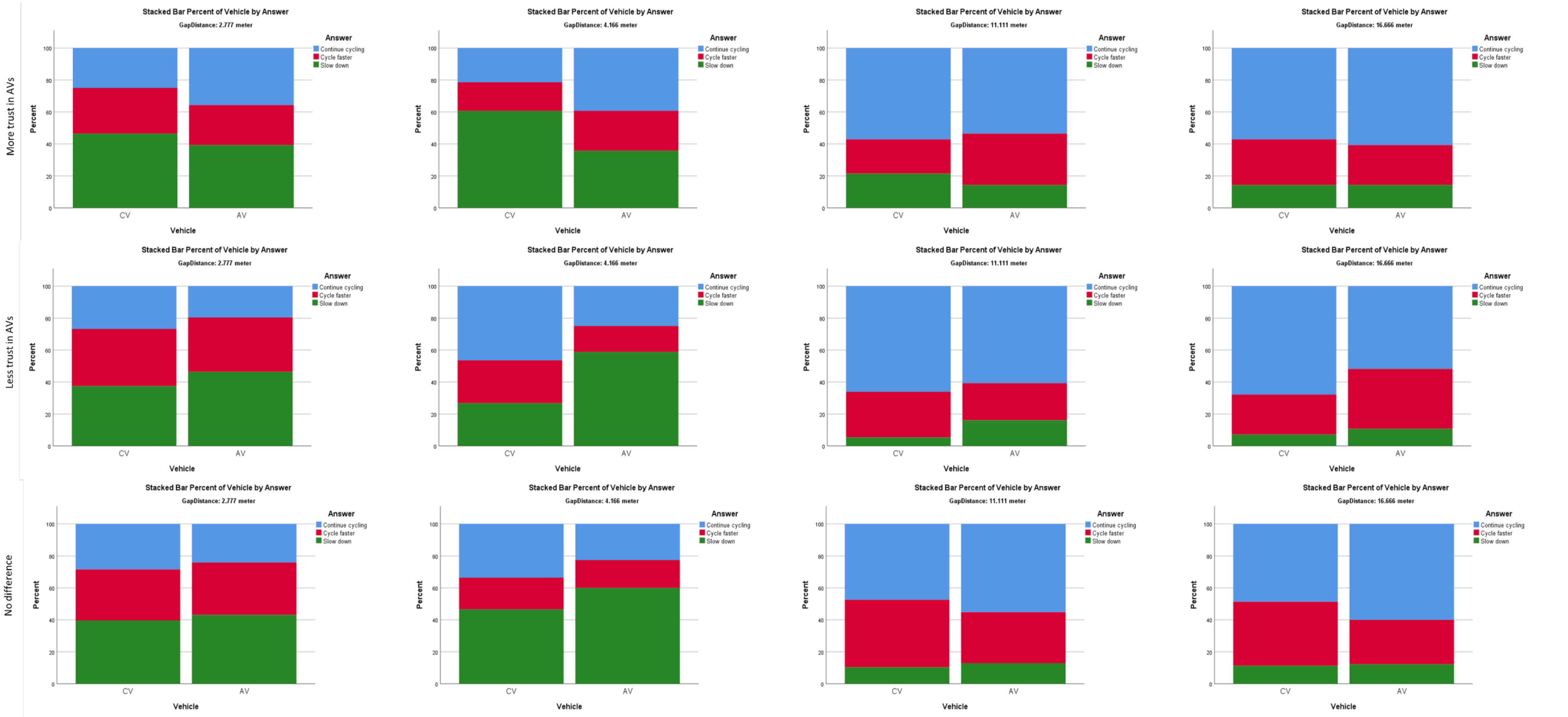


Figure 53 Effect of a switch in gap distance per vehicle divided by stated trust

Appendix H: Complete survey questions

Q1.1 This survey will take approximately 20 minutes of your time.

Please read each question carefully and answer it to the best of your ability.

Feel free to ask as many questions as you want!

Q1.2 What is your participant's number? (ask experiment leader)

____

Q93 Which version will be used? (ask experiment leader)

- ◯ A
- ◯ B
- ◯ C

Q2.1 How old are you?

____

Q2.2 What is your gender?

- ◯ Female
- ◯ Male
- ◯ Other/ I prefer not to say

Q2.3 What is your native language?

____

Q2.4 What is your nationality?

____

Q2.5 How long have you been living in the Netherlands?

____

Q2.6 What is your highest degree obtained?

- ◯ Less than high school
- ◯ High school graduate
- ◯ Bachelor degree
- ◯ Master degree
- ◯ Doctorate
- ◯ Other

Q2.7 What is your current occupation?

- ◯ Employed full time
- ◯ Employed part time
- ◯ Unemployed looking for work
- ◯ Unemployed not looking for work
- ◯ Retired
- ◯ Student
- ◯ Other

Q3.1 The following questions are about your eye-sight.

Q3.2 Do you use glasses/ contact lenses (or other instruments to improve your vision) in everyday life?

- ◯ Yes
- ◯ No

Q3.3 Are you colour blind?

- ◯ Yes
- ◯ No

Display This Question:

If Are you colour blind? = Yes

Q3.4 What kind of colour blindness do you suffer from? (Which colours?)

____

Display This Question:

If Do you use glasses/ contact lenses (or other instruments to improve your vision) in everyday life? = Yes

Q3.5 Did you used them during the experiment?

- ○ Yes, I used glasses
- ○ Yes, I used contact lenses
- ○ No

Display This Question:

If Did you used them during the experiment? = No

Q3.6 Did you feel that you needed them?

- ○ Yes
- ○ No

Q4.1 The following questions are about your behaviour as a Cyclist.

Please answer the following questions:

Q4.2 How often do you cycle in a day?

- ◯ Never
- ◯ Rarely (0-2 times a day)
- ◯ Often (2-4 times a day)
- ◯ Frequently (4+ times a day)

Q4.3 What is the main reason for your cycling trip?

- ◯ Commuting
- ◯ Leisure
- ◯ Other

Q4.4 Other, namely:

____

Q4.5 What range describes best your daily cycling time?

- ◯ 0 - 15 minutes
- ◯ 15 - 30 minutes
- ◯ 30 - 45 minutes
- ◯ 45 - 60 minutes
- ◯ 60 minutes and above

Q4.6 Are you a car driver?

- ◯ Yes
- ◯ No

Q4.7 How long ago did you get your license?

- ◯ Less than 1 year
- ◯ 1-2 years
- ◯ 3-5 years
- ◯ 5 or more years

Q4.8
As a cyclist, how often do you...

	Never	Rarely	Sometimes	Often	Very Often
Forget to look properly because you are talking to friends who are with you	○	○	○	○	○
Cross from between parked cars when there is a safer place to cross nearby	○	○	○	○	○
Think it is OK to cross safely, but a car is coming faster than you thought	○	○	○	○	○
Forget to look properly because you are thinking about something else	○	○	○	○	○
See a small gap in traffic and "go for it"	○	○	○	○	○
Rush across a road without looking because you are in a hurry	○	○	○	○	○
Cross whether traffic is coming or not, thinking the traffic should stop for you	○	○	○	○	○
Get part way across the road and then have to rush the rest of the way to avoid traffic	○	○	○	○	○
Cross from behind a stationary vehicle	○	○	○	○	○

Cross when you cannot see both ways very well (like on a bend or top of hill)	○	○	○	○	○
Not look because you do not hear any traffic around	○	○	○	○	○
Use a mobile phone and forget to look properly	○	○	○	○	○
Not notice a car pulling out (say from a driveway) and cycle in front of it	○	○	○	○	○
Cross without waiting for the traffic light to turn green	○	○	○	○	○
Cycle on infrastructure not intended for cyclists (like pavements)	○	○	○	○	○
Cycle on the road rather than on the bicycle lane	○	○	○	○	○

Q5.1
Information experiment

16 scenarios will be shown to you. The scenarios will be from the point of view of the cyclist and you will be cycling towards a crossing. In the videos you will be seeing a vehicle arriving at the crossing as well. When the video stops you need to decide whether you will cross or not. After each video you will therefore be asked to answer the same question, with the same answer options:
"What will you do?"

- Continue cycling
This option means you will continue cycling in the same pace as before and cross before the vehicle does.

- Cycle faster
This option means you will speed up so you can cross before the vehicle crosses.

- Slow down
This option means you will let the car cross first. Therefore, you brake or stop pedalling to slow down.

You will be asked to answer this question out loud and within 5 seconds after the question is shown. Thereafter the video will continue with the next scenario.

You will first see an introductory video, in which there will be no vehicle, so you can watch around you if you like.

After 8 scenarios there will be a short break, but you may always stop in between. There is a small chance that the virtual reality environment causes discomforts, such as nausea, eyestrain or disorientation. If you are not feeling well, please inform me, so you can take a break. If you feel uncomfortable we can decide to stop the experiment.

Q82

Misery Scale

Symptom		Score
No problems		0
Slight discomfort, but no specific symptoms		1
Dizziness, warm, headache, stomach awareness, sweating, etc.	Vague	2
	Some	3
	Medium	4
	Severe	5
Nausea	Some	6
	Medium	7
	Severe	8
	Retching	9
Vomiting		10

Q83

To make sure you don't get sick, we ask you to fill in this Misery Scale before, during and after the experiment.

How much motion sickness do you experience on a scale from 0 to 10 based on the Misery scale before the experiment (see picture)?

○ 0

○ 1

○ 2

○ 3

○ 4

○ 5

○ 6

○ 7

○ 8

○ 9

○ 10

Q84 You can now start the first part of the experiment.

Q90 What would you do?

	Continue cycling	Cycle faster	Slow down	No car seen
1	◯	◯	◯	◯
2	◯	◯	◯	◯
3	◯	◯	◯	◯
4	◯	◯	◯	◯
5	◯	◯	◯	◯
6	◯	◯	◯	◯
7	◯	◯	◯	◯
8	◯	◯	◯	◯
9	◯	◯	◯	◯
10	◯	◯	◯	◯
11	◯	◯	◯	◯
12	◯	◯	◯	◯
13	◯	◯	◯	◯
14	◯	◯	◯	◯
15	◯	◯	◯	◯
16	◯	◯	◯	◯

Q5.2

Misery Scale

Symptom		Score
No problems		0
Slight discomfort, but no specific symptoms		1
Dizziness, warm, headache, stomach awareness, sweating, etc.	Vague	2
	Some	3
	Medium	4
	Severe	5
Nausea	Some	6
	Medium	7
	Severe	8
	Retching	9
Vomiting		10

Q5.3
Fill in after 8 scenarios:

How much motion sickness do you experience on a scale from 0 to 10 based on the Misery scale before the experiment (see picture)?

- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7
- ○ 8
- ○ 9
- ○ 10

Q85

Misery Scale

Symptom		Score
No problems		0
Slight discomfort, but no specific symptoms		1
Dizziness, warm, headache, stomach awareness, sweating, etc.	Vague	2
	Some	3
	Medium	4
	Severe	5
Nausea	Some	6
	Medium	7
	Severe	8
	Retching	9
Vomiting		10

Q86 Fill in after 16 scenarios:

How much motion sickness do you experience on a scale from 0 to 10 based on the Misery scale before the experiment (see picture)?

- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7
- ○ 8
- ○ 9
- ○ 10

Q6.1 Did you notice any differences between the vehicles?

- ☐ Yes
- ☐ No

Skip To: End of Block If Did you notice any differences between the vehicles? = No

Q6.2 What differences did you perceive?

____

____

____

____

____

Q6.3 The following questions are about your experience in the presented trials.
Please recall how you felt during the experiment.

Q6.4 These questions are about the following vehicle (see picture below):

Q6.5

Q6.6 Crossing the road in front of this vehicle, was to me...

	1	2	3	4	5	6	7	
Very difficult	○	○	○	○	○	○	○	Very easy

Q6.7 How much do you agree with the following statement?

I believe that I had the ability to cross in front of this vehicle...

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

Q6.8 To cross the road in front of this vehicle seemed to me...

	1	2	3	4	5	6	7	
Very unsafe	○	○	○	○	○	○	○	Very safe

Q6.9 These questions are about the following vehicle (see picture below):

Q6.10

Q6.11 Crossing the road in front of this vehicle, was to me...

	1	2	3	4	5	6	7	
Very difficult	○	○	○	○	○	○	○	Very easy

Q6.12 How much do you agree with the following statement?

I believe that I had the ability to cross in front of this vehicle...

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

Q6.13 To cross the road in front of this vehicle, seemed to me...

	1	2	3	4	5	6	7	
Very unsafe	○	○	○	○	○	○	○	Very safe

Q7.1 Do you know what an automated vehicle is?

○ Yes

○ No

Q7.2 How much do you know about automated vehicles (aka autonomous vehicles and self-driving vehicles)?

Rate your knowledge on a scale of 1-6, with 1 being you know almost nothing, and 6 being you know a great deal.

○ 1

○ 2

○ 3

○ 4

○ 5

○ 6

Display This Question:

If Do you know what an automated vehicle is? = No

Q7.3 An automated vehicle is a vehicle that is able to take over tasks from the driver, such as steering, and lane changing, but also detecting other road users.

Q7.4 Did you think that any of the shown vehicles was an automated vehicle (also known as an autonomous vehicle or self-driving vehicle)?
There is no right or wrong answer.

- ◯ I was not thinking about automated vehicles at all during the experiment
- ◯ I did think about automated vehicles, but I did not think any of the vehicles was automated
- ◯ I did think about automated vehicles, and I did think some vehicles were automated
- ◯ I did think about automated vehicles, and I did think all vehicles were automated

Display This Question:

If Did you think that any of the shown vehicles was an automated vehicle (also known as an autonomou... = I did think about automated vehicles, and I did think some vehicles were automated

Q7.5 Which ones were automated? Why did you think that?
Please give a complete answer.

____

____

____

____

____

Q7.6 The next questions are about your trust in automated vehicles.
There are no right or wrong answers.

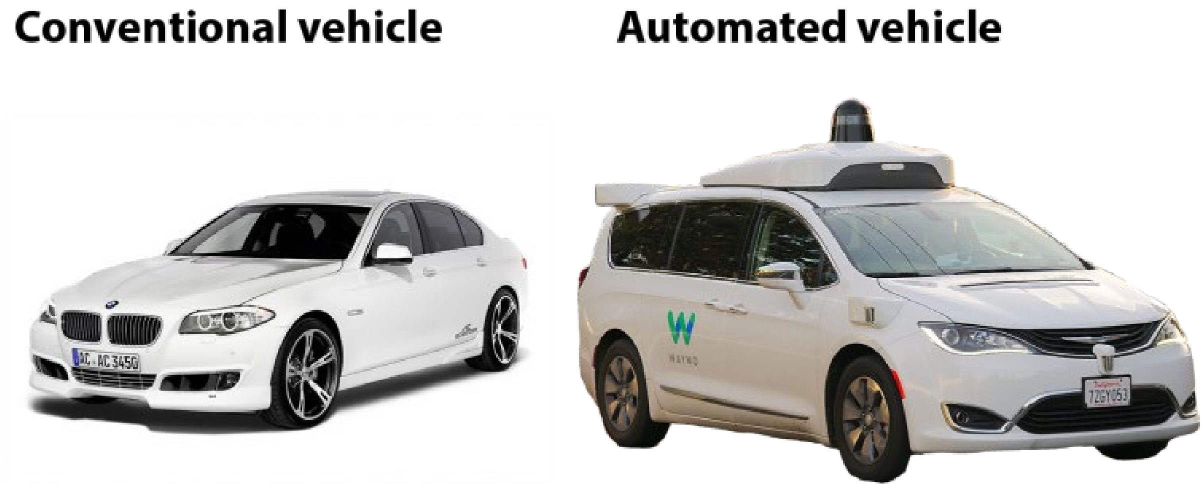
Q7.7 Please answer the following questions.

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Globally, I trust the automated vehicle.	○	○	○	○	○	○	○
I trust the automated vehicle to keep to a lane	○	○	○	○	○	○	○
I trust the automated vehicle to avoid obstacles	○	○	○	○	○	○	○
I trust the automated vehicle to keep distance from me	○	○	○	○	○	○	○
I trust the automated vehicle to drive safe	○	○	○	○	○	○	○
I trust the automated vehicle to have seen me	○	○	○	○	○	○	○
I trust the automated vehicle to obey the traffic rules	○	○	○	○	○	○	○
I trust the automated vehicle to stop for me when I cross, even when I do not obey the traffic rules	○	○	○	○	○	○	○

I would feel comfortable if my child, spouse, parents - or other loved ones - cross roads in presence of an automated vehicle	○	○	○	○	○	○	○
I would recommend my family and friends to be comfortable while crossin roads in front of an automated vehicle	○	○	○	○	○	○	○
I would feel more comfortable doing other things (e.g. checking emails on my smartphone, talking to my companions) while crossing the road in front of an automated vehicle	○	○	○	○	○	○	○

Q8.1 You have seen 2 different vehicles in the scenarios you have watched.
One of the vehicles was a conventional vehicle and the other was an automated vehicle that is driving around in the USA right now.

Q8.2



Q8.3 You can now continue the VR experiment with the next 16 scenarios

Q92 What would you do?

	Continue cycling	Cycle faster	Slow down	No car seen
1	○	○	○	○
2	○	○	○	○
3	○	○	○	○
4	○	○	○	○
5	○	○	○	○
6	○	○	○	○
7	○	○	○	○
8	○	○	○	○
9	○	○	○	○
10	○	○	○	○
11	○	○	○	○
12	○	○	○	○
13	○	○	○	○
14	○	○	○	○
15	○	○	○	○
16	○	○	○	○

Q87

Misery Scale

Symptom		Score
No problems		0
Slight discomfort, but no specific symptoms		1
Dizziness, warm, headache, stomach awareness, sweating, etc.	Vague	2
	Some	3
	Medium	4
	Severe	5
Nausea	Some	6
	Medium	7
	Severe	8
	Retching	9
Vomiting		10

Q9.1
Fill in after 24 scenarios:

How much motion sickness do you experience on a scale from 0 to 10 based on the Misery scale before the experiment (see picture)?

- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7
- ○ 8
- ○ 9
- ○ 10

Q88

Misery Scale

Symptom		Score
No problems		0
Slight discomfort, but no specific symptoms		1
Dizziness, warm, headache, stomach awareness, sweating, etc.	Vague	2
	Some	3
	Medium	4
	Severe	5
Nausea	Some	6
	Medium	7
	Severe	8
	Retching	9
Vomiting		10

Q89 Fill in at the end of the experiment:

How much motion sickness do you experience on a scale from 0 to 10 based on the Misery scale before the experiment (see picture)?

- ◯ 0
- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10

Q10.1 Did you feel different about the vehicles once you knew one was automated and the other was not?

- ◯ Yes
- ◯ Maybe
- ◯ No

Q10.2 In what way?

____

____

Q10.3 The following questions are about your experience in the presented trials.
Please recall how you felt during the experiment.

Q10.4 These questions are about the normal vehicle (see picture below):

Q10.5

Q10.6 Crossing the road in front of this vehicle, was to me...

	1	2	3	4	5	6	7	
Very difficult	○	○	○	○	○	○	○	Very easy

Q10.7 How much do you agree with the following statement?

I believe that I had the ability to cross in front of this vehicle...

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

Q10.8 To cross the road in front of this vehicle seemed to me...

	1	2	3	4	5	6	7	
Very unsafe	○	○	○	○	○	○	○	Very safe

Q10.9 These questions are about the automated vehicle (see picture below):

Q10.10

Q10.11 Crossing the road in front of this vehicle, was to me...

	1	2	3	4	5	6	7	
Very difficult	○	○	○	○	○	○	○	Very easy

Q10.12 How much do you agree with the following statement?

I believe that I had the ability to cross in front of this vehicle...

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

Q10.13 To cross the road in front of this vehicle, seemed to me...

	1	2	3	4	5	6	7	
Very unsafe	○	○	○	○	○	○	○	Very safe

Q11.1 The following questions are about your "Presence" in the presented VR environment.

Presence is defined as "the subjective experience of being in one place or environment, even when one is physically situated in another" (Singer & Bitmer, 1999)

Please fill in all the questions quickly. There are no wrong or bad answers, it is only about how you experienced the VR environment.

Q11.2 Please state how you felt about the VR environment.

	Not at all			Moderately			Very
How much were you able to control events?	○	○	○	○	○	○	○
How responsive was the environment to actions you initiated (or performed)?	○	○	○	○	○	○	○
How natural did your interactions with the environment seem?	○	○	○	○	○	○	○
How much did the visual aspects of the environment involve you?	○	○	○	○	○	○	○
How natural was the mechanism (e.g. VR glasses) which controlled movement through the environment?	○	○	○	○	○	○	○
How compelling was your sense of objects moving through space?	○	○	○	○	○	○	○
How much did your experiences in the virtual environment seem consistent with your real world experiences?	○	○	○	○	○	○	○
How compelling was your sense of moving around inside the virtual environment?	○	○	○	○	○	○	○

How much delay did you experience between your actions (e.g. turning your head) and expected outcomes?	○	○	○	○	○	○	○
How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	○	○	○	○	○	○	○
How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?	○	○	○	○	○	○	○
How much did the VR glasses interfere with the performance of assigned tasks or with other activities?	○	○	○	○	○	○	○
How well could you concentrate on the assigned tasks or with other activities?	○	○	○	○	○	○	○
How completely were your senses engaged in this experience?	○	○	○	○	○	○	○
Were there moments during the virtual experience when you felt completely focused on the task or environment?	○	○	○	○	○	○	○

How easily did you adjust to the VR glasses used to interact with the virtual environment?	○	○	○	○	○	○	○

Q11.3 Do you think that the virtual reality crossing experience in the experiment differs from real life?

○ Yes

○ No

Q11.4 During the experiment, how safe did you feel while crossing the road in comparison to real life?

○ Unsafe

○ Slightly unsafe

○ No difference

○ Slightly safer

○ Safer

Display This Question:

If Do you think that the virtual reality crossing experience in the experiment differs from real life? = Yes

Q11.5 In what way did the crossing experience differ from real life?

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Q12.1 Our previous studies have shown some interesting results which we have not been able to explain. Therefore, we would like to interview you once we have analyzed the data. This interview would help us understand how the results should be interpreted.

We would really appreciate if you could help us.

Q12.2 Would you be interested in participating?

- ○ Yes
- ○ No

Q12.3 On what email can we reach you?

____

Q12.4 **DEBRIEFING**
Thank you for participating in this experiment!
The experiment of today was designed to give insights into the cyclists' behaviour around automated vehicles. In each video we have varied various variables, such as the type of vehicle and the speed of the vehicle.
We could not inform you further about the nature because this could cause changes in your expectations and behaviour.
Would you be so kind to inform your friends, fellow-students, etc. about this experiment without telling what it is really about? :)

Q12.5 Do you have any suggestions for this VR experiment? Or any remarks?

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