EYE-TRACKING IN AMBULANT BEHAVIORAL RESEARCH – A REQUIREMENTS ANALYSIS

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Abstract Mobile eye-tracking seems to be a very promising tool in behavioral research. This study is commissioned by the University of Twente to investigate the current situation of mobile eye-tracking and the possibilities to implement this at an ambulant lab at the university. Eventually this led to a recommendation on what equipment would suit best. To achieve this, the study is built up in four phases. First, a case study is described to give an indication about how mobile, out of the lab, research is performed en what the obstacles could be during this research. Second, a literature study is performed on the current situation of (mobile) eye-tracking at the fields of the five Behavioral Sciences departments that could profit from a possible purchase of an eye-tracking device: human factors, communication sciences, educational sciences, eHealth and automotive. Both the case as the literature study are used to set up a questionnaire that is used as a guidance during six interviews with members of the different departments. Using the MoSCoW-method, a set of requirements is marshalled from the interviews. These requirements are eventually matched with the current supply of eye-tracking devices. This led to the conclusion that no single eye-tracking device satisfies the needs of the departments. However, the purchase of both a mobile (head-mounted) as a remote (desk-mounted) device is recommended. Only the larger manufacturers, SMI and Tobii, satisfy the needs of the departments. Eventually the first recommendation is the purchase of a combination of Tobii Glasses 2 and Tobii TX300.

Samenvatting Mobiele eye-tracking lijkt een veelbelovend instrument te zijn bij onderzoek op het gebied van gedragswetenschappen. Deze studie, die deels wordt uitgevoerd in opdracht van de Universiteit Twente, onderzoekt de huidige situatie van mobiele eye-tracking en tevens de mogelijkheden om dit toe te passen binnen een ambulant lab op de universiteit. Uiteindelijk leidt dit tot een aanbeveling over welke apparatuur het beste gebruikt kan worden aan de universiteit. Om dit te bereiken is dit onderzoek opgebouwd in vier fasen. Allereerst wordt een casus beschreven waarin een indicatie wordt gegeven over hoe mobiel, buiten het lab, onderzoek uitgevoerd kan worden tegenwoordig en wat hierbij de struikelblokken kunnen zijn. Als tweede is een literatuur studie uitgevoerd over de huidige stand van zaken van (mobiele) eye-tracking op de gebieden van de vijf Gedragswetenschappen afdelingen die kunnen profiteren van een mogelijke aanschaf van een eye-tracking apparaat: human factors, communicatiewetenschappen, onderwijskunde, eHealth en automotive. Zowel de casus als de literatuur studie zijn gebruikt om een vragenlijst op te stellen die gebruikt is als leidraad tijdens interviews met zes medewerkers van de verschillende afdelingen. Door middel van het gebruik van de MoSCoW-methode zijn ‘requirements’ vast gesteld uit de interviews. Deze requirements zijn uiteindelijk naast het huidige aanbod van eye-trackers gelegd. Hieruit kon geconcludeerd worden dat één enkel eye-tracking apparaat niet afdoende is om aan de eisen van de afdelingen te voldoen. Echter is dit wel het geval wanneer zowel een mobiel als een vaststaand apparaat aangeschaft wordt. Alleen de grotere fabrikanten van eye-trackers, SMI en Tobii, voldoen aan de benodigde specificaties. Uiteindelijk wordt een combinatieaankoop van de Tobii Glasses 2 en de Tobii TX300 aanbevolen.

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Introduction

Commissioned by the department of Social Sciences of the University of Twente, this paper will map the possibilities and requirements of eye-tracking as a part of an ambulant campus lab. This ambulant lab fits perfectly in the profile of the University of Twente, which intends to be an innovative university, oriented towards applied research: High tech, human touch.

The idea of a campus lab is for the present nothing more than an idea. Nevertheless, before giving form to a large idea like this, it is wise to look at the possibilities and obstacles. The aim of a campus lab is to take research out of the lab into the real world. This will highly improve the ecological validity of the current research. This will not only benefit the applied character of the research at the university, but will also be relevant for the industry. An example of a campus lab can be found at the University of Wageningen, at which they developed a food lab that made it possible to experiment with food consumption in a real restaurant environment. When developing an ambulant social science campus lab at the University of Twente, we must think of automotive research while driving, consumer research in the campus supermarket, research at home or using the navigation on a Smartphone while walking through campus.

Eye-tracking seems to be a promising method to implement into a social science campus lab. The method of eye-tracking is widely used in the field of human factors, but also seems promising to use at other fields of psychology and social sciences. With the upcoming rise of for example Google Glass mobile eye-tracking is more relevant than ever. This paper aimed to present the current state of eye-tracking on the basis of both a case study and a literature study. This knowledge helped thereafter to map the needs and possibilities of eye-tracking in the different fields of the social sciences department of the University of Twente; human factors, communication sciences, eHealth, educational sciences and automotive research. Based on the literature study, case study, and a look into the current supply of eye-tracking devices a questionnaire was set up. Based on this questionnaire, interviews with employees from the five social sciences departments of the University of Twente were held. Using the MoSCow-method, these interviews were transformed into a set of requirements for an eye-tracker as part of an ambulant lab. These requirements are used to give a well-considered recommendation towards the stakeholders of the Social Science lab about which eye-tracking device will suit best into an ambulant lab.

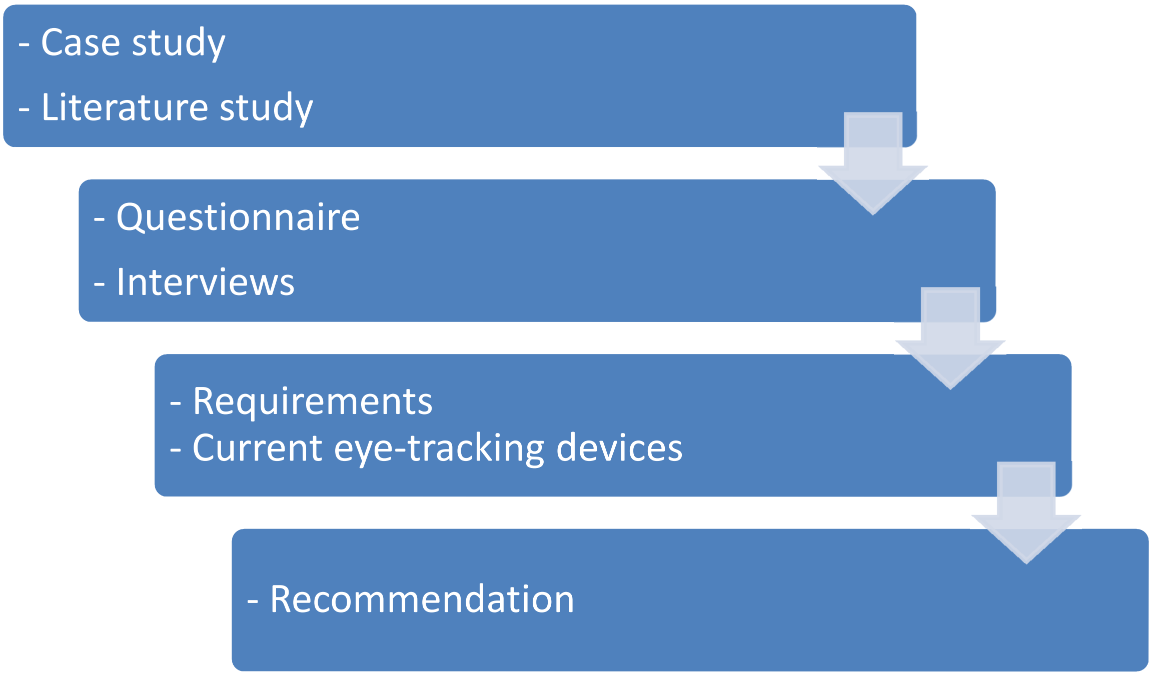


Fig. 1. Schematic setup study

During this study one main research question will be attempted to answer. To eventually answer this question, four sub-questions were determined.

Main research question:

- What are the requirements for an eye-tracker suitable for ambulant behavioral research?

Sub research questions:

- What problems can occur during out-of-lab eye-tracking?
- What is the current state of (ambulant) eye-tracking?
- What are the requirements for an eye-tracker at the five departments of the University of Twente?
- Which eye-tracking devices (with what specifications) are currently available?

Short introduction important concepts eye-tracking

Most eye-tracking devices use infrared light to measure the reflection of the eye to determine where the pupil is looking at. It is impossible for an eye-tracker to have an ongoing representation of the direction of the pupil. Therefore, all eye-trackers take snapshots of the position of the eye at a fixed rate. Every snapshot is used as a representative of a larger interval of time. These intervals are measured in Hz. The higher the amount of Hz the eye-tracker measures, the smaller the interval of time the snapshot represents. For example, a 50 Hz eye-tracking system takes a snapshot once every 20 ms. The amount of Hz is called the sample frequency.

During the analysis of the gathered eye-tracking data fixations are the most important factors. A major part of the studies from the literature study focusses on fixations. Fixations are the moments when a person shifts his gaze towards a certain point. Using fixations, researchers can track where the participants' attention is located. The most used characteristics of fixations are the duration and the amount. A series of fixations, or scanpath, can determine the route of viewed objects. Fig. 10 shows a visual representation of fixations and the scanpath. The movements, or lines, of the gaze in between fixations are called saccades. During saccades no information is registered. Saccades are especially an important factor of eye-tracking during analyzing reading behavior. At fig. 10 the blue lines between the dots are saccades.

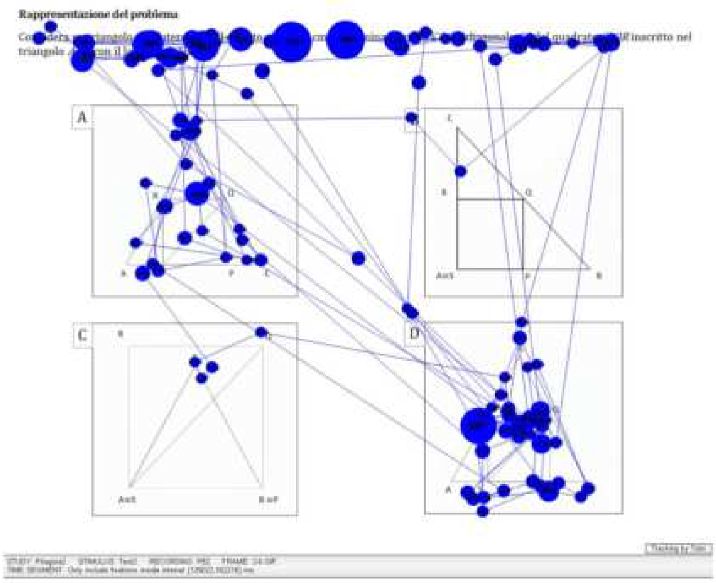


Fig. 2. Graphic display of fixations. The blue dots are fixations. The larger the dot, the longer the fixation (Porta et al., 2012).

To analyze where the fixations of participants are located, researchers often use Areas of Interest (AOIs). Areas of Interest are the areas that are identified to measure the amount and duration of the fixations at that regions. If the research purpose is whether customers look at the ads placed at different spots on a website, these ads are the AoI's. When selecting these areas as AoI's, you can for example collect data about when costumers first looked at the ads, for how long they looked and how many times. In fig. 11 for example, are the different parts of a television news clip marked as five AOI's. These different AOI's can be used at the data analysis to analyze the amount and time of fixations on the different parts of the clip.

Fig. 3. Still from data analysis of Rodrigues, Veloso and Mealha (2012). Five areas in the clip are marked as AOI's.

Some mobile eye-tracking devices use markers to mark the Areas of Interest (AoI's). The use of markers significantly quickens the data analysis, especially with mobile head-mounted eye-trackers. The image of the scene constantly moves, and therefore it can be difficult to analyze specific areas. Because the boundaries of the important areas are preset using markers, no extra effort has to be taken during the analysis.

To visualize the results of the eye-tracking data heatmaps can be used. Heatmaps are visual representations of the area's participants looked at. By using different colors, in one image a clear oversight is given of how much, or for how long the participants looked at certain areas. Figure 5 at page 14 shows an example of results that are made visual by using a heatmap.

I. Eye-tracking in practice: case study on VTS-operators

A recent case study will be discussed to illustrate the difficulties and problems that can occur during eye-tracking research in ambulant situations. This study regarded research on Dutch Vessel Traffic Services operators (VTS-operators) at junction points in the Dutch waterways. Eye-tracking was conducted in the natural working environment at the controller posts. The objective of the study was to determine the obstacles that can occur during out-of-lab eye-tracking research, with a regular desk-mounted eye-tracking device. This study is a perfect chance to take a look into the obstacles and difficulties that can occur. On the other hand, it also provides a look into the advantages and possibilities of eye-tracking outside of the lab.

Setup

Setup VTS-workplace

The operators' primary job is to regulate the traffic flow, using the radar, IVS (Information- and Following system for Shipping) and AIS (Automatic Identification System), along with the information supply towards the vessel traffic. The workplace of the VTS operator consists of multiple monitors, a marine traffic communication device ("marifoon") and an ordinary telephone. The top row of monitors, that are placed approximately 2 meters above the ground, are real-time camera's which record the most important sections of the waterway area. The lower row of monitors consists of the marifoon-device, a PC with internet which can be used to fill out the details of incidents that shift, a radar-device and IVS90.

IVS90 was the measured device for the eye-tracking measurements. This device keeps track of the ships that pass the concerned area. Important data about the ships, like their name, cargo, size and amount of passengers are displayed. This data has to be tracked constantly to keep up the necessary overview of the area.

A total of five VTS operators were studied during their real-time job. This implies that the research setup had to be built at the traffic post workplace. In contrast to a lab setting, the setup had to be adjusted to the environment of the current workplace of the operator.

Setup eye-tracking

Eye tracking in a real-time working environment can be more challenging than lab experiments. In the ideal situation, the eye-tracking of a computer monitor can be measured through a direct connection of the device (i.e. laptop) on which the eye tracking software is installed to the measured monitor. In this way the interface on the monitor is measured graphically optimal. However, the measurement of the IVS90 system could not be performed this manner, since IVS90 is not an operating system that can be run on a regular laptop or pc.

During the recordings of this research, an external video source was used. This implicates that the monitor of the IVS90 device was recorded through a camera that was connected to the laptop that had the eye-tracking software installed. The camera was placed at the right of the participant, approximately at the height of 150 cm. This implies that the camera did not stand directly in front of the monitor and eye-tracker, but recorded in a diagonal angle.

The eye-tracking device was placed in front of the measured monitor. The angle of the eye-tracker was adjusted to the position of the operator. The eye-tracking software on the laptop showed a real-time image of the eye-movements of the participant on the screen.

A Tobii X60 stand-alone eye-tracking unit (fig. 2) was used during this study, in combination with a laptop device running on Windows 7 and equipped with the corresponding Tobii Professional software.

Fig. 4. Tobii X60 stand-alone eye-tracking unit.

Occurred difficulties during research

Limitations in reach of the eye tracker

The used eye-tracker had a limited reach. Before conducting the experiments, several test-recordings were taken to measure the reach of the eye tracker. If the patterns of eye movements could be measured on multiple monitors, more data could be gathered about the used systems. To measure multiple monitors which are placed on a regular desk, the range of the eye tracker should be larger than the 60 cm area behind the eye-tracker. Unfortunately, only one monitor directly behind the eye-tracker could be measured. When trying to measure multiple screens, the tracking of the eye-movements at both the left and right side disappeared completely or were unnatural jerky and rapid. This limited the objectives of the study, because only one of the multiple screens could be measured. A selection had to be made in the monitor(s) that would be measured. In lab studies this limited reach of the eye-tracker could be by-passed by using another research design, but this is in real-world environments frequently not feasible.

We have to note that the operators were sitting nearby the eye-tracker, approximately 1 meter. Recordings that are taken further away could probably have a wider range to record. However, the further away the participant is placed, the harder the eye-tracking data could be obtained. The eyes need to be in short distance of the eye-tracker in order to capture the pupils. Besides, most of the time when executing experiments in a natural environment outside of the lab the setting cannot be adjusted to the experiment, but the experiment has to be adjusted to the already existing setting.

Limitations in movement of the operator

The usage of a stand-alone eye-tracking unit in a natural working environment had some implications for the controllers on the possibilities to move freely behind their desk. When the controllers were not sitting directly in front of the eye-tracker, most of the time the eye-tracker lost the pupils of the controller out of sight. The controllers who had multiple screens to track and control needed to sit at the same place, without moving too far to the right or left to acquire the most accurate eye movement data. Even when the controllers moved back- or forwards, the eye-tracker easily lost the pupils out of sight. The researchers had to keep track of the eye-tracking software to make sure that the pupils were tracked. If they were not, the researcher had to ask the controller at a suited moment to replace themselves at the right spot behind the eye-tracker.

Connecting equipment to the available systems

As described earlier, the optimal way to perform the eye-tracking study was to have a direct connection of the laptop with the eye-tracking software to the measured monitors. In a lab experiment, this would probably not be a problem. Every monitor would be controlled by the experimenter, and the connection of the laptop to the measured screens would be easy to set up. However, the measured monitor of the VTS-operators could not be connected to the laptop because this was a closed system that functioned on its own, unlike a regular computer or laptop.

Because of this, the measurements had to be performed through an external camera. This had some considerable consequences for the resolution of the measured monitors. The resolution decreased highly in comparison with the use of a direct measurement of the monitor through a connection with the laptop. In this study a high resolution was not of high priority. Nevertheless, problems could easily arise when conducting other experiments in an equivalent situation that need a higher resolution of the monitors.

Camera placement

Another problem that arose is the placement of the camera. The camera had to stand at no more than 150 cm away from the screens to capture the monitors, and at the other side the camera could not be placed nearby the monitor because only a small part of the monitor would be captured. The placement of the camera turned out to be difficult because the right angle and distance nearly always interfered with the space the operators needed to work freely. In this setting a balanced approach between getting the right data and maintaining a workable environment had to be chosen. Unfortunately this meant that the camera was placed at a sloping angle, which influenced the accuracy of the capturing of the eye movements and the visibility of the monitor.

Calibration time

The VTS-controller is a 24/7 workplace. This implicates that every preparation preceding the actual measurements had to be done during the working hours of the controllers. The most problematic interruption of the controllers was the calibration. In order to measure properly, a calibration had to be performed of the eye-tracker and the measured monitor. This could be done within a couple of minutes, which was not a huge obstacle for the controllers. However, during the calibration of one of the participants, multiple wrong outcomes of the calibration occurred. In a lab setting, this would not be a big problem, besides from the fact that the test would probably take some more time. In the case of the controllers, every minute they could not work and scan their monitors counted. Thus, when performing (eye-tracking) research in a natural working environment, an extensive preparation can help to deal with problems that occur during the actual measurements. When encountering problems during the measurements that were not anticipated on, there could be implications on the gathered data but even more on the mood of the participants.

Sensitivity of the use of cameras

When performing research in a non-lab environment, like with the VTS-operators, some privacy-related issues may be more sensitive. In this case, the use of cameras became more problematic than anticipated on beforehand. The VTS-operators refused to be filmed during their work during a longer period of time. The design of the study initially included the use of a camera that recorded the operators during the period of eye-tracking. This would facilitate a much easier data analysis, in which events during the recordings could be matched with the eye-tracking data. The alternative to the camera recordings was to keep a written track of the events. Luckily, in this case there were recorded hardly any busy periods, which meant that there were no problems with keeping track of the events. However, in many research settings this could become very problematic and may threaten the reliability of the study.

Conclusion

When research has to be performed out of the lab and not on a regular computer or laptop, a desk-mounted eye-tracker can cause several problems. When conducting this research most problems that occur are mobility problems. It can be very hard to adjust the eye-tracking equipment to a working environment that already exists. There is a chance that the eye-tracker cannot reach the desired research surface and the participants cannot behave like they would without the presence of the eye-tracker.

II. Literature study: current situation (ambulant)eye-tracking

Eye-tracking has proven to be a useful tool in several research fields in the past decades. A short literature overview should provide an indication of the current state of eye-tracking. This overview is based on the multiple research fields at the behavioral science department of the University of Twente that use, or could use, eye-tracking within their studies. These research fields are; human factors, eHealth, automotive, ICT in education and communication sciences.

Human Factors

Eye-tracking has been a widely practiced tool within the field of human factors. As cited by Çinar (2009) is "eye-tracking a very successful research method that is used in perception and visual research as well as the other human factors for years. (p.672)" In 1999, Karn, Ellis and Juliano discussed in their overview study on eye-tracking the use at that moment and the possibilities for the future. The use of eye-tracking was primarily confined to military aircraft cockpit issues. Back in 1999, the possibilities of eye-tracking as a behavioral measurement that can overcome questions about design problems which are often not easily be answered by participant reports were already acknowledged.

This prognosis of Karn, Ellis and Juliano (1999) has turned out to be correct. Eye-tracking has been a very useful tool within the field of human factors. Especially in-lab eye-tracking has been practiced past decades. In-lab research has aimed to study the human-computer interaction. With the rise of internet and computer usage, the usability of websites has been a popular research topic. For example, Çinar (2009), who studied the usage of a university website, by observing participants who were trying to finish certain tasks at the current website and a proposed better website design. By looking at the amount of fixations and fixation time during the tasks, they concluded that the proposed website was more effective and efficient. They illustrated the findings by creating heatmaps (for example see fig. 5)

Fig. 5. Illustration from Çinar (2009), pp. 674. Heatmap used to illustrate the findings on a usability comparison of University websites.

Next to the research on computer and website use, eye tracking has also been used on the topic of mobile phone applications usage the last couple of years. Kim, Thomas, Sankaranarayana, and Gedeon (2012) showed that mobile phone use, and thus a much smaller screen, cannot be compared to the use of much larger computer screen. Eye-tracking turned out again to be a very useful tool to study these differences of behavior. Both studies of Çinar (2009) and Kim et al. (2012) can be used to improve the designs of websites and mobile phone applications.

The last couple of years eye-tracking is not exclusively used in lab environments. More and more, researchers try to use eye-tracking in a more natural environment. Before, scene perception was studied by using photographs or videos of the real world (Henderson, 2003). However, due to the development of more accurate and mobile devices, eye-tracking studies can be performed out of the lab. Foulsham, Walker and Kingstone (2011) made the transfer from the lab studies using video's and photographs to a study in a real world environment. They compared the gaze allocation of participants who watched video clips of a route through the university campus and participants who actually walked the exact same route. They concluded that although there were similarities between the two research conditions, the results were at some points clearly different. Having real people nearby, the engagement to the task and the freedom to move their head and body were factors that changed the behavior of the real-world participants. In fig. 6 this difference in gaze behavior is visible. There are clear differences in proportion of gaze on people, path and objects in the environment when walking the route instead of watching the same route at a screen. The participants watched for example more towards far objects when they were watching the route on the screen.

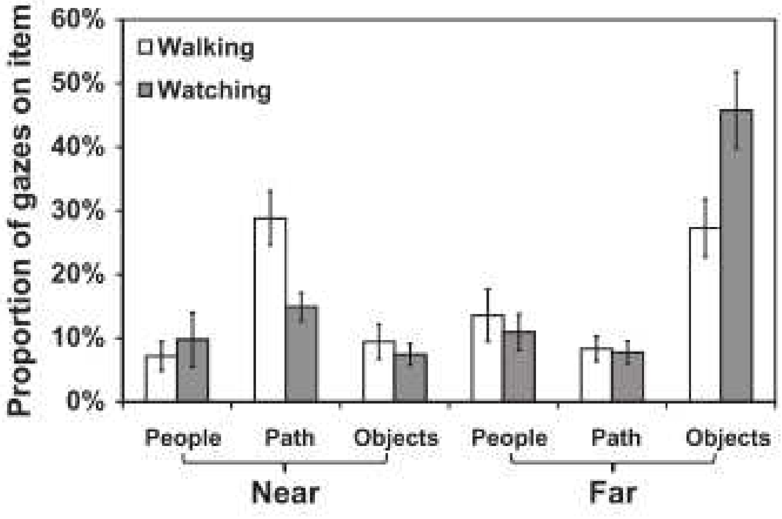


Fig. 6. Results from Foulsham et al. (2011). Differences are found between walking through a real-life environment and watching a video of that same route. Participants looking with different proportions at the items in the environment.

When performing studies out of the traditional lab environment, more and different disciplines can be researched. An example of a discipline in human factors that is hard to study out of the natural environment is the subject of clinical errors. Eye-tracking can be used as an objective and qualitative measure of situational awareness and therefore possibly reducing clinical error. Williams, Quested and Cooper (2013) states that ”as new technology makes eye-tracking devices both more affordable and more usable, we look forward to the insights that this technology may reveal about the work of health care professionals in dynamic, uncontrolled, and emergency situations, and particularly in paramedic education. (p. 26)”.

Eye-tracking seems to be one of the most promising tools in the development of coming computer and mobile devices. Mateo, San Agustin and Hansen (2008) for example, explored the possibilities of eye-tracking as a replacement of the computer mouse. The error rates were comparable, however gaze pointing turned out to be faster than mouse pointing. These results are promising for systems in which individuals can't use their hands, or need them for other functions, for example gaming.

The study of Mateo et al. (2008) was exclusively oriented towards computer devices. However, comparable systems could be used for the upcoming use of mobile (phone) devices. Nagamatsu, Yamamoto and Sato (2010) developed a prototype interface, called MobiGaze, which uses user's gaze to operate a handheld mobile device. Although the accuracy sometimes lacked, the results were promising, assuming that mobile devices will have increased processing power. The system could also be used as a feature of E-book readers. The reading history could be recorded, which could for example be used to anticipate important passages or flipping pages. These systems for commercial use are not only in the future, but are developed at the moment. According to latest rumors Amazon is working on "a superphone that uses four forward-facing cameras to track your face and eyes to create a 3D user interface (Anthony, 2013)."

Next to the "traditional" technologies like personal computers, mobile phones, tablets and e-books, eye-tracking could have an enormous contribution to an upcoming device currently known as HUD (Head up Display) glasses. A screen is integrated into glasses, which makes it a wearable device that can be used while still looking through the glasses. The possibilities seem extensive. HUD glasses will be connected to internet and are location aware. Real-time traffic information, navigation, integration of social media, fast camera use and interactive information are only some of the features that can be integrated. Both Samsung and Google have announced HUD glasses and it seems a matter of time when it will claim its place on the market. However, research on the possibilities of HUD glasses and the role of eye-tracking is still in its infancy. Paletta, Santner, Fritz and Mayer (2013) state that "with the advent of Google glasses and increasingly affordable wearable eye-tracking, monitoring of human attention will soon become ubiquitous (p. 1)."

eHealth

eHealth is a relatively new concept within healthcare and psychology. eHealth can be described as electronic communication and information technology in the health sector. Many aspects of eHealth directly or indirectly meet the field of human factors. Electronic communication and information technology implies intensive communication between humans and computer-interfaces. Furthermore, eye-tracking can be used as a tool to indicate or diagnose mental disorders.

Because of the novelty of the concept of e-health, it is not commonly studied in combination with the use of eye-tracking. However, recent studies on the usability of internet-delivered interventions increasingly discover the usefulness eye-tracking. Crutzen, Cyr, Larios, Ruiter and de Vries (2013) studied the adherence to an internet-delivered intervention. By adding social presence elements to the website, participants could conceivably use the website longer and more frequent. Despite the fact that there were no notable differences between the intervention-site with or without social presence elements, eye-tracking made a major contribution to the study. They marked the social presence elements as Areas of Interest (See Fig. 7). This way the eye-tracking results gave them an extra layer of information about how the participants perceived the information, and whether the presence of these elements influenced the way participants looked at the site. In line with this study, Harris, Sillence and Briggs (2009) studied the influence of positive (trustmarks) and negative (adverts, pharmaceutical sponsorship) credibility cues on the behavioral response to quality health-risk information. Again eye-tracking provided crucial information in whether the credibility cues influenced the information search at health-related websites. Kules and Xie (2011) also used eye-tracking to study behavioral responses on health risk information websites. Their objective was to map the searching behavior of older adults on health information website MedlinePlus. Fixation count and total fixation duration on particular website AoI's (Areas of Interest) were used in combination with data about clicking behavior and interview data. This research shows that eye-tracking should be accessible for all ages. From young children to older care recipient, an eye-tracking device should be versatile to serve all target groups.

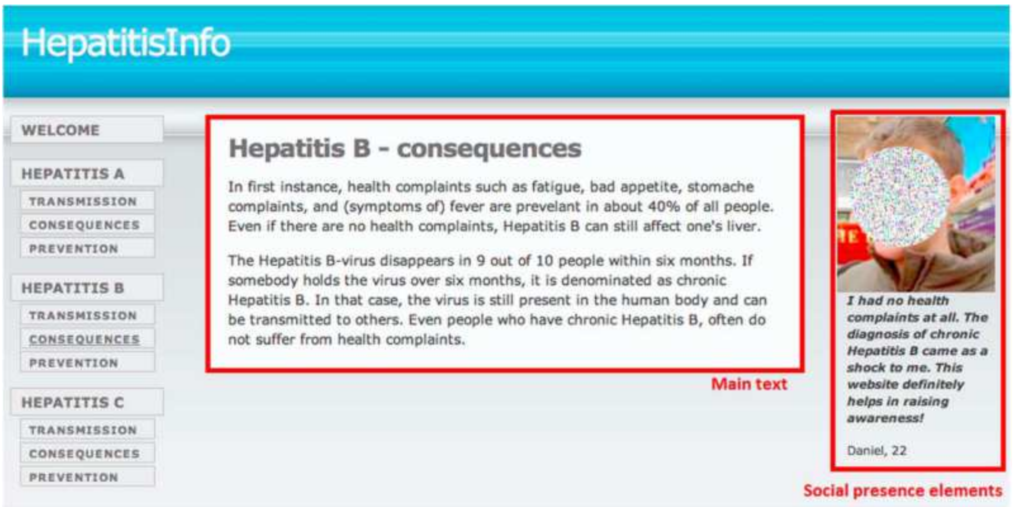


Fig. 7. An example of how AOI's/lookzones are used in eHealth research. The red lined areas are the parts the researchers are interested in. The box at the right is the added social presence element described above (Crutzen et al., 2013).

eHealth is, as already stated, an upcoming concept and therefore much research still has to be done. The use of healthcare from distance through internet and computer-based systems seems to be a matter of time. However, it takes effort and time to design products (internet-delivered interventions, health related information websites) that will function efficiently.

Automotive

In 1996, Tock & Craw studied the possibilities of an in-car device that could measure the eyes of the driver. This was part of a larger detection system that could possibly detect drowsiness of car drivers. The drivers' handling of the car (steering, throttle, braking, speed, etc.) was used as a parameter to correlate with. Although the results were promising, the researchers saw mainly potential for using eye-tracking cameras in driving environments with professionals (trains, aircrafts), rather than commercial usage. Nowadays, in-car fatigue detection is still a very up-to-date topic within the automotive research (Horak, 2011; Li, Y., Hu, Wang, & Ding, 2010; Tayyaba, Jaffar, & M., 2010).

Initial automotive research focused mainly on the usage of eye-tracking in devices that could trace fatigue in car drivers, as described above. Later on, more studies aimed to use eye-tracking as a research tool, rather than use it as a research goal. Eye-tracking turned out to be very useful to study the possible loss or shifts of attention. Beh and Hirst (1999) for example used eye-tracking to study the effects of music during driving, and in 2009, Uchida, Asano, Yokoya, Ueda and Iihoshi, performed a similar study on the effects of hands-free phone use on drivers' visual behavior and detection performance.

Most of the current automotive studies on eye-tracking use simulator or in-car environments. The absence of lab studies makes this field of research a perfect example of the usage of ambient and out-of-lab methods of eye-tracking.

In line with the research on the effects on music and hands-free phone use, much research has been done on real driving situations. Spies et al. (2011), for example, studied the use of a touchpad with an adjustable haptic surface. This study is a good example of how eye-tracking could be integrated into early development of new ideas, as well as on how eye-tracking could be a tool that can be integrated into a wider range of ambulant research measurement devices. Spies et al. (2011) took a concept idea of the possible advantages that a haptic touchpad could have on the distraction from the driving task. They tested this theoretical idea in a very early stage of development. The theory turned out to be successful, and therefore very useful in the further development of a new Audi user interface. If no difference was found between a flat and haptic touchpad, no further money and time had to be invested in the development of a similar interface. Thus, including eye-tracking into early stages of development could save a considerable part of the budget. The researchers did not only test their concept using eye-tracking, but also video data from 4 cameras, driving performance from the driving simulator and comments of the subjects trough a microphone were captured. This way a complete view of the realistic circumstances could be made, when synchronizing the captured devices together.

Another simulator study (Di Stasi, Contreras, Candido, Canas, & Catena, 2011) focused on other road users: motorcyclists. Eye-tracking was used to map the differences between experienced and inexperienced drivers. Like Spies et al. (2011) a simulator and a head-mounted device were used to perform the measurements. Several eye-related measures could be identified as predictors for the amount of experience drivers have. Studies like Di Stasi et al. (2011) could be a starting point to use these findings in for example training of motorcyclists.

In contradiction to the research methods of Di Stasi et al. (2011) and Spies et al. (2011) which used simulators and head-mounted eye-trackers, Inman (2012) used a real-time car and route in combination with a dashboard mounted eye-tracking system. They used this setup to research roadway messaging. They compared the glance on the traffic signs with the answers on the identification of the signs. One of their findings was that the participants could correctly answer questions about the speed limit, without glancing at the signs. However, the same did not apply for warning signs (fig. 8).

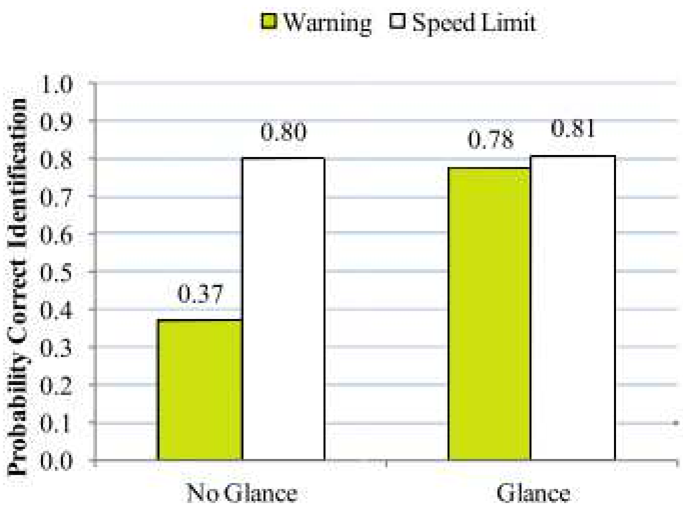


Fig. 8. Table from Inman (2012). The identification of warning signs was dependent on glancing on the signs. For speed limit signs, glancing did not make any difference.

Most of the discussed automotive studies are highly ambulant. None of the studies were bounded to only a computer screen and a lab setting. However, there is a tendency towards preferring driving simulators instead of real-time car settings. This could likely have small implications on the validity of these studies.

Educational Sciences

Ever since the mid-1970s, eye -tracking is used in a vast number of studies. Early research focused mainly on the role of eye movements in reading (Rayner, 1998; Just, Carpenter, & Masson (1982). Reading plays an important role in learning, and because of this it is a widely researched topic within educational sciences. But also without reading, eye-tracking can be of great value to both the research on educational phenomena, as well as a tool to support learning.

Nearly all educational sciences studies are lab studies. First of all, much research has been done on topics that are connected to the educational field: learning from multimedia materials, concept-map formation, cognitive styles, comprehension of language, educational computer games and learning on computer based interfaces (Booth, Sridharan, McNamara, Grimm, & Bailey, 2013; Dogusoy & Cagiltay, 2009). A study of She and Chen (2009) on the impact of multimedia on science learning is an example that did use eye-tracking in their research setup.

This study can be seen as a good example of how eye-tracking is used in the field of education and learning. Like in many studies in this field students (with an average age of 12) are used. They used the biological process of mitosis as the information that had to be learned, and employed a two (narration/on-screen text) by two (animation/simulation) design. The 60 Hz Eye Gaze System was used to track the gaze of the participants. They used the number of fixations, total inspection and mean fixation duration on the Areas of Interest from the eye-tracking data. This way they could link between eye-movement behavior and cognitive process. Next to learning, some studies in the field of education target to research attention and object recognition. For example Underwood, Templeman, Lamming and Foulsham (2008) who used eye-tracking to study how and whether incongruent objects attract visual attention. Again, eye-tracking played a great role in understanding the way people process information. The current research on educational phenomena could in many cases be improved by using eye-tracking. For example Arguel and Jamet (2009), who studied how to use video and static pictures in the learning process of procedural contents. They state that "in a future study, it could be relevant to observe the process of visual exploration during learning by using online measures with an eye-tracking device (pp. 359)."

Next to using eye-tracking as a tool to study educational phenomena, current research focuses also on the usefulness of eye-tracking systems in learning processes. Cantoni, Perez, Porta and Ricotti (2012), for example, aimed to build an E-learning platform that is able to recognize students' emotional and cognitive conditions. Using these conditions, this could help the platform to match eye behaviors to crucial points in problem solving, regions users look for when searching for an answer, ignoring certain data and whether users waver between two answers. Pupil size, fixation duration, saccadic speed, gaze plots and heat maps (see fig. 9) were used. Such use of eye-tracking could be an indication on how to use the human gaze to support people during their learning process. Now the learning environment becomes more and more digital, the way to support people could shift too. Although the studies on this topic are limited, the study of Cantoni et al. (2012) shows the extensive possibilities. Knowing where people look at, could reveal a short look into their thinking process and therefore could be very helpful to support learners.

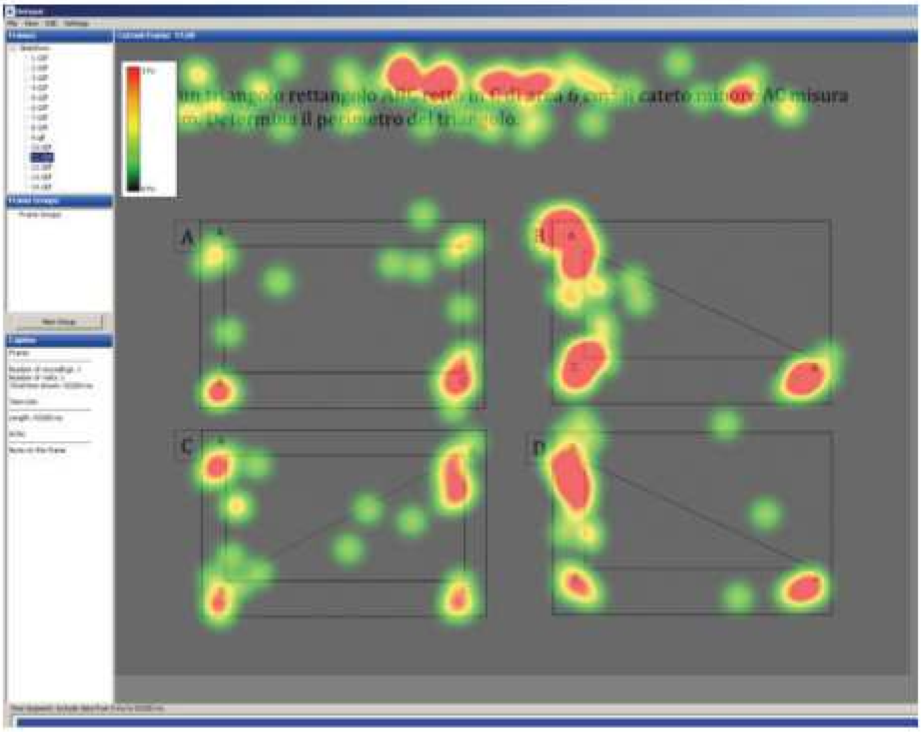


Fig. 9. An example of how eye-tracking could be used to immediately help learners by looking at their gaze-locations. When learners look at the wrong area's for the answer, real-time hints could be given (Cantoni et al., 2012).

As already stated, mobile eye-tracking seems to not to be an urgent need in the field of educational science. This is not any different from the University of Twente, where the educational research targets ICT applications. However, non-ambulant eye-tracking is used a lot in the field of educational sciences. And it can be even more important, for example Rosch and Vogel-Walcutt (2012) state that 'development of training systems should begin by using eye-tracking to gauge user interactions with programs to gauge where, how, and when the instruction should or could be altered (pp. 322)."

Communication Sciences

The use of eye-tracking in the field of communication sciences was initially mainly used in marketing. Attention and findability play a great role in the marketing of products. Initially only advertisements in papers and billboards were tested. Lohse (1994), for example, studied how characteristics of yellow pages advertisements influenced consumer information processing behavior.

Later on, the expanding use of internet triggered the research on online advertisements. Eye-tracking could point out many aspects of consumer behavior on websites. Kuisma, Simola, Uusitalo and Öörni (2010) studied the effects of animated banners on consumers' memory of advertisements. Fixations were used to explain where consumers were looking, and whether animated banners influenced their viewing behavior. Apart from the outcomes of the study, this is a typical lab study in the field of communication sciences. Eye-tracking has a great share in explaining human behavior in combination with for example advertising. For advertisers it is crucial to know where, how and how many ads to place on a website to get the desired attention. Another example from the field of communication sciences is the study of Daugherty and Hoffman (2014) where fixations were used is to research the capturing of attention in a website environment. They studied the effects of word-to-mouth on the internet (eWOM) within social media on consumer attention. They used fixations of consumers to measure the attention that was focused onto negative, positive and neural messages. Fixations are the major eye-tracking factors that are used during these studies. Where and for how long consumers are looking at certain areas is crucial information for the industry.

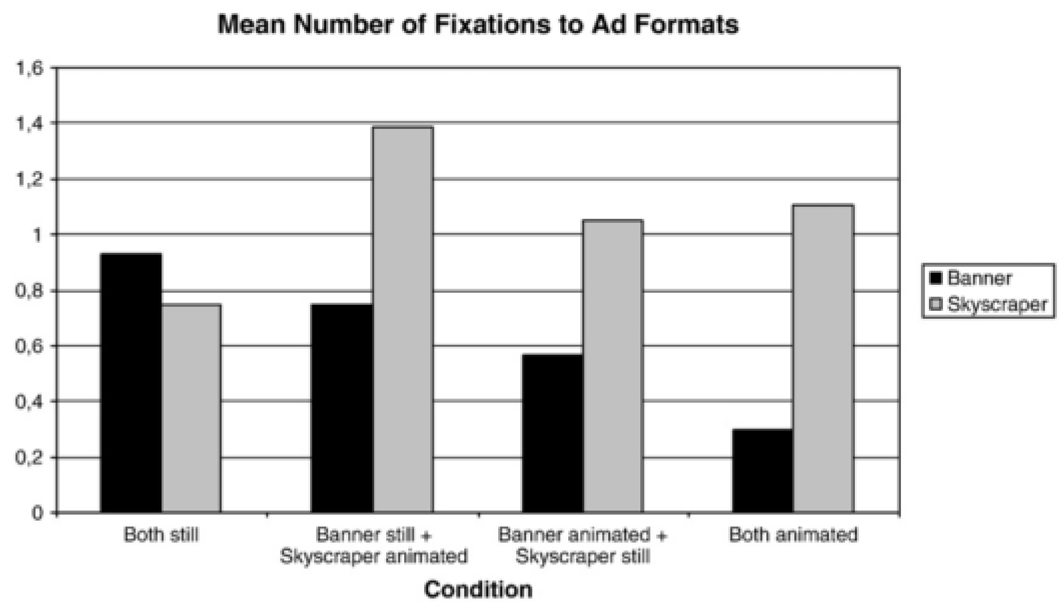


Fig. 10. Results of the study of Kuisma et al. (2010). The mean number of fixations to the ad formats (Banner or Skyscraper) changes when one or both types of ads are animated.

Both the studies of Kuisma et al. (2010) and Daugherty and Hoffman (2014) are examples of recent lab studies in the field of communication sciences. However, consumer research out of the lab seems scarce. Mobile eye-tracking is only used in very recent studies. Harwood, Jones and Carreras (2013) used a mobile eye-tracking device to study the influence of shedding light on consumer behavior in real retail environments. This study could be seen as an example of how mobile eye-tracking could be performed in the near future. The researchers used a real shoe shop as their research environment. Costumers were asked to participate. Due to the fast calibration, the study of the individual participants did not take long. To keep the circumstances approximately the same for all participants some minor changes were implemented in the shop. For example no other costumers were present in the shop and the background noise or music was removed. The participants were asked to explore the target merchandising unit. Between the setups the participants were interviewed in another room, so the light conditions could be changed. This research out of a lab setting gave the researchers more opportunities. The research was done in a real shopping environment and the participants were easy to recruit. These sorts of research can directly provide practical advice for marketers and the industry. Furthermore, Behe et al. (2013) explored the possibilities of mobile eye-tracking in the retail environment. They recognize that eye-tracking could play a key role in understanding what consumers view, using mobile eye-tracking equipment, for example product placement on a retail shelf.

Thus, the use of mobile eye-tracking seems to be a still developing and therefore a lot of possibilities exist. The current research on advertising is focusing mainly on lab research. However, it could highly increase the validity of these studies if they conducted their experiments in a more natural environment. For example outcomes of research on billboard advertising on bus stops could be considerably different when they were performed on people who actually take the bus, instead of people who are asked to look at an advertisement in a lab setting.

Table 1. Schematic overview of studies from the literature study from all 5 departments.

Research Field	Study	Eye-Tracker	Sampling rate	Head mounted	Desk mounted	Amount of fixations	Fixation Duration	First Fixation	Heatmaps	Pupil size	AOIs	Gaze Path	Fixation Density
Human Factors	*Foulsham et al. (2011)*	ASL Mobile Eye	60 Hz	X		X	X					X	X
		EyeLink II	500 Hz	X									
	Mateo, San Agustin, Hansen(2008)	Open source Eyetracking system	30 Hz	X			X				X		
	Cinar (2009)	Tobii 1750	50 Hz		X	X	X		X		X		
eHealth	*Crutzen et al. (2013)*	Applied Science Lab Model 504	60 Hz		X	X	X				X		
	Kules, Xie (2011)	Tobii T120	120 Hz		X	X	X				X		
	Harris, et al. (2009)	SMI iViewX	1250 Hz		X	X	X				X		
Automot.	*Spies et al. (2011)*	Dikablis	50 Hz	X		X	X				X		
	Di Stasi et al. (2011)	EyeLink II	500 Hz	X			X				X	X	
	Inman (2012)	Smart Eye AB	60 Hz		X		X				X	X	
Educ. Sc.	*Cantoni et al. 2012)*	Tobii 1750	50 Hz		X		X		X	X	X		
	She et al. (2009)	LC Technologies Inc.	60 Hz		X	X	X				X		
	Underwood et al. (2008)	SMI EyeLink I	500 Hz	X		X	X	X					
Comm. Sc.	*Kuisma et al. (2010)*	Tobii 1750	50 Hz		X	X	X				X		
	Harwood et al. (2013)	Tobii Glasses	30 Hz	X		X	X				X		
	Daugherty et al. (2014)	eyesDx	N/A	N/A	N/A		X				X		

Based on the literature study, it can be concluded that there are differences in the use of eye-tracking at the different fields of social sciences.

In some fields eye-tracking is used for a long time, whereas in other regions it is relatively new. Studies about eHealth are all from the past years, and therefore the use of eye-tracking does not have a large history in that field. In the fields of Educational Sciences and Human Factors eye-tracking is a widely used tool for many years.

The use of mobile eye-tracking is widely used in some fields, but never in others. The fields that can benefit the most from a mobile eye-tracking device are Communication Sciences and Automotive. At the field of Human Factors there are also research opportunities. However at the fields of eHealth and Educational Sciences, mobile eye-tracking is not widely used and the need to introduce it to these fields seems low. Research questions from these fields can rarely be improved by a more mobile setting.

Overall, the measurement on screens is the most used implementation of eye-tracking. Only at the automotive department the majority of eye-tracking studies is performed in a more mobile setting. At the fields of Educational Sciences and eHealth eye-tracking is a very useful tool, however only on computer-, phone- and tablet screens.

From table 1 it can be concluded that fixations are the most important eye-tracking factors. Every study used fixation duration and a large majority used the amount of fixations. In most studies AOIs are used to analyze these fixation data. When AOIs were not used, it concerned mobile eye-tracking studies. This could implicate that AOIs are less important when measuring mobile eye-tracking. Fixation density, first fixation, pupil size and scan paths are less widely used factors. Also heatmaps are less used, and seem to be more an extra visualization tool than a necessary analyzing tool.

The sampling rate between studies varies from 30 Hz to 1250 Hz. Between the different fields there are no clear differences. All sorts of Hz are used in all research fields.

III. Interviews amongst future users

To get a full insight in the needs of the university regarding eye-tracking, the future users are a very important factor. Eventually the eye-tracking device needs to fit the research at the university and capable of answering the various research questions. Therefore employees from the concerned Social Sciences departments are interviewed.

Based on the case study, literature study and a look into the specifications of the current available eye-tracking devices, a set of questions is composed. The designs of the studies described in the literature study are accurately looked into. All factors described in these designs were divided into 3 groups: software, hardware and mobility. Afterwards these factors were matched with the specifications of several eye-tracking systems to see whether all specifications of eye-trackers were mentioned, for example the possibility to measure both EEG and Virtual Reality. At last the case study was used to recognize possible pitfalls in mobile eye-tracking research. Those pitfalls therefore merely were related to the "mobility" group. At last all factors that were distinguished were transferred into questions. These questions are used as a guide when interviewing employees from the five departments of the university that could take advantage of a purchased eye-tracking device. The complete set of questions can be found in appendix A.

The use of this set of questions implies that the interviews were semi-structured. The questions were used as a guideline during the interviews. In this way, every aspect that is determined by using the case study, literature study and a look into the specifications of the current available eye-tracking devices is discussed. Every interview was taken by the same researcher. When interviewees did not understand a question, or did not have any experience with the topic discussed in the question, the interviewer explained the topic and tried to give examples of studies and designs in which this topic played a role. The interviewer encouraged the interviewees to explain their answers. A "yes" or "no" answer usually was followed by a question to explain their answer further. The motives of the interviewees to like or dislike certain aspects of an eye-tracker were at least as important for the researcher. Frequently the interviewees were asked whether their opinion was shared with other members of their department. After the set of questions the interviewees were given the opportunity to ventilate topics that were not included in the questions.

The outcomes of the interviews are subdivided into the groups “hardware”, “software” and “mobility”, preceding by a short description of the practice of eye-tracking at the university. These groups contain the different categories that could be important when purchasing an eye-tracking device. Each category is divided into; an introduction, which gives a short description about why this category can be crucial; the outcomes of the interviews, which describes the opinion of the interviewees on these topics; and a conclusion, which gives the importance of the category, as well as which implications the importance of this category has on the requirements of an eye-tracker.

Respondents

A total of 10 persons from the 5 departments of the University of Twente were contacted through e-mail to participate with the interviews. This e-mail explained the objectives of the current research and emphasized the importance of the opinion of the researchers at the different departments. The set of questions that was used as guideline was sent attached to the mail, so that the interviewees could prepare for the interviews. Three of the contacted persons declined participation because of a lack of experience and/or future interest in the subject. One of the contacted persons did not respond. The contacted persons consisted of post-doc researchers, doctors, PhD students, teachers and professors. All of them had, or could have interest in eye-tracking at the UT. Some of the persons had former experiences with eye-tracking research and/or education. This was in the range of teaching eye-tracking in a course once a year to being part of multiple eye-tracking studies.

Additionally to the staff members of the University of Twente, one expert on eye-tracking and former member of the University of Twente was contacted. He/she did not participate with an interview, but gave advice that could be helpful in the ‘Recommendations’ part.

To take the privacy of the participants in account, which explicitly was asked for by several interviewees, no real names are used. Also therefore the exact position (i.e. professor, PhD student, etc.) of the participants is not described. In the text, the following names are used to describe the participants:

Interviewee A = Member of Communication Sciences – Corporate and Marketing Communication (CS – CMC) department of the UT.

Interviewee B = Member of the Educational Sciences and eLearning department of the UT.

Interviewee C = Member of the Human Media Interaction department of the UT.

Interviewee D = Member of the Psychology, Health and Technology department of the UT.

Interviewee E = Member of the Communication Sciences – Corporate and Marketing Communication (CS – CMC) department of the UT.

Interviewee F = Member of the Automotive department of the UT.

Practice of eye-tracking at the university

Previous practice of eye-tracking systems at the University of Twente

At the university an eye-tracker is available to use the last couple of years. This concerns a 60 Hz video based desk-mounted eye-tracker that records both eyes simultaneously, and that runs on Facelab 4.5 (Seeing Machines In. Acton, USA). A remarkable fact that came forward during the interviews is that only few interviewees have worked with the device. The interviewees that have worked with the device state that it is a practicable device, but it has some major disadvantages. The 60 Hz sampling frequency is experienced by the interviewees as too low. For many purposes this frequency did not satisfy the needs. The placement of the participant behind the eye-tracker was highly defining the results of the gaze data. When the participants moved slightly behind the desk, the whole eye-pattern would displace. This was experienced as highly disturbing. The eye-tracker was mounted onto the desk permanently. This kept several interviewees from using the device, because they wanted to use it at different locations, with participants other than students.

Tobii and SMI are the eye-tracking manufacturers that are mentioned most when asked for former experiences with eye-tracking devices; 5 out of the 6 interviewees mentioned Tobii and 4 out of 6 SMI. At the HMI department the ITU open-source eye-tracking device is used. Their experience is that it could become problematic for researchers with a non-technical background to control the device. Furthermore, they encountered major problems with different light conditions.

Factors that were encountered as highly undesirable during former research were eye-trackers that only functioned with a head-rest. Especially when studying small children this turned out to be very problematic. Also large head-mounted devices that were clearly uncomfortable were mentioned as highly undesirable.

To get a better view on how eye-tracking was used at the university in the past years, the contents and directions of the master theses that used eye-tracking are very interesting. We can learn that nearly all studies on the different departments of social sciences are done using a computer screen. Even when the used objects are in real time rarely perceived on a screen. For example a master thesis on consumer behavior. They used eye-tracking to measure the impact of social cues and nutrition claims on packaging designs. These package designs were presented on a screen. One can imagine that the ecological validity of this study can possibly be improved by using a device that can measure consumer behavior in a more natural environment. However, in many cases the structured environment is preferred by researchers to rule out uncontrollable factors, and thus make more solid claims.

At the department of communication sciences most theses are performed that used eye-tracking. Besides the research on packaging designs, other examples are the use of eye-tracking to research the influence of trust features on an online financial service website and research on the use of different lay-outs of web questionnaires.

An example of the practice of eye-tracking at the Psychology department is a research on factors that influence the trust in Wikipedia. Eye-tracking was used to measure the eye-movements towards different parts of a Wikipedia page. A comparison could be made between what the participants reported to be important factors when judging its credibility and where participants actual looked at.

At the theses of the HMI department eye-tracking is used for example to research the influence of textual cues to illustrations in a text. This is also done by using a computer screen. Also research is done on how to improve computer screens. For example by using eye-tracking to study how participants handle touch screens.

It is common to use students as participants during master thesis research. Therefore the variety of participants is narrowed. Kids and elderly are rarely used as participants, and the equipment does not have to be adjusted to them.

The look into several master theses of the last years gives an indication about how eye-tracking is used at the university. Because of the restricted mobility of the available eye-tracker, all studies are performed in a lab setting on a screen. Participants could barely move behind the eye-tracker, because of the sensitivity of the device.

Current use of eye-tracking at the University of Twente

At the moment only one of the five departments at the University of Twente use eye-tracking in their education and research program. At the Communication Sciences department every student is required to perform one small research with an eye-tracker during a practical course. Eye-tracking is used in a few research plans. One example that is mentioned is a study on whether children notice the "kijkwijzer"-icon (Dutch version of Parental Advisory) on DVD-covers.

At the Human Factors -department, not long ago, eye-tracking was a part of their "Research Methods" course. In this course students actively worked with an eye-tracking device. Because of personnel changes, both the educational as the research activities on eye-tracking has been brought to zero.

At the Educational Sciences department eye-tracking is not used at all at the moment. In the past eye-tracking research was performed at the department. This concerned research on so called "agents" in a digital environment, for example animations that help children when they work with educational computer games.

At the other departments eye-tracking is not used at the moment and/or in the past.

Future use of eye-tracking at the University of Twente

Four out of the five departments are planning to use eye-tracking in the future. Only at the automotive department the interviewee does not recognize eye-tracking being a direct added value to the current situation.

At the Communication Sciences department eye-tracking is seen as a very promising tool for the future. When an available eye-tracker becomes more flexible in where to use and mobile during the use, the interviewee(s) see many opportunities. Currently the ideas often don't fit the capabilities of the available eye-tracker: "We want to transfer our ideas into concrete research plans, but at the moment this is impossible due to the available device".

At the Educational Sciences department, concrete plans exist on the use of eye-tracking as an important field of research. Eye-tracking could be very useful when creating learning environments. The interviewee has already lay contact with eye-tracking manufacturers to inform him/her about the available devices. Also at the rest of the department there exists much enthusiasm about the possible purchase of an eye-tracker. Especially with their research on kids, eye-tracking could give an extra dimension to their research. Interviewee B: "Following children's eyes can give us a unique insight in their mode of thought".

At the Cognitive Psychology and Ergonomics there is a need for eye-tracking to make its revival at the department. However, at the moment the expertise is not present to set up either research or education.

At the eHealth-department eye-tracking would be used in the near future to test and design their intervention. These interventions are for example mobile applications for nurse practitioners or patients. To know how these applications are used, preferably in real-life situations, eye-tracking could be a very useful tool.

At the automotive department no future plans exist for using eye-tracking.

More ambulant use of eye-tracking at the University of Twente

When an ambulant lab is carried out at the university, it is important to know in which ambulant directions and area's the interviewees see research- and educational opportunities. Like the future use of eye-tracking, most interviewees see potential in more ambulant eye-tracking at the university. Interviewee A states: "A benefit of mobile eye-tracking is the possibility to set up studies in a more natural environment". And even in the lab the mobility of an eye-tracker could be of added value: "If people can walk around freely in the lab, this would add many opportunities to the current research" (Interviewee C). Interviewee D recognizes especially the opportunities in the real-time lives of participants: "With eye-gaze we can accurately know how we can stimulate people to adjust their lifestyles and how to unlearn unhealthy patterns of behavior by using technology". Furthermore, Interviewee E has worked with eye-tracking glasses, and was satisfied with the results.

At the other side, comments are made about the possible downfalls of mobile eye-tracking. For example when using glasses (head-mounted device), Interviewee A has his/her concerns about whether these head-mounted devices makes the participants more conscious of the fact that their eye-movements are being measured. Interviewee B states that the mobility of the eye-tracker can't interfere with the quality of the data: "The quality of the data can't suffer because of the mobility."

Hardware

Sampling rate

Intro

It is impossible for an eye-tracker to have an ongoing sampling frequency. Therefore, all eye-trackers take snapshots of the position of the eye at a fixed rate. Every snapshot is used as a representative of a larger interval of time. These intervals are measured in Hz. The higher the amount of Hz the eye-tracker measures, the smaller the interval of time the snapshot represents. For example, a 50 Hz eye-tracking system takes a snapshot once every 20 ms. The amount of Hz is called the sample frequency.

Different kinds of research require different amounts of sample frequencies. When researchers aim to study saccadic movements and reading, the amount of Hz should be higher than research on the visibility of billboard advertising or traffic signs.

Outcomes interviews

At the campus of the University of Twente a 60 Hz table-mounted eye-tracker is available. Some interviewed persons have worked with this eye-tracker. Nearly all state that 60 Hz is a too low sample frequency to work with. Interviewee A noticed that “while working with the device the eye movements went too fast for the eye-tracker, and therefore the data missed the essence of what I tried to measure.” Interviewee B agreed with this conclusion and stated: “for my research, I need equipment that is more powerful than 60 Hz.” The future research plans of the Educational Sciences departments require a high sampling rate. To accurately perform reading research, a 60 Hz device is not sufficient.

The lower the amount of sample frequency, the more data has to be recorded to get accurate answers to research questions (Andersson & Nyström, M., Holmqvist, 2010). Researchers of the university already encountered the difficulty of obtaining enough participants. When the sample frequency will be low, even more and longer testing is necessary. Anderson, Nystrom and Holmqvist (2010) state out that with research using babies or primates as participants, the raise of the amount of trials is sometimes impossible, and therefore eye-tracking equipment with a high sample frequency is required. However, this does not apply to the research at the university.

Previous research shows that at a certain threshold the amount of sample frequency could rule out the problem of sampling errors. Andersson, Nystrom and Holmqvist (2010) state that this threshold lies around 200 Hz. Above 200 Hz, there is minimal benefit regarding sampling errors.

Conclusion

Concluding, a sample frequency 60 Hz is too low to meet the requirements of the research at the university. This statement is shared by the current literature, which shows that 200 Hz is needed to bail out sampling errors. Thus, 200 Hz seems to be the minimum required sample frequency for an eye-tracker at the university. There is little difference between devices with higher than 200 Hz frequencies. Which means that a 2000 Hz device does not by definition meet the requirements better than a 500 Hz device.

Importance of measuring interfaces

Intro

The measurement of interfaces has turned out to be one of the most important practices of eye-tracking. Especially desk-mounted eye-trackers are nearly always focused on measuring screen-interfaces. This concerned primarily computer screens, but in the last couple of years this extended to mobile phones, tablets and navigation systems.

Even when mobile interfaces are measured outside of a structured lab-setting, this lab-setting will still be often be the basis of these studies. Often, before measuring interfaces out of the lab, the research is tested profoundly in a structured lab setting.

Outcomes interviews

All departments, except for Automotive, that use (or will use) eye-tracking, are interested in the measurement of interfaces. This research varies from computer screens and laptops to TV-screens, mobile phones and tablets. Interviewee B, for example, notes that "computer screens are at the moment the most important interfaces, however devices like tablets are becoming more important in our research." Every possible digital interface will be measured, if a practicable device is available. Because the focus of multiple departments lays on children and youth, it is important that they can work with the devices they use on a daily basis. Mobile phones and tablets are important factors of the lives of today's youth, and therefore can’t be missed out because of a lack of suited equipment. Interviewee D: “Mobile phones are nowadays very important factors for the youth, and therefore the demand for eye-tracking devices that can measure this, is fairly high.”

Not only the type of screen, but also the purpose of that screen varies significant, for example usability at HMI, serious gaming at eHealth and learning through applications at educational sciences.

Conclusion

An important aspect of the eye-tracker should be that it is suited to measure screens. Besides, ideally the eye-tracker should be able to connect to the measured screen. This will highly improve the quality of the measurements, because the data is not obtained through an external camera.

A built-in eye-tracker that can only be used at that (computer) screen is not recommended. This will highly limit the possibilities of the eye-tracker. There are no possibilities to measure devices other than that certain computer screen. Tablets and mobile phones should be measured accurately with the eye-tracker.

Variable distances

Intro

In our daily behavior, we constantly look at both objects close to us, for example our phone at 30 cm away, as at objects much further away, like an advertisement sign 100 meters away. Not every eye-tracker is capable of measuring both distances accurately. Especially desk-mounted eye-trackers are not build to measure at longer distances. Most mobile eye-trackers are capable of measuring at longer distances, but the accuracy can differ a lot.

Outcomes interviews

The measurement of objects at variable distances is not a direct must-have according to the interviewees. Especially when using a desk-mounted eye-tracker, interviewees do not recognize the utility of the possibility to measure at longer distances. However if a mobile eye-tracker can measure accurately at both longer as shorter distances, this would be used at the university. At the eHealth department, in-home research is something that will be focused on in the near future. When a mobile eye-tracker is capable of being accurate when looking at the other side of the room, considering the depth in that room, this would surely enhance both the validity as the opportunities the eye-tracker will provide. Variations of interviewee A's quote was heard multiple times on this subject: "At the moment this [eye-tracking at longer distances] is not a very important factor, however in the future this could surely be useful. The more eye-tracking comes out of the lab, the more important depth and distances will be."

Conclusion

Desk-mounted devices are rarely used for purposes that require long distance measurements. The interviewees made clear that this is also not required. However, when using head-mounted devices, accurate long distance measurement can be an important factor. To measure long distance objects accurate, distinguishing depth is one of the key factors. The difference in depth when measuring for example a computer screen instead of an environment of variable distances can be seen in fig. 9. When calibrated at C, in this case the computer screen, hardly any error in depth occurs. However, this could become problematic when calibrated at C, but also A and B have to be measured accurately in an environment of variable distances. The errors that occur when measuring A and B are called parallax errors. Not every eye-tracker is capable of correcting these parallax errors. Most eye-trackers that can correct for parallax errors use binocular disparity information, to rule out the errors that occur at A and B at fig. 9. An eye-tracking device that can correct parallax errors would be advisable, because of the decreased accuracy. However, when looking at the interviews, accurate measuring on longer and variable distances are not essential requirements.

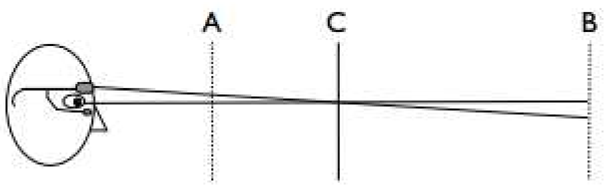


Fig. 13. Parallax errors can occur when there is calibrated at C, but the eye-tracker cannot correct the errors that occur when measuring at A and B (Evans, Jacobs, Tarduno, & Pelz, 2012).

Accuracy of measurements

Intro

The accuracy of measurements varies between different eye-trackers. Not every research topic needs a high accuracy to answer the research questions. Knowing whether drivers notice traffic signs (Shinoda, Hayhoe and Shrivastava, 2001), consumers noticing products placed on the upper shelf (Harwood et al., 2013) require less accuracy than knowing what words were read at a website (Kules & Xie, 2011), or whether computer-users noticed the red exit button at the top corner (Habuchi, Kitajima, & Takeuchi, 2008).

Outcomes interviews

All interviewed persons highlight the importance of an as high as possible accuracy. Interviewee C, for example, commented: “for our research it is absolutely required to have detailed and accurate data.” At their department, a lot of research is performed on reading and for example recognition of words. If the eye-tracking device is not capable of showing accurately at which word participants are looking, research questions cannot be answered with certainty. Thus, accurate measuring of details is essential in their research. When researchers cannot be certain whether details are noticed by participants, their research questions can impossibly be answered with certainty. Especially researchers that primarily test on screens state that high accuracy can be seen as a key factor. With lower degrees of deviation, the accuracy will be better and therefore the results will be better.

Conclusion

The accuracy of eye-trackers can be measured in the amount of degrees. From the literature study we can learn that amount of degrees that is seen as acceptable when measuring computer screens lies between 1.0 and 0.5 degrees. However, some of these studies are outdated if it comes to eye-tracking devices and therefore the processing power and specifications of the devices. When looking at the specifications of today’s eye-tracking devices, a threshold of 0.5 degrees or lower is realistic to meet the standards of the interviewees. Devices with an accuracy of 0.5 degrees or lower are suitable to determine the examples of mentioned in the description; distinguishing words and the ‘close’- button at the upper right corner of the screen.

Use of markers

Intro

Some mobile eye-tracking devices use markers to mark the Areas of Interest (AoIs). AoIs are the regions that are interesting to be measured. If the research purpose is whether customers look at the ads placed at different spots on a website, these ads are the AoIs. When selecting these areas as AoIs, you can for example collect data about when costumers first looked at the ads, for how long they looked and how many times. The use of markers significantly quickens the data analysis, especially with mobile head-mounted eye-trackers. The image of the scene constantly moves, and therefore it can be difficult to analyze specific areas. Because the boundaries of the important areas are preset using markers, no extra effort has to be taken during the analysis.

Outcomes interviews

According to the interviewees the effort of analyzing specific areas in a moving image can be very time consuming, and therefore markers can be a useful feature. However, some eye-trackers have built-in features that can mark moving AoI's.

None of the interviewees that used markers before, sees the use of them as very difficult during testing. Interviewee C: "Markers are relatively easy to work with." However it could, in some cases limit the research questions for a small amount. The preparation of the setup will need some extra time and effort, but this in no contrast to the time and effort that is needed when every AoI has to be marked by hand afterwards. As Interviewee A states: "I don't think the use of markers would be problematic. With a decent preparation, for example a shelf can be measured easily. However when many shelves should be measured, this could become troublesome."

Conclusions

Markers can be a good solution for making AoIs in a less effort- and time-consuming manner. The use of markers is accepted by the interviewees. However the most ideal solution will be eye-trackers that can make accurate AOIs in moving images, without the use of markers.

Measuring for a longer period of time

Intro

Not every eye-tracker is capable enough to use at longer periods of time. Especially mobile eye-trackers frequently have a limited period of use. When looking at the literature study, only a few studies do use eye-tracking for longer than 30 minutes.

Another issue when measuring for a longer period of time, is the processing of the captured data. The processing can be very time consuming, when multiple participants are tested for longer than 30 minutes.

Outcomes interviews

The effort- and time consuming processing of larger sets of data is something that is highly recognized by the interviewees. In their research they have experienced that the data of tests that take longer than 30 minutes can be overwhelming and therefore hard to analyze.

When looking at the use of eye-tracking at the university in the near future, there is not a vast need to measure for longer periods of time at most departments. However, at for example the eHealth department (Interviewee D), the use of mobile eye-tracking for even several hours is mentioned. There are plans to measure several psychological measurements at the homes of elderly, to know how and when to support them in their daily lives. Eye-tracking is mentioned to be a possible tool. If this kind of research will be implemented, eye-tracking should be mobile and capable of measuring for several hours. Other departments do not completely exclude the possibility of measuring longer periods of time, but do not have a clear vision of how this will be brought into practice. Interviewee D: "At the moment I don't have experiences with research practices that are longer than 30 minutes, however I can imagine that it will be used in the near future."

Conclusion

In the near-future it is not a must to measure eye movements for a longer period of time. However, if it is possible, there is a possibility that it will be used. Most desk-mounted eye-trackers can measure for longer periods of time. When looking at the case study, nearly all participants were measured for longer than 30 minutes, without failure of the eye-tracker. However, most mobile eye-trackers depend on battery use, and therefore are not always capable of measuring for a longer period of time.

EEG integration

Intro

Some current eye-trackers are capable of integrating EEG data with eye-tracking data. In several studies eye-tracking is one of the several tools that is used. For example Spies et al. (2011) used eye-tracking in combination with video data from 4 cameras, driving performance data from a driving simulator and subjects comments via a microphone. Eye-tracking is sometimes just an extra, but not necessary, tool. At the Human Computer Interaction department of the University of Twente eye-tracking is used several times as an extra measurement to obtain a more complete set of data.

Outcomes interviews

At the Communication Sciences department only one example of a graduation thesis that used as well eye-tracking as EEG is known. However, in current and past research at the University of Twente this integration is of both tools is very rare. Skin conductance seems to be a slightly more used measuring instrument to combine with eye-tracking, especially as an extra tool that can give more information about arousal.

If EEG integration is available, it will be used in the future. At several departments EEG integration is seen as a usable extra tool. As Interviewee B notes: “If EEG integration is available, it will be used. For example in serious gaming.” However, none of the interviewed persons points EEG integration out to be a strictly necessary feature of an eye-tracking system. If researchers need to use both EEG and eye-tracking, an integration of both tools is useful, but not a must.

Conclusions

EEG integration is not a necessary tool. When research questions require both the use of EEG and eye-tracking measurements, this can be performed separately. If the possibility exists, it will probably be used once in a while.

Virtual reality/3D/6D

Intro

Similar to EEG, it is possible to combine the application of Virtual Reality with eye-tracking. Virtual Reality is a completely computer operated environment that gives the users the illusion they are in another space than they are in reality. Virtual Reality is most known for its usage on gaming purposes, but has also enormous potential for more functional applications like training of pilots and soldiers. The tracking of head- and eye-movements gives Virtual Reality-devices the change to change with the perspective of the carrier. Eye-movements can play a crucial role in the development of Virtual Reality environments and interactions, and also in research on the human behavior in a virtual environment.

Outcomes interviews

Interviewees from the departments of Human Computer Interaction and Communication Sciences have to a small extent experience with virtual reality in combination with eye-tracking. Interviewee E has seen the possibilities of Virtual Reality and eye-tracking: “I have seen that it can work decently. If this is would be available at the university, I would certainly consider to use this integration.” At the HMI department oculus rift is used several times. Thus, the expertise of working with such systems is available at the university. At the social sciences department however, there is nearly any experience with Virtual Reality.

Virtual Reality is not seen as a strict necessary feature of an eye-tracker. Nevertheless, the possibilities of Virtual Reality in the future are recognized by most interviewees. Especially at the department that partly is occupied with marketing sees the potential. When Virtual Reality is one of the features of an eye-tracker that is purchased by the University, some interviewees indicated that they will use it.

Conclusions

Virtual Reality is an option in which participants see the possibilities, but which surely is not a necessary feature. Some interviewees stated that they would use the feature if it was available. This is however not enough to see the implementation of Virtual Reality as a necessary requirement. If the system has an option to integrate with Virtual Reality it is seen as an extra, but for the time being no extra costs should be spend for this integration.

Software

User-friendly software

Intro

There are major differences in the software of the different eye-tracking devices. Some software require a decent amount of knowledge and experience to work with it fluently. This software is mostly accompanied with the possibility to adapt in a larger extend to the needs of the researcher. Software that is more user-friendly will be less adaptable, but a lot easier to use and quicker to learn.

Outcomes interviews

User-friendly software is seen as one of the most important features of an eye-tracker. Every interviewee underlined the important role of easy to use software. Social scientist have, as stated by the interviewees themselves, often not the technical knowledge and background. This could interfere with a system that is hard to handle. Besides, if it takes the researcher a lot of time and effort to gain the experience to work with it fluently, the threshold of using the system could be too high. Interviewee A state that it is "important that the software helps with the so called "x's and y's". The software has to be capable of doing the technical work and therefore facilitate the use of the different options. For example heatmaps and lookzones have to be easy to analyze, without needing extra technical knowledge." Interviewee E adds that "when Matlab and C++ have to be used to analyze the data, this will raise the threshold to use the device and software."

Furthermore, in actual practice students are often the ones who work with the software. They do not have the time and skill to apply complex programming. To allow both students as researchers to work with the equipment, all interviewees highlight the importance of easy to use software that can be mastered quickly. Like Interviewee B states: "Especially at a non-technical department like Psychology, support from the software will be an important factor." If user-friendly software is not included, technical support from the university will be needed to facilitate use of the eye-tracker.

However, it could be of value when there is any room for making adjustments to the software to the preferences of the researchers, only when this is possible without harming the user-friendliness of the software.

Conclusions

User-friendly software is an important feature of an eye-tracker. The software has to be used without programming language. Options like selecting AoI's and computing the duration and amount of fixations have to be included into the software. These options should be able to be used naturally, without any knowledge of the software. When other programs and many adjustments are needed to make the software work, technical support from the university is needed.

Analyzing whether software is user-friendly or not can be difficult. The statements of the interviewees about the different manufacturers can be crucial to know how they experienced the different software. The difference especially lies in the fact to what extend the software guides the user through the different options. Most manufacturers provide information or previews about their software. When this is possible, the main factors that have to be paid attention to are: does the software needs other programs to conduct for example heatmaps or statistical analysis? Is the software based on options to deal with the data, or does the software provide the data and is it difficult to understand all the options? Can the analysis be done by using a strict predestinated order, or has to figure the user this out themselves?

Fixations

Intro

Fixations are the most important factors while analyzing the eye-tracking data. A major part of the studies from the literature study focusses on fixations. Fixations are the moments when a person shifts his gaze towards a certain point. Using fixations, researchers can track where the participants' attention is located. A series of fixations, or scanpath, can determine the route of viewed objects.

Outcomes interviews

All interviewees acknowledge that the measurement of fixations is crucial when conducting eye-tracking research. Both with research on the interaction with interfaces, as research on communication between humans, fixations are a crucial factor. Interviewee E: "Fixations are the most important factor when measuring eye movements."

In the literature study, mobile eye-trackers often lack of accurate measurements of fixations. An eye-tracker that can only tracks to what regions participants approximately look, but at which the fixations are not available or inaccurate, is highly undesirable.

Important aspects that are mentioned as used in previous research are the duration of fixations, the amount of fixations and the location of fixations. Interviewee D: "Position, duration and amount of fixations are the factors that are needed in almost every eye-tracking research." Also the averages of these fixations and the merged fixation data of multiple participants are important.

The interviewees highlight the importance of the support from the software while analyzing the fixation data. "The program should definitely offer options to calculate this [fixations] data. If not, this would be very disappointing, and I would think twice before using the eye-tracker. (Interviewee A)"

Conclusions

The accurate and easy measurement of fixations has high priority, and should be one of the most important features of the eye-tracker. The position, duration and amount of fixations should be easy to obtain through the software.

Saccades / rapid eye movements

Intro

Saccades are the movements of the gaze in between fixations. During saccades no information is registered. Saccades are especially an important factor of eye-tracking during analyzing reading behavior. At fig. 10 the blue lines between the dots are saccades.

Outcomes interviews

Overall, saccades are seen as less essential than fixations. For example Interviewee A who states that "At the communication sciences department, saccades are not important." However, mainly at the Educational Sciences department saccades will be used extensively. Reading is an important aspect of the learning process of children. To research the reading behavior of children, accurate measurement of saccades is essential.

At this moment, no research can be done on reading behavior, because the sample frequency of the current available eye-tracker at the university is insufficient (60 Hz). This problem is supported by the literature about eye-tracking. Juhola, Jantti and Pyykk (1985) argue that to accurately measure saccadic velocity, the sample frequency should be at least 300 Hz. Inchingolo and Spanio (1985) showed that even a 200 Hz device would satisfy in most cases. This was tested with saccades larger than 5 degrees. When it comes to reading behavior, saccades are mostly shorter than 10 degrees. Both studies underline that 60 Hz is insufficient for analyzing reading behavior.

Conclusions

Not every department will use the measurement of saccades. However, it is a desirable function on an eye-tracker to measure saccades accurate. From the literature we know that eye-trackers higher than 200 Hz will be needed to research reading behavior.

Identifying Areas of Interest

Intro

Areas of Interest are the areas that are identified to measure the amount and duration of the fixations at that regions. For example, different parts of a website (ads, text, pictures, etc.) are marked as AOI's. These different AOI's can be used at the data analysis to analyze the amount and time of fixations on the different parts web site.

Outcomes interviews

All interviewees state that Areas of Interest (AoI's) are essential for analyzing eye-tracking data. Again, interviewees highlight the importance of the assistance of the software when making these AoI's. It is seen as a required function of the software. In the software of desk-mounted eye-trackers this is certainly a feasible function. When the image is not moving, it is in most devices quite easy to set up AoI's. However, when the image is moving, like in head-mounted devices, it is way more difficult to detect fixed and not moving AoI's. In the ideal situation, the software is capable of identifying AoI's in moving images. If this is not possible, markers can be a practicable alternative.

Conclusions

For a desk-mounted device it is required that AoI's are effortless to make by using the software. When moving images are made through a head-mounted device, it would be ideal when the software could recognize AoI's. Some devices can recognize selected AoI's by their borders in the image, even when it's moving. When this is not possible, are markers a fair alternative.

Use of heatmaps

Intro

Heatmaps are visual representations of the area's participants looked at. By using different colors, in one image a clear oversight is given of how much, or for how long the participants looked at certain areas.

Outcomes interviews

The interviewees state that heatmaps are generally not used for analyzing the data. Interviewee A, for example, remarks that "heatmaps are used for the visualization of the data, rather than for data analysis." In some cases qualitative research is done using heatmaps. Most of the time they will be used to make the data accessible and the images of heatmaps will be used to place into articles.

Despite the limited role in the data analysis, a majority of the interviewees account that it is very important for an eye-tracker to have a function that can easily produce heatmaps. The eye-tracker that is used in the past at the university did not have an option in the software that could produce heatmaps. By different interviewees this is seen as a shortcoming. Thus, in the past there was a strong need for making heatmaps, and they state that this would not be any different in the future.

Interviewee D suggest that the heatmaps should be produced by the accompanying software, instead of importing the data into other programs. It is the interviewee's experience that this is much easier to use.

Heatmaps of multiple participants in one image is not included in every devices' software. Four interviewees stated this as a desired option to be included.

Conclusions

The software should be capable of producing heatmaps without extra effort and without importing the data into other programs. Furthermore, the option to merge multiple participants into one image is desirable.

Mobility

Mobility of eye-tracking system during testing

Intro

When looking at the case study, one could conclude that more mobile equipment could prevent several problems that occurred during testing. When participants could walk around freely, without being obstructed by the placement of the eye-tracker, multiple screens could be measured, and the eye-movements could be conducted the whole time. This could give crucial information about the loss of concentration of the participants.

Outcomes interviews

Every interviewee recognizes the possibilities of a mobile eye-tracking device. For example Interviewee A, who states that: “Mobile eye-tracking will give us a lot more opportunities to research. At the moment we are very limited.” However, it is not seen as an absolute necessity by every interviewee. There are many research opportunities that are at the moment impossible. Examples of studies that are stated by the interviewees to be done with a mobile eye-tracking device are the measurement of primary school students in more natural school environments (Interviewee B), research on group conversations (Interviewee C) and research in supermarkets and shops (Interviewee A).

Conclusions

The mobility of an eye-tracking system should be one of the key factors when applied in an ambulant lab. However, the interviewees have highlighted the importance of a system that is accurate and that can measure on interfaces like a computer screen and tablets. If an eye-tracker is suitable for these purposes, then mobility could be a very interesting feature. To meet the purpose of an ambulant lab, mobility should always be a requirement, but only if other important requirements are not neglected because of the mobility.

Setup and calibration time

Intro

As concluded in the earlier described case study, the time to set up and calibrate the eye-tracking system can be crucial. Especially in out-of-lab studies, time could be crucial. Many times participants in the field do not have unlimited time to participate, and therefore the setup of the eye-tracking system cannot take too long. During the case study, calibration took several times before succeeding with several participants. This affected the time they could spend on their job, and therefore their mood and willingness to co-operate with the study.

Outcomes interviews

The interviewed persons state that it is important that the system could be used at different locations, for example at schools. However, Interviewee A point out that “this would only add value if the setup of the eye-tracking system would not take much extra time and effort.”

Interviewee E points out that much of the practical part of the eye-tracking will be executed by students. This implicates that the threshold for people who want to practice the eye-tracking without major experience with the system has to be low. Therefore, both the setup and calibration should be as easy as possible, without needing much technical skills.

Both at the Educational Sciences department as at Communication Sciences, much research is done with adolescents and kids as participants. In previous research Interviewee A and B have perceived that when the procedure before the actual testing (i. e. calibration) takes too long, kids and adolescents soon get bored and distracted. Therefore they point out that an as low as possible calibration- and setup time is required in an eye-tracking system.

Conclusions

An easy setup that requires no extra technical knowledge is crucial. No extra knowledge of other statistical programs, like transporting data into Matlab or R, should be required. Besides, the setup of the hardware should be easy to implement, without external technical help.

Calibration has to be run in less than a minute. This is necessary to counteract the loss of attention of children and prevent irritations of participants that are held from their job or have restricted time to cooperate.

The calibration of a desk-mounted device is often different from head-mounted devices. With a desk-mounted device, a 5-points calibration (or lower) will be presented on the screen. When looking at the literature studies, this would not cause many problems. Only when the eye-tracking device cannot be connected to the measured screen, like in the case study, calibration can be problematic. With head-mounted devices there are often options to calibrate as well before and after measuring. Calibration after measuring is desirable. This will prevent agitation among the participants when calibration has to be repeated multiple times. When participants can get to work immediately, they will be way less aware of the device, which leads to more valid results.

Outdoor use of eye-tracker

Intro

Outdoor use of eye-trackers is currently not commonly practiced. One example that is described in the literature study, is the study of Foulsham, Walker and Kingston (2010). They compared the eye-movements of participants during an outdoor walk through campus with those who watched that same walk at video screens. Their results show that there are differences between real-life outdoor situations and simulated outdoor situations. Thus, if research questions focus on outdoor environments, actual outdoor use of the eye-tracker would be the most valid.

Especially head-mounted devices are currently build to perform outdoors. Many desk-mounted devices are affected by the lighter and more changing environment caused by the sun and weather. However, not all head-mounted devices are capable of dealing with natural infrared light that floods the eye camera. Evans et al. (2012)were forced to let participants wear hats to prevent problems. On cloudy days, this was not necessary.

Outcomes interviews

Outdoor use of eye-tracking is by none of the interviewed persons executed in the past. Only a few persons mention outdoor use of an eye-tracker as being relevant in future research. For example Interviewee A, who states that in communication sciences research “outdoor measurements certainly have potential, for example when measuring traffic signs, signals on buildings or outdoor advertising.” The majority does not think outdoor use will be used on a regular base. Semi-outdoor use of eye-tracking, like in a car, is also not practiced at the university. Interviewee F states that “this requires equipment that is suitable for these conditions. I have no idea whether this will be used at this department if this is available.”

Conclusions

The measuring of eye-tracking outdoors, and therefore in open air is not seen as a direct criterion when purchasing an eye-tracker. However, it would add extra value to the practice of eye-tracking in more realistic environments. Especially when automotive research would implement eye-tracking more in their research, an eye-tracker that can easily record in open air would be essential. In many automotive studies from the literature study, the importance of changing light conditions is mentioned. Eye-trackers that can measure outdoor should be able to deal with many different light conditions. Many eye-trackers are not capable of dealing with those conditions. The criterion for eye-trackers that should be functional in open air is that it demonstrable works in for example car- and sports environments.

Indoors research out of the lab

Intro

All in field research is done outside of the lab, but not necessarily in open air. Many eye-tracking studies are for example performed at participants’ homes, at schools or at rooms at participants’ work environments. For these purposes, there is no direct necessity for the eye-tracker to be fully mobile and head-mounted during measurements, but it has to be easy to relocate from the lab to the environment of measurement.

Outcomes interviews

In contrast to outdoor research, there is a great need for measuring indoors out of the lab. As stated before, most interviewed persons have worked with a desk-mounted eye-tracker that could not move anywhere besides its stand at the university. By the interviewees this was encountered as a huge obstacle. The need for an eye-tracker that can easily be moved to the field is high.

Indoor, but out of lab, research environments that are mentioned are especially supermarkets and schools. In schools an eye-tracker that can be mounted onto a laptop would be sufficient. For research at a supermarket, interviewees highlighted the necessity of head-mounted, and therefore more mobile, equipment.

Conclusions

An eye-tracker that is easy to relocate, is a highly desired option. Such an eye-tracker should fulfill some criteria. The eye-tracker should not be bounded to one particular place, like the current situation at the University campus. The eye-tracker should be easy to move, for example by a suitcase with all the supplies for the eye-tracker, and the eye-tracker itself. The eye-tracker should be capable to connect to the used computer, without extra applications that have to be installed. Also the computer that has the executive program installed should be mobile. This will be in the form of a laptop, tablet or even mobile phone. A basis computer running the executive program that is a not movable personal computer, is highly undesirable.

Free movement

Intro

In the case study is already seen that participants that can't move freely behind the eye-tracker can be very disturbing. The participants were restricted in their job because the eye-tracker easily lost track of the eye movements when moving to the left or right, or ahead or backwards. Especially in less structured environments this could have a negative influence on the results. Data could be lacking or incomplete because of the lack of registration of the eye-movements when the participants moves too much.

Mobile eye-trackers are built to move freely, and thus these problems are not applicable. However, when working with desk-mounted devices, this is a factor that can be a factor to keep in mind.

Outcomes interviews

Interviewees have mainly worked with desk-mounted devices. Both Interviewee A and B state multiple times that is experienced as very disturbing that when participants moved behind the eye-tracker, the whole gaze pattern changed. Some freedom to move behind the desk should be very desirable, certainly because many times there will be worked with small children and youths. These groups of participants are, according to the interviewees, often not capable of being located at one exact spot for a longer period of time. Interviewee B: "6 year old children that have to sit at the same position for a couple of minutes was a disaster."

To counteract the loss of data when participants move behind the desk, some eye-trackers have a built-in head rest. Due to this head rest, participants are highly restricted in their movements, but the data will be completer and more accurate. Interviewee B has worked with such head rests in the past and advices against the use of it in a future eye-tracker. Again, small children and youths are often incapable of working with a head rest. When measuring children, is of great importance that the equipment is not disturbing. A head rest clearly disturbed the participants in former research of the interviewees.

Conclusions

An eye-tracker with a head rest is absolutely not advisable. However, an eye-tracker that does not have a head rest should offer the possibilities to move freely behind the eye-tracker, without loss of data. There are limits to all desk-mounted eye-trackers as it comes to freedom of movement, because every device has its limited reach. If we look at the literature, problems occurred when the participants had no space to move at all. When this space is approximately 30cm x 15cm (width x height) the freedom of movement is sufficient.

Furthermore it is a must that when participants move in and out of sight of the range of the eye-tracker, the eye-tracker automatically keeps track of the gaze, without any interference of the researcher.

IV. Requirements

MoSCoW- Method

To categorize the requirements that came forward during the case study, literature study and eventually are conceptualized during the interviews, the MoSCoW-method is used. Using the MoSCoW-method a classification is made based on the importance of the different requirements (Tudor & Walter, 2006).

The MoSCoW-method is subdivided into 4 categories: “Must have”, “Should have”, “Could have” and “Won’t have”. The requirements that fall into the “Must have” category should be certainly be aspects of the eye-tracker. If these requirements are not aspects of the eye-tracker, the eye-tracker won’t fit the demands of the departments and/or the ambulant lab. The criteria used for this category is that there is no alternative manner to get a satisfying result. For example to measure saccades, a minimum sample frequency of 200 Hz is needed. There are no alternative ways to measure saccades with a lower sample frequency. If an eye-tracker is purchased that is missing one of the “Must have” requirements, this could be seen as a bad bargain, and therefore not a success. The “Should have” requirements do not determine the success of the purchase of an eye-tracker, but are still of great importance of the proper functioning of the device into an ambulant environment. Contrary to the “Must have” category, there are alternatives for these requirements. Although it is not the ideal way, if these requirements would be missing other options are available to take place for this requirement. For example it is easiest to make heatmaps directly with the software of the eye-tracker. However this is also possible by transport the data from the eye-tracking software to other data processing programs. The “Could have” requirements can be of value, but are less important than the “Should have” requirements. “Could have” requirements can be seen as nice extra options, but not directly necessary for answering current and near future research questions. The “Won’t have” category are features of an eye-tracker that are seen as highly undesirable.

The requirements are selected from the outcomes of the interviews. In the conclusions of every topic the specifications of eye-trackers that will cover the needs of the interviewees are outlined. Due to the prior case- and literature study all the factors that are important during (mobile) eye-tracking are covered. To ensure completeness of the list, the specifications of some eye-trackers are revised to look for possible missing requirements.

Differences

Most of the time, the MoSCoW-method is used for products that still have to be designed and produced. This differs from the current case, in which the supply of eye-trackers already exists. The university is not planning to make its' own eye-tracker. Therefore, the design of the MoSCoW categories and the interviews differs slightly from the normal use.

Firstly, because the supply of eye-trackers and its specifications was already known, the interviews were, as already stated, semi-structured. The possibilities of specifications of an eye-tracker are not endless for the interviewees, thus the researchers had to consider these limited specifications. To an extent, the interviewees had to be informed about the possibilities that are currently available. If this was something that was still to be build, the interviews would be way less structured. This would imply that the direction of the answers would depend more on the interviewees, instead of the interviewer.

Because of the semi-structured fashion of the interviews, it had no added value to count the amount of quotes of the interviewees, and categorize using that numbers. This study used a more qualitative fashion to structure the requirements. Because the categories already roughly exist before the interviews took place, there is no need to count the quotes. By using the quotes of the interviews about the topics that were discussed during the interviews, an accurate categorization could be made by the researchers.

The "Won't have" (or sometimes "Would not") category is normally used for requirements that are not important enough, or perhaps may be important in the future. In the current study this category is used to categorize requirements that are seen as highly undesirable by the interviewees. These "requirements" are highly unadvisable to be included into an eye-tracker.

Structure results

The categories during the interviews were divided into "Hardware", "Software" and "Mobility". To keep the data uncluttered, the requirements are also firstly divided into these categories. Thereafter the requirements were merged into one overview.

When the four MoSCoW-categories were all merged into one overview, they were laid out side by side with the current supply of eye-trackers. This supply of eye-trackers is created by looking at the literature study, the experiences of interviewees and a thoroughgoing look into the most up-to-date devices.

Schematic outcomes requirements

Tab.6. Requirements MoSCoW Hardware

Hardware	
Must	
Minimum sample frequency of 200 Hz	There are no alternatives to measure saccades with a device that has a lower sample frequency.
Capable of measuring computer screens, mobile phones and tablets	Computer screens, mobile phones and tablets all are included in the research objectives at the university. Performing phone and tablet studies on a computer will harm the validity.
Accuracy under 0.5 deg.	Accuracy above 0.5 degree will have an adverse effect on the reliability of the results.
Should	
-	
Could	
Measuring accurate at longer distances	Will create more options to research and is crucial for some purposes, but most research questions can be answered without measuring at longer distances.
Measuring longer than 30 minutes.	Can be useful for several research questions. However setups can be adjusted to overcome this problem, for example by splitting the measurements up in multiple sessions.
Full integration with EEG	Can be useful in some specific research questions. However, the absence of this integration does not mean that EEG and eye-tracking can't be measured at the same time.
Integration with Virtual Reality	Can enhance the possibilities in the future. At the moment and near future Virtual Reality is not used.
Wont	
-	

Tab. 7. Requirements MoSCoW Software

Software	
Must	
User friendly software	In the current situation at the university, where no expert on eye-tracking is available, the software should be accessible for researchers with less knowledge of eye-tracking, and students.
Measuring position, time and amount of fixations	Most important factors of eye-tracking. The position, time and amount of fixations are all measured factors in current and future research at the university.

Option for making Areas of Interest for static eye-tracking	To analyze the fixation data, Areas of Interest are a necessary tool. External programs are capable of making AOIs but often require time-consuming methods to count the fixations.
Options for measuring saccades	Crucial for research at Educational Sciences. No alternatives available.
Should	
Option for making merged heatmaps for multiple persons	Merged heatmaps can be made by using alternative data programs.
Option for making heatmaps for a single person	Heatmaps for a single person can be made by using alternative data programs.
Could	
Option for making Areas of Interest for moving eye-tracking	Feature that facilitates easy data processing. However, markers are a decent alternative.
Wont	
-	

Tab. 8. Requirements MoSCoW Mobility

Mobility	
Must	
Calibration in less than 60 sec.	Crucial for research questions that need to measure kids. No alternatives available.
Portable eye-tracking device	If the eye-tracking device is not portable, research questions that target environments out of the university lab setting are not possible to answer.
Should	
Calibration after measuring	Reduces the time spent on calibrating. However with a calibration time below 60 seconds this is not a huge obstacle.
Portable device that runs the software	Eye-tracking can still be performed without a portable device that runs the software, although it gets more restricted.
Could	
Mobile eye-tracking system during testing	Participants still see a lot of research opportunities without a mobile eye-tracking system.
Proven to be capable in open air	Outdoor use gives more opportunities, but the research questions of the respondents does not directly aim to measure in open air.
Wont	
Large head-mounted device	Research objectives with kids are hard to perform with a large head-mounted device.
Extra technical knowledge to apply setup	The threshold to use the equipment becomes to large when extra technical knowledge is needed. Only can be moderated by an expert that is not available at the university.
Eye-tracker with head-rest	A head-rest is a huge obstacle on studies with kids and longer studies.

Tab. 9. Merged Requirements MoSCoW Hardware, Software and Mobility.

Must
Minimum sample frequency of 200 Hz.
Capable of measuring computer screens, mobile phones and tablets
Accuracy under 0.5 deg.
User friendly software
Measuring position, time and amount of fixations
Option for making Areas of Interest for static eye-tracking
Calibration in less than 60 seconds
Portable eye-tracking device
Options for measuring saccades

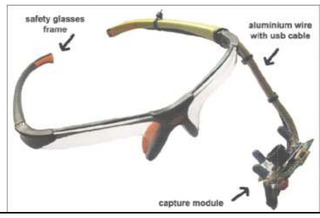
Should
Option for making merged heatmaps for multiple persons
Option for making heatmaps for a single person
Calibration after measuring
Portable device that runs the software
HD-quality

Could
Measuring accurate at longer distances
Measuring longer than 30 minutes.
Full integration with EEG
Integration with virtual reality
Mobile eye-tracking system during testing
Proven to be capable of outdoor use

Won't
Large head-mounted device
Extra technical knowledge to apply setup
Eye-tracker with head-rest

Overview selected eye-trackers

Based on the literature study and a look into the current offer of eye-tracking devices, a selection is made of nine eye-trackers that should cover the whole spectrum.

SMI Glasses 2.0	Head-mounted 60 Hz	
Tobii Glasses 2	Head-mounted 60 Hz	
ASL XG Eye	Head-mounted 30 Hz	
Mobile ITU	Head-mounted 40 – 150 Hz	
Tobii TX300	Desk-mounted 300 Hz	
SMI RED-500	Desk-mounted 500 Hz	

Tobii X2-60	Desk-mounted 60 Hz	
SMI RED-M	Desk-mounted 60 Hz	
EyeLink II	Head-mounted 500 Hz	

Tab 10. Requirements MoSCoW combined with eye-tracking devices. Green boxes stand for the fact that this device scores positive for that certain requirement. Red implies a negative score.

Must	***SMI Gl. 2.0***	***Tobii Gl. 2***	***ASL XG Eye***	***Mobile ITU***	***Tobii TX300***	***SMI RED500***	***Tobii X2-60***	***SMI RED - M***	***EyeLink II***
Minimum sample frequency of 200 Hz.	Red	Red	Red	Red	Green	Green	Red	Red	Green
Capable of accurate measurement of computer screens, mobile phones and tablets	Red	Red	Red	Red	Red	Red	Green	Green	Green
Accuracy of 0.5 degree or lower	Red	Red	Red	Red	Green	Green	Green	Green	Green
User friendly software	Green	Green	Green	Red	Green	Green	Green	Green	Red
Measuring position, time and amount of fixations	Green	Green	Green	Red	Green	Green	Green	Green	Green
Option for making AOI's for static eye-tracking	Green	Green	Green	Red	Green	Green	Green	Green	Green
Calibration in less than 60 seconds	Green	Green	Green	Red	Green	Green	Green	Green	Red
Movable eye-tracking device	Green	Green	Green	Green	Green	Green	Green	Green	Red
Options for measuring saccades	Red	Red	Red	Red	Green	Green	Red	Red	Green

Should									
Option for making merged Heatmaps for multiple persons	Red	Green	Green	Red	Green	Green	Green	Green	Green
Calibration after measuring	Green	Green	Green	Green	Red	Red	Red	Red	Red
Free movement of participants	Green	Green	Green	Green	Green	Green	Green	Green	Green
HD-quality	Green	Green	Green	Green	Green	Green	Green	Green	Red
Option for making Heatmaps for a single person	Red	Green	Green	Red	Green	Green	Green	Green	Green

Could	*SMI Gl. 2.0*	*Tobii Gl. 2*	*ASL XG Eye*	*Mobile ITU*	*Tobii TX300*	*SMI RED500*	*Tobii X2-60*	*SMI RED-M*	*EyeLink II*
Correction for parallax errors									
Measuring longer than 30 minutes.									
Full integration with EEG									
Integration with virtual reality									
Proven to be capable of outdoor use									
Measuring accurate at longer distances									
Option for making AOI's for dynamic eye-tracking									
Portable device that runs the software									
Completely mobile during testing									

Won't									
Large head-mounted device									
Extra technical knowledge to apply setup									
Eye-tracker with head-rest									

V. Conclusion and Recommendation

None of the devices meets all the requirements that have been set. Also none of the devices even meet the “Must”-requirements. The device that could potentially meet all requirements that are set as a “Must” is the EyeLink II. This device has the power of at least 200 Hz sample frequency (500 Hz) and an average accuracy of 0.5 degrees, but is also capable of head-mounted, and thus more mobile, measurements. This is a combination that is unique in the current supply of eye-trackers. At the first hand the best option to purchase. However, the device has some serious shortcomings, especially when measuring with the scene camera. The video quality (NTSC/S-Video) of the scene camera is disappointing. Compared to other devices this quality is too low, and can be an obstacle during various types of research, for example on handheld devices. The software can only be run on a Windows XP computer with FireWire, which is a computer that is becoming rare. That same software could be another obstacle. The form of the data of the scene camera is quantitative. Analysis of this data can be complicated, because there are no options for scoring etc. This should be done by hand by the researcher. And at last, the mobile character of this head-mounted device is a little delusive. The subject is tethered to the earlier described Host PC by a 6 meter cable. This implies that although it is a head mounted device, the research is limited to a lab setting.

This absence of one ideal device requires a second look at the Table 10. As stated in the paragraph above, the EyeLink II is a rare eye-tracker that has both the specifications of a higher sample frequency and mobility. This distinction lies in the fact that most eye-trackers are either head-mounted and mobile, or are desk-mounted and have more power. Nearly all head-mounted devices are incapable of having a high sample frequency and measuring saccades, whereas desk-mounted devices obviously fall short on the mobile aspects that are required. Unfortunately, we know from the interviews that both sides are required at the university. This distinction is also remarked during the interviews by Interviewees D and E. They recommended that it was going to be difficult to find one device that can meet all the requirements, and therefore a distinction between head-mounted and desk-mounted devices could be a logical solution. “From my point of view, I would suggest to buy both a remote as a mobile eye-tracker (Interviewee E).” When dividing both categories into two separate tables, this distinction becomes clearer. This could lead to a purchase of eye-tracking equipment that still meets all the requirements that are set.

Head-Mounted

In Table 11 mobile head-mounted devices are grouped. Now both categories are grouped, the requirements that are less necessary for both categories are scored out. This should lead to requirements that are more specific for both categories. This won't cause any problems, at least if the same requirement is not scored out for both head-mounted as desk-mounted devices. If so, this would not probably not be a real requirement, because it is not needed in both categories. The following requirements are scored out in the head-mounted section:

Minimum sample frequency of 200 Hz. A sample frequency of 200 Hz is absolutely not necessary for a head-mounted device. Only if saccades and real short fixations are measured, this frequency is needed. 30-60 Hz will be sufficient when not measuring computer monitors. In real-life measurements factors that can be measured with 200 Hz or higher do not play any role.

Accuracy under 0.5 degrees. Accuracy is important, but an accuracy under 0.5 degrees is not absolutely necessary. When measuring in real-life environments, the difference between 0.3 degrees or 0.7 will not even be noticed. This is exclusively needed when performing specific research on computer screens.

Options for making AOI's for static eye-tracking. As the name already gives away, static AOI's are exclusively used with static eye-tracking, and thus desk-mounted eye-tracking. For head-mounted eye-tracking, dynamic AOI's are relevant.

Saccades. Saccades go in hand with sample frequency. Most mobile head-mounted eye-trackers do not have the amount of Hz to measure saccades decently. Using head-mounted eye-trackers to perform reading research can be exhaustive, although when reading on paper they will have its' advantages.

Head-rest. Head-mounted eye-trackers never work with head-rests, because they are built to operate as mobile as possible. Therefore the use of a head-rest is not an issue when purchasing a head-mounted eye-tracker.

Tab. 11. Requirements MoSCoW mobile eye-tracking devices. Green boxes stand for the fact that this device scores positive for that certain requirement. Red implies a negative score.

Must	SMI Gl. 2.0	Tobii Gl. 2	ASL XG Eye	Mobile ITU	EyeLink II
Minimum sample frequency of 200 Hz.					
Capable of accurate measurement of computer screens, mobile phones and tablets	Green	Green	Green	Red	Green
Accuracy of 0.5 deg. of lower					
User friendly software	Green	Green	Green	Red	Red
Measuring position, time and amount of fixations	Green	Green	Green	Red	Green
Option for making AOI's for static eye-tracking					
Calibration in less than a minute	Green	Green	Green	Red	Red
Movable eye-tracking device	Green	Green	Green	Green	Green
Options for measuring saccades					

Should					
Option for making merged Heatmaps for multiple persons	Red	Green	Green	Red	Green
Option for making Heatmaps for a single person	Red	Green	Green	Red	Green
Calibration after measuring	Green	Green	Green	Green	Red
Free movement of participants	Green	Green	Green	Green	Green
HD-quality	Green	Green	Green	Red	Red

Could					
Correction for parallax errors	Green	Green	Red	Red	Green
Measuring longer than 30 minutes.	Green	Green	Green	Red	Green
Full integration with EEG	Green	Red	Red	Red	Red
Integration with virtual reality	Green	Red	Red	Red	Red
Proven to be capable of outdoor use	Green	Green	Green	Red	Green
Option for making AOI's for dynamic eye-tracking	Green	Green	Green	Red	Red
Portable device that runs the software	Green	Green	Red	Green	Green

Won't					
Large head-mounted device	Green	Green	Red	Red	Red
Extra technical knowledge to apply setup	Green	Green	Green	Green	Red
Eye-tracker with head-rest					

Interpretation assembled requirements and eye-tracking devices

With the separation of the types of eye-trackers and the deletion of the non-relevant requirements in both categories, the distinction between suited and non-suited eye-trackers becomes clearer.

When looking at Table 11, two eye-trackers score insufficient to even be considered as a suitable eye-tracker; Mobile ITU and EyeLink II. The Mobile ITU eye-tracker seemed to be a decent option beforehand. The costs are very low, but the possibilities and challenges seemed to be interesting. However, if we only look at the scores at the "Must" category, the specifications of the Mobile ITU are unsatisfactory. This eye-tracker meets only 2 of the requirements. If we look at the "Should", "Could" and "Won't" categories, the only requirements that are scored sufficient are the mobility related ones. The Mobile ITU eye-tracker is not a serious option to purchase at the University of Twente.

The second head-mounted eye-tracker that scores insufficient is the EyeLink II. This eye-tracker falls into a higher price range than the Mobile ITU. It is already discussed that this eye-tracker could meet the requirements capable of both mobile and desk-mounted devices, and is built to use for both purposes. However, if we look at it as a mobile eye-tracking device, it does not meet the requirements. The majority of the "Must"- requirements are insufficient. Also half of the "Should" and "Could" requirements satisfy the needs. The EyeLink II only meets half of the requirements that are set. It seems that the versatility of the device becomes its' disadvantage when dividing both categories into separate tables. Where the EyeLink II was the most suitable option when looking for a purchase that is both mobile and has the power to measure above 200 Hz, it has too many shortcomings when looking at it as a pure mobile device.

The three devices that are serious options to purchase are the SMI (SensoMotoric Instruments) Glasses 2.0, the Tobii Glasses 2 and the ASL XG Eye. All three have nearly all "Must" and "Should" requirements positive. However, we have to take the "Won't" requirements also in consideration. If a device scores negative on one of those factors, this means that it has disadvantages that are mentioned as highly undesired. The ASL XG Eye has one of those unwanted factors; a large head-mounted device. As already discussed this is considered to be a major disadvantage, due to the many studies with kids and the interviewees' previous experiences with these kinds of devices. A major disadvantage like this rules the ASL XG Eye out as a possible device to purchase. Although the specifications of the device are good, from the interviews can be learned that the appearance of the eye-tracker can cause too much trouble for the researchers.

This leaves only the SMI Glasses 2.0 and the Tobii Glasses 2 as possible purchases. Both devices have the maximal score on both the “Must” and “Should” categories. Only on the “Could” section, the SMI Glasses 2.0 score better due to the full integration of EEG and Virtual Reality. If we look at the experiences of the interviewees, both SMI and Tobii are rated as reliable and user-friendly. These are also the manufacturers that are most used in both the interviewees’ research as in the literature study.

Desk-mounted

As already explained in the Head-mounted section above, some requirements are scored out due to their irrelevancy on one of the two categories. The following requirements are scored out in the desk-mounted section (tab. 12):

Option for making AOI’s for dynamic eye-tracking. Desk-mounted eye-trackers are not functional to perform dynamic research, in which the image of the recorded scene constantly changes. Therefore an option to make AOI’s for these regions is not necessary.

Calibrating after measuring. Calibration after measuring is usually used with mobile eye-trackers, because the camera is constantly changing. With desk-mounted eye-trackers the image is unchanged for the whole time, and therefore the calibration only takes place once, before the actual measurement.

Completely mobile during testing. Desk-mounted eye-trackers are not mobile at all, and therefore this requirement is not applicable.

HD-quality of the camera. Desk-mounted eye-trackers usually do not use a camera, but are connected to a computer device. When a camera is needed, like in the case study, the use of a head-mounted device more suitable. Besides, if a camera needs to be used in combination with a desk-mounted device, this camera needs to be purchased by the user and is not included in the equipment.

Correction for parallax errors. Parallax errors occur when the camera has to detect the depth of the objects in the environment. This is irrelevant when measuring only a computer screen. Only mobile eye-trackers experience these errors.

Proven to be capable of outdoor use. Only mobile eye-tracking research is performed in open air. There is no need in desk-mounted research to be used outdoors. The only factor that can be important is that the eye-tracker needs to be capable of dealing with minor changes of the light conditions that can occur indoors.

Tab.12. Requirements MoSCoW desk-mounted devices. Green boxes stand for the fact that this device scores positive for that certain requirement. Red implies a negative score.

Must	***Tobii TX300***	***SMI RED500***	***Tobii X2-60***	***SMI RED - M***	***EyeLink II***
Minimum sample frequency of 200 Hz.	green	green	red	red	green
Capable of accurate measurement of computer screens, mobile phones and tablets	red	red	green	green	green
Accuracy of 0.5 deg. or lower	green	green	green	green	green
User friendly software	green	green	green	green	red
Measuring position, time and amount of fixations	green	green	green	green	green
Option for making AOI's for static eye-tracking	green	green	green	green	green
Calibration in less than a minute	green	green	green	green	red
Movable eye-tracking device	green	green	green	green	green
Options for measuring saccades	green	green	red	red	green

Should					
Option for making merged Heatmaps for multiple persons	green	green	green	green	green
~~***Calibration after measuring***~~	hatched	hatched	hatched	hatched	hatched
Free movement of participants	green	green	green	green	green
~~***HD-quality of camera***~~	hatched	hatched	hatched	hatched	hatched
Option for making Heatmaps for a single person	green	green	green	green	green

Could					
~~***Correction for parallax errors***~~	hatched	hatched	hatched	hatched	hatched
Measuring longer than 30 minutes.	green	green	green	green	green
Full integration with EEG	green	red	red	red	red
Integration with virtual reality	green	red	red	red	red
~~***Proven to be capable of outdoor use***~~	hatched	hatched	hatched	hatched	hatched
~~***Option for making AOI's for dynamic eye-tracking***~~	hatched	hatched	hatched	hatched	hatched
Portable device that runs the software	green	green	green	green	green
~~***Completely mobile during testing***~~	hatched	hatched	hatched	hatched	hatched

Won't					
Large head-mounted device	green	green	green	green	red
Extra technical knowledge to apply setup	green	green	green	green	red
Eye-tracker with head-rest	green	green	green	green	green

Interpretation assembled requirements and eye-tracking devices

Again, the specifications of the EyeLink II seem to be insufficient due to its versatility. Overall it seemed to be the most promising option, but after dividing head-mounted and desk-mounted eye-trackers into separate categories, the EyeLink II device seems to be unsatisfactory. Although the EyeLink II scores slightly better on the requirements for a desk-mounted device, it has too many disadvantages. The more complicated software, longer calibration and the fact that it is a large head-mounted device that needs extra technical knowledge apply the setup all contribute to the fact that this is not a device that comes in consideration as a possible purchase.

Similar to the head-mounted eye-trackers, Tobii and SMI are the manufacturers that deliver the best suiting eye-trackers. However for desk-mounted eye-trackers the supply is larger. From the four remaining eye-tracking devices, we can distinguish two sorts. Eye-trackers that are smaller and easier to carry, but do only have 60 Hz and eye-trackers that are a bit larger but have way more power. Although mobility is important in an ambulant lab setting, the possibility to measure at 200 Hz or more has priority, certainly if the university decides to purchase a head-mounted device as well. The priority of the higher amount of Hz rules out the Tobii X2-60 and the SMI RED-M. Both devices have 60 Hz sampling frequency, which is mentioned several times as too low in the interviews. This leaves the Tobii TX300 and the SMI RED500 as possible options. Both devices are comparable. The Tobii TX300 has less Hz (300) than the SMI RED500 (500). However from the literature study and interviews can be learned that above 200 Hz the noticeable differences are negligible. The Tobii TX300 has the option for full integration with EEG and Virtual Reality. This is the opposite of the head-mounted devices, where SMI had this integration.

Recommendation

The purchase of both a desk-mounted and head-mounted is recommended to satisfy the set all requirements. From the interpretation of the requirements and the current eye-tracking devices the conclusion is formed that both Tobii and SMI meet the requirements at both categories. Thus, both large manufacturers could supply the university from eye-tracking equipment that will satisfy the future users. Because the specifications of both manufacturers are reasonably comparable, it is highly recommended to purchase both eye-trackers from the same manufacturer, and not for example a head-mounted eye-tracker from SMI and a desk-mounted eye-tracker from Tobii. The software of different manufacturers can differ to a great extent. This implies that it needs more time and effort to use both programs fluently.

Both SMI and Tobii are known as reliable companies as it comes to support. This is confirmed by Interviewee E, who worked with eye-trackers from both manufacturers. She stated that support can be important when facing difficulties with the equipment. With other companies, the support was of less quality.

Because the purchase of eye-trackers from both SMI and Tobii is proven by the requirements analysis to satisfy all the needs of the university, a factor that can become crucial are the costs. Both companies promised a combined system discount after contacting them about the costs. SMI could name an exact discount on the normal price. Tobii could for the being time not name a discount, because of the fact that the Glasses 2 are only released a short time ago. However, it is ensured that the university would be considered a “substantial discount”. Without the discount, Tobii is still 7.6 percent cheaper than the SMI package. However, the monthly license use of Tobii is not included. If this license would be paid every month, within 16 months the costs of both systems are the same. We have to keep in mind that this is without the discount of Tobii. To

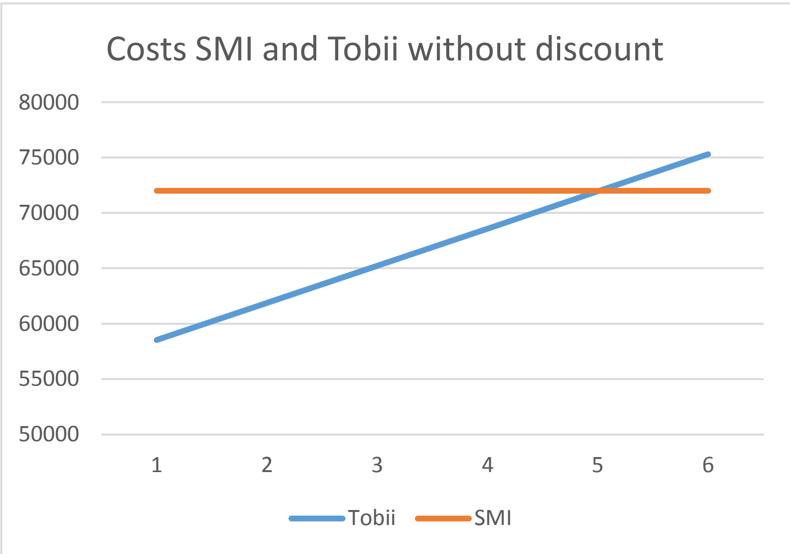


Fig. 14. Costs of the SMI and Tobii devices without discount. The horizontal axis are the amount of years, and the vertical axis are the costs in euros.

get the most out of a possible deal, the increase of the costs of Tobii which exceed the costs of SMI already after 1.5 year can be used. If the planning of the university is that the eye-tracker will be used for, for example, at least 10 years, this can be used to negotiate with Tobii. The exact costs can be found in Appendix B.

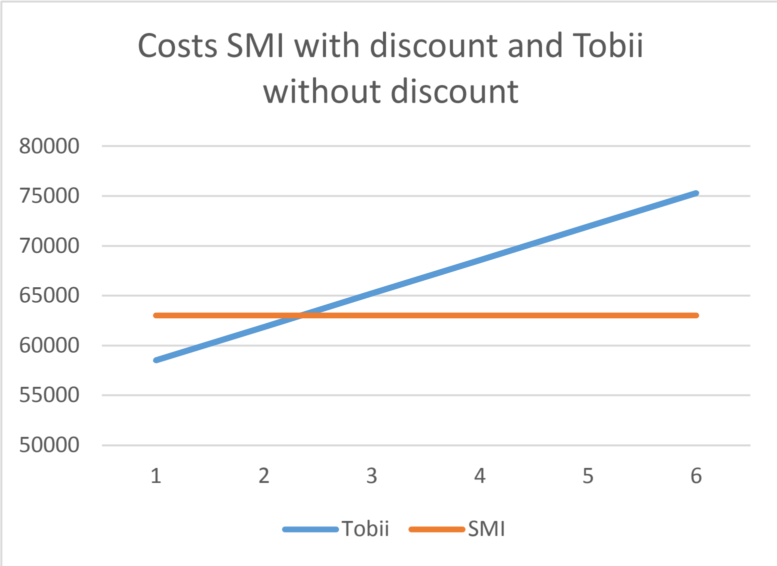


Fig. 15. Costs of the SMI with discount and the Tobii device without discount. The horizontal axis are the amount of years, and the vertical axis are the costs in euros.

Because of this small differences in price, the experiences of both the researcher of the case study, the interviewees and the eye-tracking expert are decisive. Although the case study had some major problems during testing, this was not due to the Tobii equipment. The equipment was simply not suitable for the testing environment. The software and support of Tobii was experienced as highly pleasant and straightforward to use. Interviewee E, who worked with both manufacturers, recommends both equally. Interviewee B already contacted Tobii for information about an eye-tracking device. Her experiences were positive. At last the eye-tracking expert recommended Tobii to be the best choice. He/she did use many different eye-tracking devices and also took part in the development of specific eye-tracking devices, which are not included into this study due to their specificity. Thus, is we look at the former experiences of the persons involved in this study, Tobii can be seen as the most reliable purchase.

This study has led to the first recommendation to purchase a combination-deal of the Tobii Glasses 2 and the Tobii TX300. The recommended support package for the Glasses 2 is the Tobii Glasses 2 Live View Wireless Package. For the TX300 only one package is available.

If, for example, the costs are too high to purchase two high-end eye-trackers, some alternatives exist. These alternatives will meet less requirements, but still can be suitable at the university. It could be conceivable that the university only has the possibilities to purchase only one eye-tracker. This eye-tracker should only meet the most important features and therefore primarily the “Must” requirements are leading. If we look at the “Must” requirements, only desk-mounted devices can possibly fit possibly all requirements. Head-mounted devices can give a lot of extra opportunities for future research, and could be indispensable in the future. However, at this moment they are not entirely necessary to meet the basic needs of the university. Both Tobii TX300 and SMI RED500 meet the “Must” requirements, except for measuring on mobile phones and tablets. After contacting both the manufacturers they state that although the measurements on such devices is better by using a head-mounted device like described in the first recommendation, there are external camera packages available to facilitate these measurements. The only downside is that this external camera packages can lead to problems that occurred during the case study, if the research will be done in an unstructured environment like at the traffic posts. Although from the interviews can be learned that research in such an environment will be very scarce at the university.

VI. Limitations

The absence of members of the Cognitive Psychology and Ergonomics Department of the university that are experienced with, or interested in eye-tracking means a gap in the information that could be acquired. If a researcher was available who had future plans with eye-tracking, he/she could provide some crucial data on how eye-tracking would be applied at this department. This gap is partly filled with an interview with a member of the Human-Computer Interaction department, which has some overlap with the Cognitive Psychology and Ergonomics department. Furthermore a former employee of the University of Twente was contacted. He/she could be seen as an expert on the field of eye-tracking. No interview was conducted, but he/she could provide some very useful tips on the choice of different devices.

The use of the MoSCoW-method could have some small disadvantages. Due to the fact that most interviewees are not experts on eye-tracking, requirements that are slightly less important could be forgotten. Despite the fact that the interviewees are highly stimulated by the interviewer to visualize their future research, it could be hard to know and name all the different factors that will be important. The case and literature study that formed the structure of the interviews should moderate these disadvantages.

Multiple interviewees mentioned the suggestion to appoint one port of call for the ambulant lab or the eye-tracking equipment. This would facilitate, and therefore lower the threshold, for the eventual use of the equipment. If eye-tracking will be used more frequently, a member of the university who exactly knows how to use the equipment is advisable.

Despite the fact that this study partly focusses on the requirements specifically at the University of Twente, the results presented in this study can be used as a tool when other institutions need to make a choice between (mobile) eye-trackers. Besides, this study will be very informative to anybody who is interested in the possibilities and obstacles of mobile eye-tracking.

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VIII. Appendices

Appendix A

Set of questions used as guideline during interviews

1. *Member of which department?*
2. *What areas of research?*
3. *Is eye-tracking used in research or education at your department at the moment?*
4. *Could you name some examples of studies that used eye-tracking at your department?*
5. *If there would be other/better eye-tracking equipment, would it be used more and/or differently?*
6. a. *Have you ever worked with eye-trackers?*

   b. *If so, which one?*

   c. *What are your experiences with this eye-tracker?*
7. *Could current eye-tracking studies be improved what concerns the ecological validity and relevance in a natural environment?*

8. *What would be the role of eye-tracking as regards to other components of an ambulant lab (skin conduction, EEG, etc?)*

   b. Does the need exist to integrate data of EEG and eye-tracking in one dataset?

9. *Is virtual reality and 3D something that currently is worked with, or maybe for in the future?*

10. *If it's possible, is there a need to measure eye-tracking out of the house (in open air)?*

11. *Is it in your (future) work important that the setup and calibration takes little time and effort?*

12. *a. In what environments will eye-tracking be conducted? Does your research always focus on specific factors, or also on the whole environment itself?*

    b. Is it the use of markers to mark the area you want to measure (for example an shelf in a shop) disturbing?
    Could you think of research setting in which this would be impossible?

13. *a. Is it important for your research to measure accurate on screens (laptop, smartphone, navigation, tablet, etc.)?*

    b. Welke rol speelt het meten van schermen in uw (toekomstige) onderzoek/werkzaamheden?

14. *Are heatmaps an important tool when analyzing data?*

15. *Are the amount and duration of fixation important factors in your research?*
    And Saccades?

16. *There are so called "open source" eye-trackers available at the market that have to be built by the users. This will reduce the costs, but probably also the functions. Could this be a replacement for commercial eye-trackers or just an extra option?*

17. *How important is it to get a detailed image (for example HD quality) of the data?*

18. *To what extent is it important for the eye-tracker to be as mobile as possible (for example a control system could be the size of a mobile phone or as laptop)?*

19. *Is eye-tracking used to measure cognitive load in your current/ future work?*

20. *To what extent is it important to effortless analyze different lookzones?*

21. *Do participants in your research or future research have to look from different distances? For example 10 meters away?*

22. *Do you measure eye-tracking for longer periods of time (longer than 30 minutes)?*

Appendix B

Tobii Technology	EUR
Hardware	
Tobii Glasses 2 Live View Wireless Package	13.900,00
Tobii TX300 Eye-tracker	32.900,00
Combined System Discount	? *
Software	
Licence Tobii Glasses Analysis Software Subscription	280,00 (monthly)
Licentie Tobii Studio Professional	6.900,00
Sub total	**53.700,00**
Packing, Transport, Insurance	150,00
Tax code -/- Academic Discount (-10%)	4833,00
Sum Total	**58.522,00**

*Still to be agreed.

Appendix C

SensoMotoric Instruments		EUR
Hardware		
SMI Eye-Tracking Glasses 2		26.900,00
iView X RED500		29.900,00
Combined System Discount		-9.000,00
Software		
Experiment suite 360 – Professional		4.900,00
	Subtotal	**52.700,00**
Packing, Transport, Insurance		250,00
Tax code 19.00%		10.060,50
	Sum Total	**63.010,50**