Using a wearable eye-tracking device on bicyclists to explore the possibity of measuring motorcyclist eye movements.

Steven de Vries

Faculty Behavioural, Management and Social Sciences (BMS)

Master Human Factors Engineering

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1st supervisor and assessor: Dr. M. Noordzij

2nd supervisor and assessor: C. Engbers MSc

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Abstract

This study was aimed at exploring the possibility of using the Tobii Pro Glasses 2 wearable eye-tracker to measure motorcyclists' eye movements. Although much research has already been done into the eye movements and visual scanning behaviors of car drivers, there seems to be a lack of literature on motorcyclists' scanning behaviors. This seems strange, because for motorcyclists, visual information is even more crucial to safe riding. Because of ethical considerations, this study used bicycles to ascertain whether the eye-tracker might be usable in the conditions one would encounter on a motorcycle. Fifteen participants were asked to wear the eye-tracker under a full-face helmet whilst completing a preset course. The percentage of eye movements that were found, were compared to baseline conditions, namely indoors, where lighting conditions were ideal for the eye-tracker. Results show that the percentages of eye movements found on the participants outdoors was significantly lower than the percentages that were found in the baseline conditions. Also, weather conditions have quite an impact on the percentages that were found. Brighter conditions with more sunlight lead to a twenty percent drop in performance when compared to heavily clouded conditions. However, when weather conditions are taken into account, and the eye-tracker is only used on heavily clouded days, it is definitely possible to track eye movements from participants wearing a full-face helmet. This leads to the conclusion that the Tobii Pro Glasses 2 are a feasible tool for measuring motorcyclists' eye movements under the right weather conditions.

Samenvatting

Het doel van dit onderzoek was om te bepalen of de Tobii Pro Glasses 2 eye-tracker eventueel gebruikt zou kunnen worden om de oogbewegingen van motorrijders te meten. Hoewel er al veel onderzoek is uitgevoerd naar het kijkgedrag van automobilisten, lijkt er een gebrek te zijn aan literatuur over het kijkgedrag van motorrijders. Dit terwijl juist bij motorrijders het kijkgedrag nog belangrijker is, aangezien zij nog meer belangrijke visuele informatie moeten verwerken dan automobilisten. Vanwege ethische overwegingen is in dit geval eerst gekozen om de eye-tracker te proberen bij 15 proefpersonen op een fiets, terwijl zij een integraalhelm droegen. De eye-tracker werd gedragen onder de integraalhelm, om op deze manier zo goed mogelijk de situaties na te bootsen die bij motorrijders worden aangetroffen. Het percentage van de oogbewegingen dat werd gevonden bij de fietsers, werd vergeleken met de percentages die bij dezelfde personen werden gevonden in een gecontroleerde omgeving, namelijk binnen, onder voor de eye-tracker ideale lichtomstandigheden. De resultaten laten zien dat de eye-tracker bij fietsers met een integraalhelm significant lagere percentages van de oogbewegingen vindt dan onder ideale condities. Ook bleek dat naarmate het licht buiten feller werd, de percentages tot twintig procent naar benden gingen. Echter, als men rekening houdt met de weersomstandigheden, en de eye-tracker alleen gebruikt op zwaarbewolkte dagen, is gebleken dat het mogelijk is om de oogbewegingen bij fietsers met een integraalhelm op betrouwbaar te meten. Hierdoor kan geconcludeerd worden dat onder de juiste omstandigheden de Tobii Pro Glasses 2 gebruikt kan worden om de oogwegingen bij motorrijders te meten.

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1. Introduction

Riding a motorcycle is an inherently dangerous activity, when compared to driving a car. Although motorcyclists account for only 1,5% of the total number of kilometers traveled in the Netherlands, up to 10% of the fatal accidents on Dutch roads involve a motorcyclist. Adding to this, every year more than 1100 motorcyclists are severely injured, making up 7% of the total number of traffic related injuries (SWOV, 2014). Whilst the number of injuries among car drivers, moped riders, and pedestrians has been declining over the years, there seems to be a tendency for motorcyclists to be even more involved in fatalities (DEKRA, 2010). According to Hurt et al. (1981), motorcyclists experience a high frequency of so called *right of way violations.* In a study by Williams, McLaughlin, Williams, and Buche (2015), right of way violations accounted for ten percent of all motorcycle accidents recorded in their study. The main cause of these accidents is the fact that car drivers often overlook motorcyclists because they have conditioned themselves to only look for other cars when turning onto a road or when changing lanes. This means motorcyclists have to pay extra visual attention to cars coming onto intersections, or cars possibly moving into their lane. So, attention and vision are very important factors of riding a motorcycle safely, therefore it could be very helpful to study and understand motorcyclists' eye movements. Not only for scientific and safety-related reasons, but also for training purposes. Showing riders where to look, and just as important, where not to look, could be a valuable addition to current training courses. So, there are multiple reasons for wanting to measure motorcyclists' eye movements, not the least of which is safety. This study is aimed at exploring the possibility of using a wearable eye-tracking device to measure the eye movements of motorcyclists.

1.1 Motorcyclists and eye movements

A motorcycle will always go where the rider is looking, and that is not always a good thing. In his book called *A Twist of the Wrist (1983)*, author Keith Code explains that motorcycling involves sometimes ignoring your own body's survival reactions. One of these survival reactions is fixating your gaze on potentially threatening objects, known as *target fixation*. When translated into traffic situations, this means that a motorcyclist is automatically inclined to fixate on the car turning into their lane. In other words, all his attention will be spent looking at what he doesn't want to hit. The reason a motorcycle will always go where the rider is looking, is because the head tends to follow the direction of the eyes, and the shoulders tend to follow the direction of the head. Turning one's shoulders will result in the motorcycle following that direction (Code, 1983). So, looking at the car turning onto the road means you are very likely to crash into it, however, an experienced rider who is aware of this survival reaction will look for ways to avoid crashing into the car. Instead of looking at the car, this rider will look for a way around it in order to avoid an accident. Although target fixation is a common occurrence in new riders, most experienced riders will be aware of it and be able to prevent it from occurring. Since the concept of target fixation, and where to look in general, are quite important for new and inexperienced riders, being able to track, and review, these riders' eye movements might prove valuable in training scenario's. Currently, there seems to be a lack of *scientific* literature on the subject of target fixation, even though it is one of the most important aspects of motorcyclists' visual behavior.

Studies have shown that distraction is a contributing factor to 10% of all traffic accidents, including cars (Kubitzki, 2011). Because riding a motorcycle requires more effort and attention than driving a car, the risk of distraction is even greater for motorcyclists than it is for car drivers. Compared to driving a car, riding a motorcycle requires much more attention and places a larger burden on the visual modality (Nagayama, Morita, Miura, Watanabem & Murakami, 1979). In addition to paying attention to traffic, road signs, corners, traffic lights and all the other things one does in a car, a rider has to keep track of the road surface, making sure there is no oil on the road, making sure there are no potholes, no sand, and no gravel. Hosking, Liu, and Bayly, (2010) Also, motorcycles lean over in corners, meaning even more attention is required of the rider in these situations. Lean angle and throttle control determine the amount of grip one has on a motorcycle. This means that riding a motorcycle requires quite a lot of attention already, making it potentially dangerous to add more tasks, such as navigation, for the rider to perform.

In the last decade, more and more motorcyclists have started using navigation systems (Ito, Nishimura and Ogi, 2015) With a navigation system, the chances of losing one's awareness for a moment are increased (Will & Schmidt, 2009). Today's navigation systems provide the user not only with route-information and turn-by-turn navigation, but also traffic information, weather information and information on speed limits. As these devices become more capable, and provide the user with more information, they run the risk of distracting the user from their primary task: operating the vehicle safely. Much research has been done on in-vehicle-information-systems (De

Waard, 1996; Pauzié & Manzano, 2007), as well as information systems for bicycles. For example, Engbers et al. (2016), studied the effects on behavior of an electronic rear-view assistance system for older bicyclists. Barely any research is available on information systems for motorcycles and their effect on the rider. As was mentioned, for motorcyclists, the ability to perceive and respond to hazards posed by other vehicles and by the road surface is crucially important (Haworth & Mulvihill, 2006). Evaluation of visual in-vehicle information systems has shown that they could negatively influence *scanning behavior* (Van Erp & Van Veen, 2004). Scanning behavior refers to the way drivers and riders visually scan the road ahead of them. Ideally, a rider's eyes would be on the road 100% of the time, but vehicle information systems have been shown to decrease the amount of time drivers can pay attention to the road. Therefore, these information systems may have negative effects on traffic safety. Given the fact that more riders are starting to use navigation systems, it is important to understand how these systems influence a rider's eye-movements.

1.2 Eye tracking

Since the visual modality is such an important asset for motorcyclists, it seems strange that barely any research has been done in this area. Perhaps one of the reasons is the lack of proper measurement tools. Since wearable eye-tracking is a relatively new technology, having emerged around 2010, there is still much room for testing the potential of these eye-trackers. Hence, this study will determine whether or not the Tobii Pro wearable eye tracker could be a useful tool for measuring motorcyclists' eye movements. The most commonly used technique for eye tracking is pupil centre corneal reflection (PCCR). This technique uses infrared light to illuminate the eye causing reflections. A sensor is then used to capture these reflections and to identify the light source of these reflections on the cornea and in the pupil. From these reflections, a vector can be calculated which is formed by the angle between the cornea and pupil reflections. The direction of this vector is what is eventually used to calculate the gaze direction (Tobii, 2017). Given the sensitivity of the instruments used, their intended usage is mostly for indoor, dust free environments, with appropriate lighting conditions. Because the Tobii Pro uses reflections, from light sources that are emitted by infrared lights in the eye tracker itself, it remains to be seen whether outdoor use could be viable. The difficulty in measuring eye movements outside lies in the fact that the sun emits infrared light. Therefore, it can become very hard for the eye-tracking device to determine which reflections are from its own infrared light emissions and which reflections come from the sun's infrared light. On top of that, for this study, the eye tracker would be worn under a full-face helmet, since the specific goal of this research is to determine whether the Tobii Pro can be used to measure motorcyclists' eye movements. For safety reasons, it has been decided to first establish if a wearable eye-tracker is capable of collecting data from under a full-face helmet on someone riding a bicycle. This way, the usability of the eye-tracker under the circumstances encountered on a motorcycle can be established in a safe, controlled manner. This study will therefore address the following research question:

Can the Tobii Pro Glasses 2 wearable eye-tracking device be used to reliably collect data from participants riding a bicycle outdoors whilst wearing a full-face helmet?

To answer the research question, the following hypotheses have been prepared:

Data collected with the Tobii Pro Glasses 2 in ideal conditions (indoors) does not vary significantly in gaze sample percentages from data collected in bright conditions (outdoors) whilst wearing a full-face helmet.

Automatically mapped gaze data scores between 0 and 1[1]*, do not differ between baseline, and outdoors conditions.*

1.3 Further considerations

Ethical considerations.

Because of ethical considerations, it has been deemed unfeasible to directly measure motorcyclists' eye movements in real world conditions. One of the reasons is that motorcycle insurance does not cover participation in research studies. Insurance basically covers normal road use, and anything that falls outside of this scenario, such as riding on race tracks, or taking part in an experimental study, is not covered. In order to make sure all participants are covered in case of accidents, they would all have to acquire permissions from their insurance companies, and most likely will have to take on an additional insurance clause, that would cover them in the event of an accident during

[1] Where 1 is a perfect score and 0 indicates that no mapping was accomplished. This will be elaborated upon in the method section.

the study. Of course, in this case, participants would have to be compensated for these expenses. Due to budgetary and time constraints, this study was unable to fulfill these conditions. Another consideration with regards to research ethics is that riding a motorcycle whilst wearing a mobile eye tracking device could prove to be dangerous, because the glasses may obstruct a rider's view. This study will hopefully show that the Tobii Pro glasses provide researchers with an unobtrusive, safe way to measure eye movements of motorcyclists.

Bicycle research.

Since using actual motorcycles for this study was ruled out, a solution was found in using bicycles. Though not exactly the same, riding a bicycle and riding a motorcycle share some of the more important characteristics. Compared to driving a car, bicyclists and motorcyclists are more vulnerable, and are having to deal with more variables, such as balance and hazard-perception. Another similar characteristic is the body positioning on a bicycle comes quite those to that on a motorcycle, providing one with roughly the same point of view as a motorcyclist in traffic conditions. Since bicycles were being used in this study, its results could also be useful for future bicycle research.

In recent years, cycling has become more and more popular as a means of urban transportation. As car ownership becomes more expensive, and driving in cities becomes more inconvenient, people are starting to look for alternative ways of transportation. The Dutch are currently number one when it comes to riding bicycles. They make up to 27% of their daily trips on bicycles, adding up to four billion bicycle trips every year (Pucher and Buehler, 2012). Current bicycle research focusses mainly on increasing bicycle use by the general population. According to Pucher and Buehler (2008), countries such as Germany, Denmark and the Netherlands are making it very convenient and practical to use a bicycle as daily transport. This is done by constantly improving bicycling infrastructure as well as discouraging people from driving their cars by increasing taxes and expenses on car ownership. Countries such as the UK and the United States are lagging far behind in this area. For this reason, a large part of current bicycle research is aimed at encouraging people to use their bicycle more as well as improving infrastructure for bicyclists. Another big part of cycling research is aimed at its health benefits (Basset, Pucher, Buehler, Thompson and Crouter, 2008). Countries such as the Netherlands, Germany and

Denmark see lower obesity rates, as well as higher active transportation rates, when compared to the United States and Australia.

As cycling is becoming more popular and more countries are looking to encourage bicycle use, research into safe bicycling is becomes more prevalent. With increased presence of bicycles on the roads, comes an increase in the number of bicycle accidents. This is leading researchers to explore bicyclists' behaviors. According to Schepers, Den Brinker, De Waard, Twisk, Schwab, & Smeets, (2013), vision plays an important role in bicycle accidents. With the increase of bicycle use and the increased importance of urban planning for bicyclists, an increase into the research of bicyclist (visual) behavior is to be expected. One study specifically focused on cyclists' gaze behaviors (Manuano, Bernardi and Rupi, 2016). They have found that the optimal visual conditions for cycling include dividing attention between the lateral and central parts of the visual scene. Also, intersections and crosswalks require more attention than cycling on a straight road, with the presence of pedestrians requiring the most attention. They also state that a lack of visual and/or physical separation between the cyclist and pedestrians seems to lead to reduced attention to these risk elements. These outcomes provide important guidelines for safe cycling infrastructure, highlighting the importance of understanding cyclists' visual scanning patterns. The fact that these results were obtained is an indication that measuring bicyclists' eye movements is indeed possible. This study hopes to show researchers that mobile eye-tracking is a viable way of studying bicyclist behavior.

2. Method

2.1 Participants

Fifteen participants (6 male and 9 female) between 22 and 56 years (M = 35.2, SD = 14.3), took part in the experiment over ten days. Of all participants, 6 were in possession of a motorcycle license, but none of the participants had experience using a navigation system on their motorcycles. Also, none of the participants had ever used handlebar mounted turn-by-turn navigation on their bicycles.

The University of Twente's Ethical Commission approved this study and all participants were required to sign an informed consent before participating. Any person able to ride a bicycle for at least thirty minutes was considered eligible for the study. Since the Tobii Pro glasses cannot be worn with other glasses, any person that could not safely ride a bicycle without prescription glasses was excluded from the experiment. Wearing contact lenses has no effect on measurements, so any visually impaired participants wearing contact lenses were eligible for the study.

2.2 Materials

Eye tracking.

In order to track participants' eye movements, the Tobii Pro Glasses 2 were used. The glasses are worn much like regular glasses with the exception of a wire running from the back of the glasses down to a recording device which was placed in a participants' pocket. To start and stop the recording of sessions a Dell tablet with Windows 10 installed was used. This tablet allows researchers to enter participant ID's and name different sessions. After each session, data was collected from the SD card in the recording unit and stored on an external hard drive as well the researcher's laptop.

Full-face helmet.

In order for the glasses to fit inside a full-face helmet, the helmet was modified to accommodate the data transfer unit attached to the right leg of the glasses. Since the helmet was in size XL, it could fit all participants. Had the study been conducted on motorcycles, there would have to have been helmets available in all sizes since fitment is a very important consideration for proper protection, but having a helmet with a looser fit was no real safety concern in this study on bicycles.

Bicycle with navigation.

To simulate motorcycle riding whilst using a navigation system this study used a bicycle with navigation instructions being displayed on the handlebars. To accommodate all participants a women's bicycle was used in a medium size. A smartphone displaying navigation instructions using the Google Maps application was attached to the handlebars (see figure 1).

Fig. 1. Smartphone mounted to handlebars of bicycle.

2.3 Procedure

Participants were welcomed and given a short explanation of the study, its goals and how the measurements would be conducted. They were given a letter explaining the study in detail as well as an informed consent form and a short questionnaire asking for additional information such as experience riding motorcycles, and use of navigation systems (see appendices A, B, C).

Indoors measurements:

To start the measurement, the eye-tracker was placed on the participant and calibrated using Tobii's controller software on the Dell tablet. The recording was started and the participant was asked to watch a 5-minute automated slideshow on a 15-inch screen. Neutral images were shown for 1 minute each on different areas of the screen. The participant was asked to sit as still as possible during the recording whilst looking at each of the images for the duration of one minute. After completion, the recording was stopped and data was saved to the SD card.

Outdoors measurements:

For the outdoors measurements two separate but similar routes were chosen that would take around 10 minutes to complete on a bicycle. The bicycle was prepared with a smartphone-holder on the handlebars. The smartphone was pre-programmed with one of two routes using a turn-by-turn navigation app (in this case, Google Maps). Routes A and B were counterbalanced across participants, i.e. participant 1 first took route A and then B (first without and then with the full-face helmet), participant 2 first took route B and then A (first without and then with the full-face helmet).

To start the first measurement (without the helmet), the eye-tracker was placed on the participant and subsequently calibrated using Tobii's controller software. The recording unit was placed in the participant's pant pocket with a cable running from the back of the glasses to the recording unit. With everything working and the route programmed into the smartphone the participant was asked to follow the turn-by-turn navigation instructions. After completion of the route, the recording was stopped and data was saved to the SD card in the recording unit.

To start the second measurement the participant was asked to put on the full-face helmet first. The eye-tracker was then placed on the participant, making sure the cable to the recording unit was routed out of the back of the helmet. The participant was then asked to once again follow the navigation instructions on the smartphone. The recording was then stopped and data was saved to the SD card in the recording unit. Participants were asked if they had encountered any problems or discomforts, after which they were thanked for their time and participation.

Data was saved to the SD card, after which the SD card was removed from the recording unit in order to transfer the data onto the researcher's computer. A back-up was made onto an external hard drive to prevent loss of data.

2.4 Data analysis

In order to analyze the data, it had to first be prepared using Tobii's Pro Glasses Analyzer software. Data was imported from the recordings, which then allowed for specific variables to be selected, such as 'EyeMovementType' which is an indicator of what type of eye movements were recorded. This variable is comprised of four labels, namely *EyesNotFound, Unclassified, Saccade, and Fixation*. EyesNotFound indicates that the eye tracker was unable to measure the eyes' position since it could not find one or both eyes. Unclassified indicates that the eye tracker did find both eyes but was unable to classify them as Saccade or Fixation. Saccade indicates the eye tracker found both eyes and that they were rapidly moving. Fixation indicates that both eyes were found and were fixating on a certain point.

Gaze sample percentages

Tobii's analysis software automatically generates a gaze sample percentage. The percentage is calculated by dividing the number of eye tracking samples with usable gaze data that were correctly identified, by the number of attempts. 100% means that one or both eyes were found throughout the recording. 50% means that one or both eyes were found for half of the recording duration. Important to note here is that low percentages do not necessarily mean a failed data collection. If one were to find a gaze sample percentage of 50%, the data might very well be usable, it all depends on where in the recording the gaze samples were found. However, the fact that lower gaze samples percentages are being found, does indicate that the eye-tracker is struggling to find the eyes properly. Hence, it can be used to compare the eye-tracker's performance across conditions, but no threshold can be provided.

Figure 2 shows a recording with a 62% gaze sample percentage. In the area inside the red box, white lines indicate that gaze samples were found, whereas the absence of white lines indicates that no gaze samples were found in that part of the recording. Here it is clear that most of the gaze samples are missing from the second half of the recording. This is most likely due to the fact that lighting conditions were too bright in the second half of the recording.

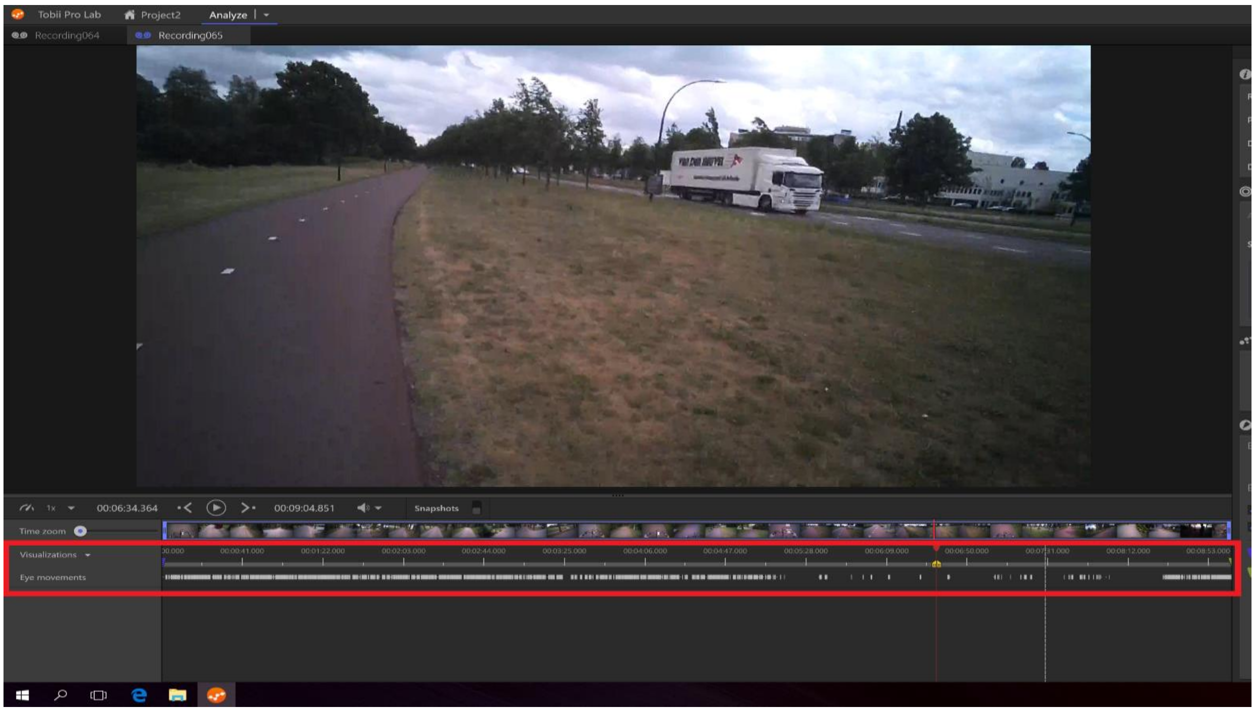

Fig. 2. Example of missing gaze samples in a recording. Where white lines indicate that the eyes were found correctly, the absence of white lines indicates that no eyes were found.

Automatically mapped gaze data scores

Tobii's software also allows for automatically mapping eye movements to a snapshot image. In this case the snapshots were comprised of the last picture in the baseline PowerPoint slideshow and a snapshot of the smartphone which was mounted on the handlebars of a bicycle. Tobii's software is able to go through each sample in a recording and mapping the fixations to these snapshots. Each individual mapped eye movement is given a validity-score between 0 and 1. Automatically mapped gaze data scores were compared for the baseline, outdoors with a helmet and outdoors without a helmet conditions. Figure 3 shows how automatic mapping of gaze samples works. Fixations are taken from the recording (shown on the left side), and when a fixation is found that matches the snapshot image (on the right side), it is mapped onto the snapshot, after which a confidence score is attached to the mapping from 0-1.

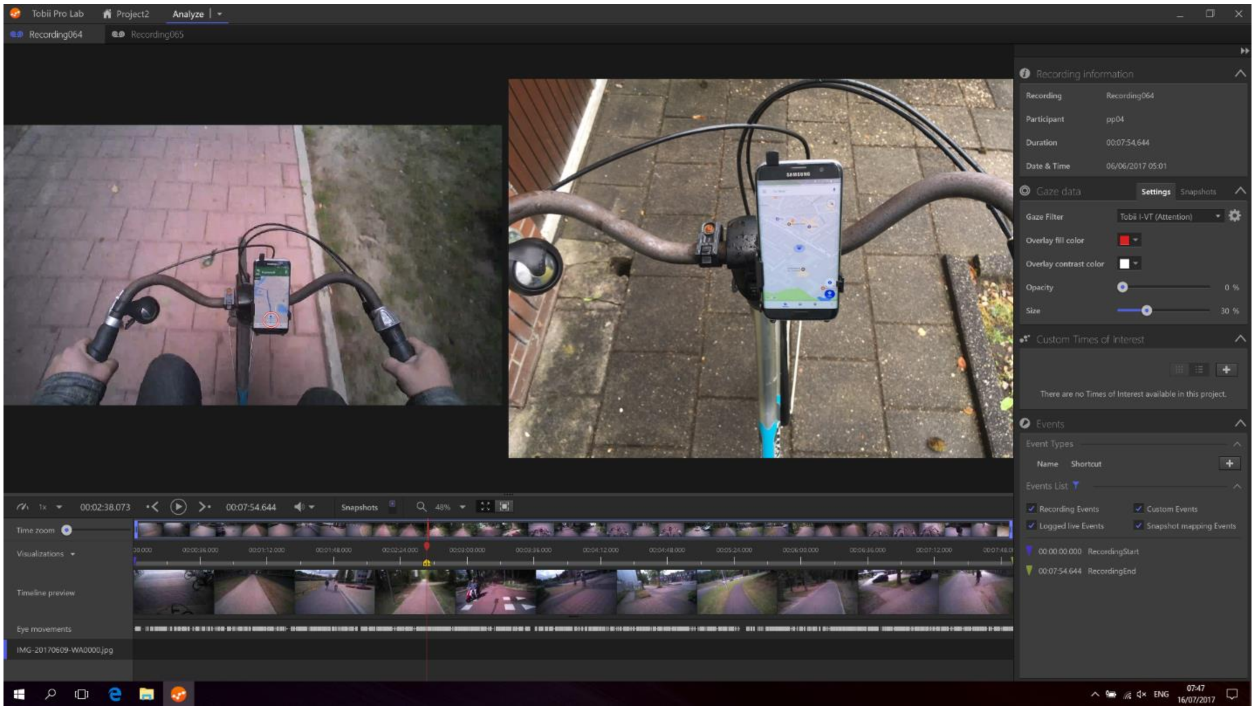

Fig. 3. Example of automatically mapping gaze data to a snapshot. Fixations are taken from the recording (left), and mapped onto the snapshot image (right).

Influence of weather conditions

At the outset of this study it was determined that sunshine might have a severe impact on the quality of data. Although efforts were made to collect data only in heavily clouded weather conditions, some variations in weather across measurements were inevitable. For this reason, weather conditions were noted for each participant. Conditions were identified as: heavy clouds, light clouds, and slightly sunny.

Data was imported into R (R Core Team (2016) and *lme4* (Bates, Maechler, Bolker, Walker, 2015) was used to perform a multilevel linear model analysis on gaze sample percentages per experimental condition, and the influence of weather conditions on gaze sample percentages. Gaze sample percentages were chosen as the dependent variable, and experimental condition and weather condition were chosen as independent variables.

3. Results

3.1 Gaze sample percentages

Comparing gaze sample percentages between the different experimental conditions shows that the baseline has provided an average of 94.6%. When measurements were done outdoors, percentages dropped to an average of 54% when no helmet was worn, and 62.4% when a full-face helmet was worn (see figure 4). Data from participants 10 and 13 are not included in the 'with helmet' conditions of this figure, since the helmet shifted the eye-tracker during the recording. This makes the data that was found in these cases unusable.

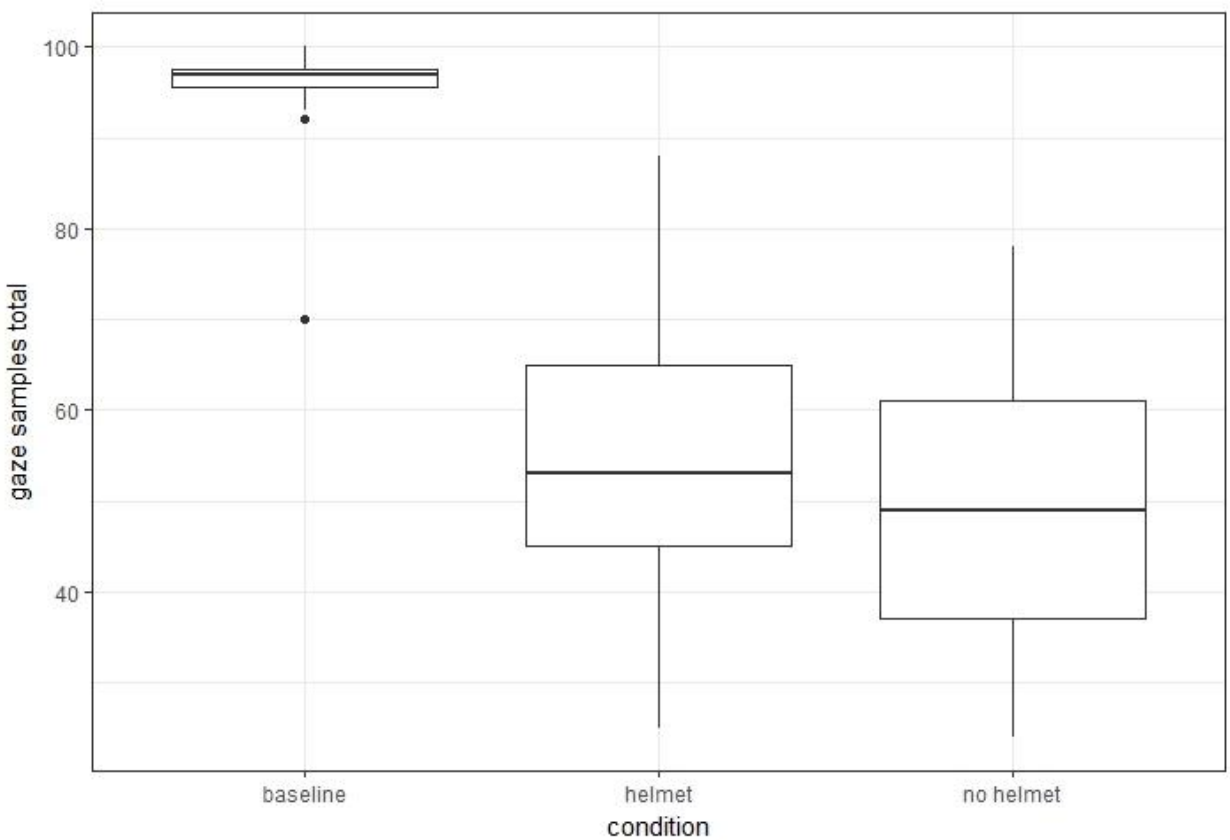

Fig.4. Average gaze sample percentages per condition.

The 'with helmet' condition was found to differ significantly from the baseline condition, $t = 16$, $p < 0.01$. The 'without helmet' condition was also found to differ significantly from the baseline condition $t = 13.45$, $p < 0.01$. This means that both outdoors conditions lead to significantly lower gaze sample percentages than the baseline condition.

3.2 Automatically mapped gaze data scores

Figure 5 shows the automatically mapped gaze data scores. In the outdoors conditions, it seems that Tobii’s Analyzer software was able to map fixations to the snapshot with more certainty, however, there were significantly more points to map in the baseline condition. In the baseline condition, 222366 fixations were mapped to the snapshot (M=0.59). In the ‘without helmet’ condition, 2304 fixations were mapped (M=0.70, while in the ‘with helmet’ condition, 6474 fixations were mapped (M=0.69). Important to note here is that in the recordings of participants 8 and 9, in the ‘without helmet’ conditions, no points were found that could be mapped to the snapshot.

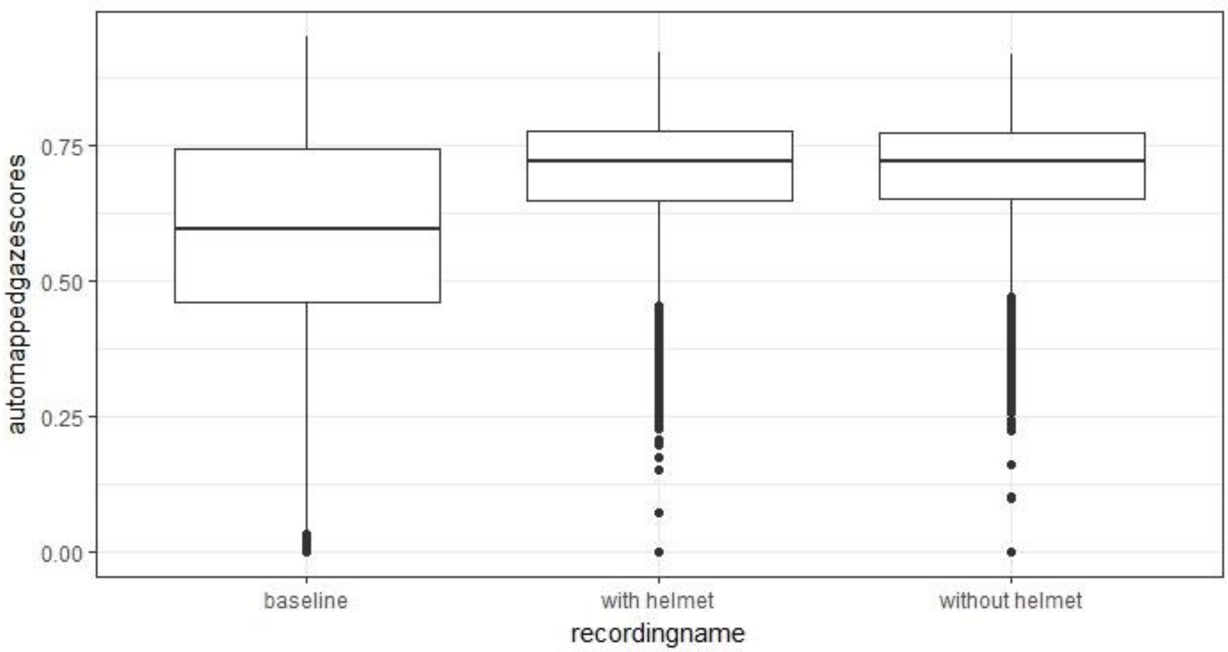

Fig. 5. Boxplots of automatically mapped gaze data scores between 0 and 1. (Where 1 means perfect mapping and 0 means no mapping was accomplished.)

To understand why automatically mapped gaze data scores were higher in the outdoors conditions, heatmaps were generated from these scores, which were projected onto the snapshot images from the corresponding conditions. Here it becomes apparent that in the baseline condition, there exists more uncertainty in the mapping of gaze points (fixations) because the spread of these points is quite large. In figure 6 (top) it becomes clear that quite a few gaze points are along the edges of the picture on the screen, which served as the area of interest, and there are multiple red areas indicating multiple points which were fixated upon by participants. On the bottom image, we see that the fixations are much more concentrated around a single point on the display, showing fewer fixations along the edges of the display.

Fig. 6. Heatmaps of automatically mapped gaze points in the baseline and outdoors conditions.

3.3 Influence of weather conditions

Figure 7 shows that weather conditions had quite an impact on the number of gaze samples that were found in the outdoors conditions. In heavily clouded conditions the eye-tracker was able to provide an average percentage of 62%. With light clouds, average percentages drop by 20%, with the same occurring in slightly sunny conditions. However, the range of percentages found in slightly sunny conditions is much larger.

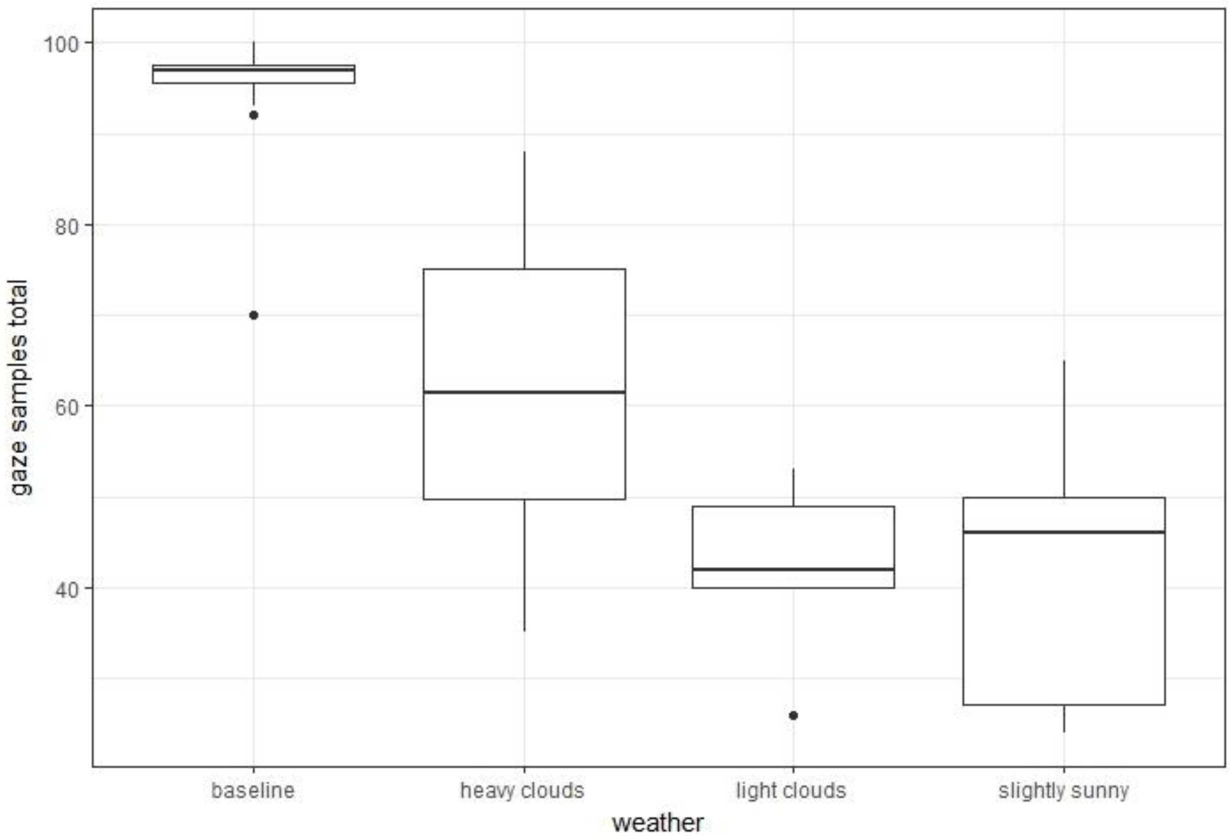

Fig. 7. Boxplots of gaze sample percentages per weather condition

Lightly clouded weather conditions lead to significantly lower gaze sample percentages compared to heavily clouded conditions $t = 20.129$, $p<0.001$. Slightly sunny conditions were also found to lead to significantly lower percentages $t = 17.52$, $p<0.001$. This means that weather conditions, and especially going from clouded to sunny conditions, have a significant impact on the performance of the eye-tracker.

4. Discussion

4.1 Findings

The main goal of this study was to determine whether the Tobii Pro Glasses 2 wearable eye-tracker are a feasible tool for measuring motorcyclists' eye movements. Due to ethical considerations, the decision was made to first collect data from bicyclists, as the risk of accidents is much lower when compared to motorcycling. The conditions in which the eye-tracker was used in this study were designed to replicate the conditions as encountered with a motorcyclist as closely as possible, by having participants wear a full-face helmet. The results show that the eye-tracker has good potential for measuring eye-movements when a full-face helmet is worn over it. As was expected, when comparing data collected in an ideal environment indoors to data collected outdoors, performance of the eye-tracker dropped. This study also shows that even though eye-tracking on motorcyclists is challenging due to weather conditions, one could definitely use a wearable tracker to determine whether information systems such as turn-by-turn navigation displays are distracting, and in what way they influence scanning behaviors. For bicycle research, these results indicate that using a mobile eye-tracking device such as the Tobii Pro Glasses 2 is a viable option for studying bicyclists' visual behaviors, confirming the findings of Manuano, Bernardi and Rupi, (2016). However, in that study, the conditions in which the eye-tracker was used were not discussed, whereas this study provides some important recommendations for optimal usage scenarios. In the sections below, we will further discuss the implications of this study as well as provide practical recommendations that could prove useful for future bicycle and/or motorcycle research in which wearable eye-tracking devices are used.

The fact that gaze sample percentages were slightly higher in the 'with helmet' condition of this study could indicate that the eye-tracker had a slight advantage in this condition due to the fact that lighting conditions were more constant because some sunlight was being blocked by the helmet. Important to note here is that the drop in performance is in large part dependent on weather and lighting conditions. Brighter conditions seemed to cause a larger drop in performance, due to the fact that more sunlight was present, and sunlight interferes with the eye-tracker's ability to pinpoint gaze directions using infrared light (Tobii, 2017).

Automatically mapped gaze data scores

The results show that using Tobii's software to automatically map gaze data to snap images is indeed possible from recordings of bicyclists. However, the number of points that were mapped seems very low, when comparing outdoors conditions to the baseline condition. Tobii themselves state that for automatic mapping to work as best as possible, it is important that the scene from the snapshot is as 'flat' as possible. This means that all objects in the snapshot are roughly the same distance from the viewpoint and match the recording as best as possible. In this study, since a bicycle was used in the outdoors conditions, the snapshot could not be made very 'flat', since a smartphone was mounted on the handlebars which served as the area of interest for automatic mapping. As can be expected, this is not an optimal situation for automatic mapping, since the area around the smartphone display is constantly changing as the bicycle is being ridden. As figure 8 shows, the area around the navigation display is likely to change a lot. This means that automatic mapping onto recordings from bicyclists may not be very successful, since the snapshot image and the actual recording tend to be quite different a lot of the time. However, this procedure might be more useful, and possibly more successful, on motorcycles, since the navigation display would be mounted against the 'dashboard' of the motorcycle, providing a somewhat fixed background for the snapshot image as well as during the recording (see figure 9).

Fig. 8. Navigation display mounted on bicycle handlebars. Here it is clear why automatic mapping proves to be a challenge, because the area around and under the display is constantly changing.

Fig. 9. Motorcycle navigation, where it becomes clear that the area behind the display provides a fixed background for automatic mapping to a snapshot image.

4.2 Recommendations

Implications for motorcycling and traffic research

For motorcyclists, and more specifically, researchers concerning themselves with motorcyclists and traffic safety, the fact that eye-movements can be tracked and studied could prove quite valuable. A recent study by Williams, McLaughlin, Atwood, and Buche (2016) has shown that over half (55%) of all single vehicle incidents (meaning the incident was caused solely by rider error and no other vehicles were involved) involve a motorcyclist negotiating a curve. While no specific causes are mentioned, rider behavior is mentioned as one of the most important predictors for single vehicle accidents. The aforementioned phenomenon of *target fixation* is an important part of rider behavior. Of course, not all single vehicle incidents are caused by target fixation, as some incidents involve gravel on the road, or the simple fact that a rider attempted to negotiate a curve with too much speed (Williams, McLaughlin, Williams, and Buche, 2015). However, being aware of target fixation and more importantly, being able to observe and study this behavior, could be a very valuable asset to motorcycle training programs. One of the most important parts of training a motorcyclist consists of teaching them where to look, and where not to look. Experienced riders will look through the turn, rather than the side of the road, and they will look around dangerous objects in their path, rather than directly at them. Being able to measure a student's eye-movements, and showing them that they might not be showing optimal scanning behaviors could be an important part of training courses. Even if the student's eye movements are not being recorded, they could be shown a pre-recorded section of film with the proper scanning behavior, to emphasize the right way to do it.

Recommendations for further research

Over the course of this study, some important aspects of measuring eye movements were found. As mentioned earlier, the lighting conditions are absolutely critical for good quality data, because as expected, even the slightest bit of sunlight during data collection will lead to drops in performance and missing data. An important recommendation from this study would be to keep lighting conditions as consistent as possible during each recording and between recordings, by making sure data is only collected in heavily clouded weather conditions. The ideal scenario would mean even measuring light intensity in lumen and only collect data in certain preferred light intensities for outdoors data collection. However, the fact that only 50% of gaze samples are found during a recording does not mean that data collection has failed. Tobii themselves state that gaze sample percentages are a way to measure the quality of data, but are not an absolute figure for assessing data quality. For this reason, Tobii does not provide a threshold for gaze sample percentages or any other measure of quality. It all depends on what the researcher is trying to find. For example, if a motorcyclist's eye movements are being recorded, and only 50% of gaze samples were found, it all depends on where these gaze samples come from, that determines whether the data is usable. If the study is on cornering techniques, and all gaze samples from the corner sections of the recording are missing, your data would be unusable. But on the other hand, if only gaze samples were lost on straight sections of road, and many gaze samples were found in corners, the data is perfectly usable. Also, low percentages of gaze samples can stem from every other sample being lost in a recording, but this does not make the data unusable. If in this example every other sample is missing on an eye-tracker which samples at 100hz, it would be as if data was collected on a device which samples at 50hz. For this study, it would mean that if all gaze samples from the moments participants were looking at the navigation display are missing, some essential data is lost. However, if every other gaze sample was missing from these moments, less data would have been found, but it would still have been useful.

This goes to show that a low gaze sample percentage does not necessarily mean poor data quality, but it does mean that one should look carefully at the recording, and see and which sections are missing gaze samples before proceeding with analyses.

Practical recommendations

An important thing to consider when using mobile eye-tracking devices is that participants with poor eyesight might not be able to see properly when wearing the eye-tracker. In this particular study, no problems were encountered concerning poor vision, but one might encounter cases in which the participant is unable to see their navigation instructions whilst not wearing their prescription glasses. Overall, participants were happy to wear the eye-tracker, and no cases were encountered in which the eye-tracker caused any discomfort. However, when a full-face helmet is also being worn, some problems arise. First of all, the helmet will have to be prepared to allow for the eye-tracker to fit properly. In most cases this means cutting away some of the foam from the inside of the helmet, along the temples. Trying several helmets and using the one with the most room on the sides would be advised. The second problem concerning full-face helmets is proper fitment. In this particular case, proper fitment was of no concern to safety, since participants were riding bicycles, and a single helmet in size XL was used. However, in some cases XL proved to be too large, causing the eye-tracker to shift around, leading to unusable data. When using an eye-tracker on motorcyclists, fitment becomes more of a safety issue. The helmet has to fit properly for it to do its job protecting the head. However, customizing a helmet to fit the eye-tracker could be detrimental to safety. Multiple helmets in all sizes, and the right helmet that allows the eye-tracker to fit properly would be strongly advised in this case.

Given the fact that gaze behavior is especially important for beginning motorcyclists, wearable eye-trackers could potentially be incorporated into training programs. This would not only give the training an edge over traditional riding lessons, but also give beginning riders more insight into the importance of gaze behaviors. Since most riding schools and training centers already have an array of helmets at their disposal, proper fitment would not be an issue here. It is also to be expected that wearable eye-trackers will become smaller and more like regular glasses, removing the need for customization of helmets to make room for the eye-tracker in future iterations. Given the amount of information that can be found in gaze behaviors of trainees, investing in a wearable eye-tracking device, and using it in training and/or advanced riding classes could be very interesting indeed for riding schools.

4.3 Limitations

Only one full-face helmet was available for this study, but multiple helmets in different sizes would have been ideal. Some data was lost due to the helmet being too loose and shifting the eye-tracker around. Because of the fact that data collection was weather-dependent, the goal of twenty participants was not reached. It has proved to be very challenging to plan data collection whilst taking weather conditions into account, since conditions change from day to day, but most people are unable to change their schedules as fast as weather conditions sometimes do. However, it does not seem that the results were influenced by a lack of participants, as the ‘with helmet’ condition consistently yielded higher gaze sample percentages across participants.

4.4 Conclusion

This study has shown that the Tobii Pro Glasses 2 can definitely be used to measure bicyclist and motorcyclist eye movements. Although performance of the eye-tracker drops significantly in outdoors environments, when special care is taken to collect data in the right conditions, and each recording is checked to make sure the relevant data was recorded, using a wearable eye-tracker in these scenarios is certainly possible.

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Appendix A

Toestemmingsverklaringformulier (informed consent)

Titel onderzoek: Exploring the possibility of using a wearable eye-tracking device to measure the eye movements of motorcyclists.

Verantwoordelijke onderzoeker: Steven de Vries

In te vullen door de deelnemer

Ik verklaar op een voor mij duidelijke wijze te zijn ingelicht over de aard, methode, doel en [indien aanwezig] de risico's en belasting van het onderzoek. Ik weet dat de gegevens en resultaten van het onderzoek alleen anoniem en vertrouwelijk aan derden bekend gemaakt zullen worden. Mijn vragen zijn naar tevredenheid beantwoord.

[indien van toepassing] Ik begrijp dat film-, foto, en videomateriaal of bewerking daarvan uitsluitend voor analyse en/of wetenschappelijke presentaties zal worden gebruikt.

Ik stem geheel vrijwillig in met deelname aan dit onderzoek. Ik behoud me daarbij het recht voor om op elk moment zonder opgaaf van redenen mijn deelname aan dit onderzoek te beëindigen.

Naam deelnemer: …………………………………………………………………………..

Datum: …………… Handtekening deelnemer: …...………………………………….

In te vullen door de uitvoerende onderzoeker

Ik heb een mondelinge en schriftelijke toelichting gegeven op het onderzoek. Ik zal resterende vragen over het onderzoek naar vermogen beantwoorden. De deelnemer zal van een eventuele voortijdige beëindiging van deelname aan dit onderzoek geen nadelige gevolgen ondervinden.

Naam onderzoeker: …………………………………………………………………..…………..

Datum: …………… Handtekening onderzoeker: ...………………………………….

Appendix B

Informatiebrief

Dit onderzoek is bedoelt om te kijken of een mobiele eye-tracker gebruikt zou kunnen worden bij motorrijders. Een eye-tracker is een geavanceerde bril met kleine camera’s die gebruikt worden om oogbewegingen te meten en vast te leggen. Om een idee te krijgen van de bruikbaarheid van de eye-tracker bij motorrijders wordt eerst gekeken of er goede metingen gedaan kunnen worden bij iemand die op een fiets zit met de eye-tracker en een integraalhelm op. Op deze manier kan het motorrijden op een veilige, gecontroleerde manier zo goed mogelijk nagebootst worden.

Wat wordt er van u verwacht?

Tijdens dit onderzoek wordt u gevraagd om een aantal taken te volbrengen terwijl u de mobiele eye-tracker draagt. De eerste taak betreft het kijken van een filmpje van tien minuten terwijl u de eye-tracker draagt. Deze meting is bedoeld om te bepalen hoe goed de eye-tracker werkt onder ideale omstandigheden. Tijdens de tweede taak wordt u gevraagd om een stukje te fietsen (ongeveer 10-15 minuten) terwijl u de eye-tracker draagt. Tijdens het fietsen zult u navigatie-instructies krijgen via een smartphone op het stuur. Tijdens de derde taak wordt u nogmaals gevraagd om een stukje te fietsen (ongeveer 10-15 minuten), maar deze keer met naast de eye-tracker ook een integraalhelm op. Deze taak is bedoeld om het motorrijden op een veilige manier na te bootsen, zodat bepaald kan worden of de helm een negatieve invloed heeft op de metingen van de eye-tracker.

Het gehele onderzoek zal ongeveer een uur van uw tijd vragen. Er zijn geen risico’s verbonden aan deelname aan dit onderzoek. U begeeft zich echter wel op een fiets in echte verkeerssituaties, dus de risico’s die verbonden zijn aan verkeersdeelname zult u ook in dit onderzoek ervaren. Als u op enig moment wenst de deelname aan het onderzoek te beëindigen kunt u dit altijd aangeven, het onderzoek zal dan per direct gestopt worden.

Wat gebeurt er met uw gegevens?

Uw gegevens worden op een anonieme manier verwerkt en opgeslagen. U heeft het recht om tot 24 uur na deelname aan het onderzoek te vragen om verwijdering van uw gegevens.

Mochten er vragen ontstaan na deelname aan het onderzoek kunt u altijd contact opnemen via onderstaande informatie:

Telefonisch: 0614844611 e-mail: vriessteven@gmail.com

Met vriendelijke groet,

Steven de Vries

Appendix C

Persoonsgegevens

Proefpersoon #:

Naam:

Leeftijd:

Motorrijbewijs: ja / nee

Zo ja, gebruikt u ooit een navigatiesysteem op de motor?

Zo nee, gebruikt u ooit navigatie op de fiets?

Contactlenzen: ja / nee