MOBILE EYE TRACKING IN USABILITY TESTING: DESIGNERS ANALYSING THE USER-PRODUCT INTERACTION

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Abstract

Today, mobile eye tracking systems have reached a high level of maturity. They are minimal invasive, allow to record a user-product interaction in its real environment and can reliably detect the user's gaze. Hence their implementation in usability testing of physical products promises great potential. This paper investigates whether the application of mobile eye tracking adds value to usability tests conducted by designers. The research question is approached in two steps. First, a laboratory experiment is conducted comparing designer`s analysis of a user-product interaction through videos recorded either from the mobile eye tracking perspective or out of the third-person perspective. Second, different types of mobile eye tracking analyses are applied to usability tests in three case studies. The results of both studies show that compared to the third-person perspective those designers seeing the eye tracking perspective describe a scene significantly more detailed and isolate significantly more causes of problems. Furthermore the application of object-based, sequence-based and visual pattern-based analysis have the potential to uncover relevant users' needs.

Keywords: Human behaviour in design, User centred design, Usability testing, Eye tracking

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1 INTRODUCTION

Today, the satisfaction of user's needs is central for the market success of products. Therefore not only a sophisticated technology, but also an excellent usability of products is necessary. This can be achieved by a user centred design process, which includes both guidelines for user-centred design as well as usability testing. The implementation of usability testing should start right from the beginning in the early phases of the design process (Cooper and Kleinschmidt, 1987; Dumas and Redish, 1999). A valuable approach to test usability in product development is video analysis of user-product interactions. By watching the videos designers are able to detect weaknesses in the product design (Shneiderman, 1992). However, the user's exact attention to single design elements can only be assumed by the interpretation of a video observation out of the third-person perspective. Here eye tracking technologies have the potential to add great value to usability testing. By tracking the user's gaze during a product application, the visual attention becomes apparent, which allows the designer to analyse the gaze data in detail.

In the field of web based applications and computer interfaces eye tracking has already been implemented successfully in usability testing (Bojko, 2013). Furthermore, an increasing number of investigations implementing eye tracking technologies have been conducted recently in the field of design research (Matthiesen et al., 2013; Maier et al., 2014; Boa and Hicks, 2014). In most of these studies, remote eye trackers were used, which are well suitable for stimuli to be presented on a screen. In contrast the present investigation uses mobile eye tracking systems, which show great potential for usability testing of physical products used in their intended environment (Mussgnug et al., 2014). The eye tracking system is integrated in glasses and therefore does not require stationary elements. This allows recording the visual attention of the user-product interaction in a non-invasive manner and can be performed in any environment. The collected data reflect the field of vision from the user's perspective including the gaze point as well as the characteristics of single eye movements in detail. Usability experts of specific departments or external companies often perform extensive analyses on user-product interactions. However, for designers themselves a good understanding of the user's interaction with the relevant products is essential to be able to create user centred products (Dumas and Redish, 1999). Hence, this contribution investigates in which way the application of mobile eye tracking adds value to usability tests of physical products conducted by designers.

This paper proceeds as follows. After introducing the fundamentals of mobile eye tracking and usability a comparison is drawn between the observations designers make when watching the user-product interaction from the typically applied third-person perspective and the findings they come up with when relying on the eye-tracking data. Once this comparison of qualitative video analyses is made, different other methods for analysing eye tracking data are introduced.

2 FUNDAMENTALS

In this section mobile eye tracking is introduced in detail first. Afterwards the term usability including a model for user-product interaction is described before the opportunities of mobile eye tracking in usability testing are highlighted.

2.1 Mobile eye tracking

Video-based eye tracking is the prevalent technology used in both, remote eye tracking and mobile eye tracking (Holmqvist 2011). A camera records the eyes from a distance, which allows a minimally invasive tracking of visual attention. Especially mobile eye trackers, where the recording components are integrated in glasses allow the user an unrestricted interaction with the product in its natural environment (Shinoda et al., 2001; Land and Hayhoe, 2001).

As illustrated in Figure 1, besides the glasses only a recording unit that can be attached to the user's belt is required. The applied eye tracking system is a SMI binocular pair of glasses with 30Hz sample rate. Next to the camera that records the eye movements to calculate the gaze location a second camera is integrated to record the user's field of vision. From the recorded data a scene video with the synchronised gaze location is created. Thereby the gaze point can be interpreted as the location of the user's visual attention (Hoffman, 1998; Duchowski, 2007). The effect of "looking without seeing" that describes phases in which a person fixates at a certain point but does not process visual information from the focussed object can be neglected as long as the user is concentrated on a task (Most et al., 2001). In general, eye movements can be divided into two main categories: fixations and saccades. During fixations the eye focusses on a certain point and visual information can be processed. Saccades are fast eye movements between fixations that allow nearly no perception of information (Holmqvist, 2011). Besides fixations and saccades there are other events such as glissades, blinks, smooth pursuit, etc. that are not relevant for the performed usability studies.

Figure 1. Mobile eye tracking glasses and recording unit (SMI, 30Hz)

2.2 Usability

Usability describes the *"extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO 9241-11).* Hence, usability tests always analyse a specific situation in order to understand users and their interaction with the product in greater detail. In the field of product development the aim of usability tests is to isolate user's needs for creating, improving or validating a concept or a product.

Generally, the use of a product can be understood as an interaction between the user and the product. By interpreting the products' design elements the user concludes how to use the product (Norman 1988). Based on the models of Bloch (1995) and Seeger (2005) the interaction can be described by three steps (Figure 2): (1) During the interaction the user perceives the products` design elements. (2) The user then recognises the design elements depending on his/her previous experience and cognitive capabilities. (3) This leads to certain behaviour towards the product. All of these steps are influenced by the context of the product application.

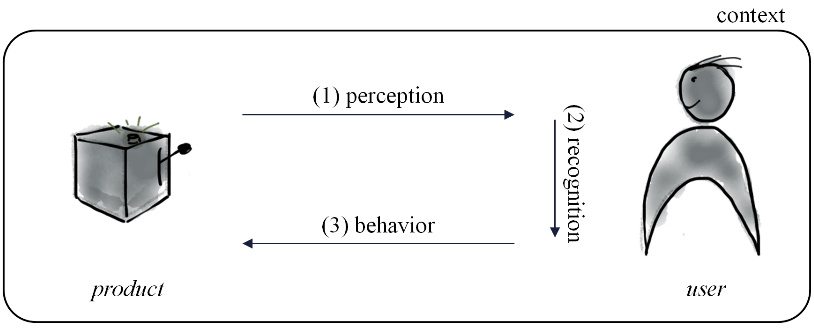

Figure 2. User-product interaction (based on: Bloch, 1995; Seeger, 2005)

2.3 Chances of mobile eye tracking in usability testing

Mobile eye tracking enables the understanding of the perception processes of the user in greater detail. This can be understood in Seeger's model by considering the first step, the perception step (Figure 2). Compared to third-person perspectives, eye tracking data contains more precise information about an individual's visual attention. This leads to three major potentials for how mobile eye tracking can enrich usability testing. First, the precise location of the gaze point is given, which allows a reliable assignment of the visual attention to specific objects. This could help to isolate the most relevant objects of the interaction. Second, the course of action could be understood in more detail, because subsequent steps of actions and visual attention can be linked (Land and Hayhoe, 2001). Third, visual patterns, which can be seen in the eye tracking data, could indicate cognitive processes in usability testing (Gidlöf et al., 2013).

Nonetheless usability testing with mobile eye tracking systems also faces some limitations. Facial expressions and posture of the user are not recorded. Both aspects are relevant for usability testing because they can help to interpret the inner state of the user and can evaluate ergonomic aspects.

3 RESEARCH QUESTION AND APPROACH

Today mobile eye tracking technologies have reached a stage of maturity, where they work reliably, their usage is user-friendly and the data acquisition is plug and play. Furthermore the technology is of great potential to support usability testing in the field of product design. Whether the specific form of mobile eye tracking analysis adds value to usability testing of physical products performed by designers is approached by the following two research questions:

Q1: Which impact has the video perspective (mobile eye tracking vs. third-person) on designers' qualitative video analysis of user-product interactions?

Q2: How mobile eye tracking data can be analysed and what value can it add to usability testing?

As explained above qualitative video analysis recorded from third-person perspective is highly relevant for today's usability testing. Hence to evaluate whether mobile eye tracking records add value to usability tests the impact the different perspectives have on the analysis of the user-product interactions is compared. Therefore Q1 is approached in a laboratory experiment, in which designers were given the task to analyse two different videos; one showing the user-product interactions from the eye tracking perspective and the other one watching the same interaction from the third-person perspective (Figure 3, left). The procedure and the results of the qualitative video analysis performed by the designers are described in section 4.

Besides the qualitative video analysis other methods can be used to investigate mobile eye tracking data. To approach Q2 three different case studies have been conducted. In section 5 for each case a different analysis method is introduced (Figure 3, right). The application of object-based analysis, sequence-based analysis and visual pattern analysis show exemplarily the value mobile eye tracking can have for usability studies. All cases were extracted from real development tasks, thereby creating a high external validity.

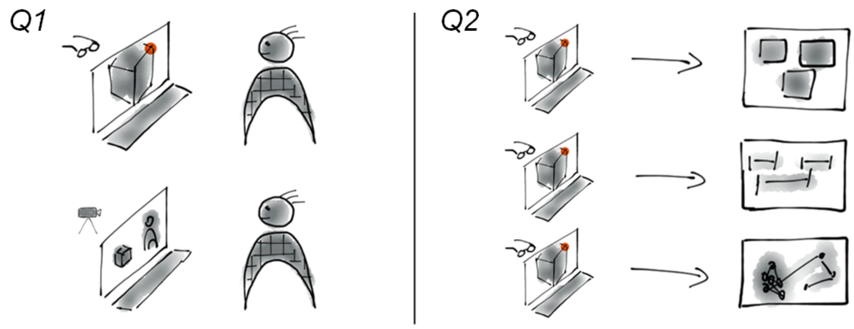

Figure 3. Left: Analysis of user-product interactions out of different perspectives (Q1) right: three analysis methods (Q2)

4 INFLUENCE OF MOBILE EYE TRACKING PERSPECTIVE (Q1)

To approach Q1 this section describes a laboratory experiment, which investigated the effects mobile eye tracking data can have on the designers' analysis of user-product interactions (Figure 3, left). The aim of the experiment was to see how well designers could identify usability problems based on different video perspectives. The participants analysed videos of a user-product interaction, which was either filmed from the mobile eye tracker or in the third-person perspective.

4.1 Participants and experimental design

Twenty graduate students and five PhD students, studying design participated in the experiment. Seven of them came from the Karlsruher Institute of Technology in Germany, 18 from the Swiss Federal Institute of Technology Zurich. Three participants were females. The average age was 25.4 years (SD = 4.1). All of them had no or little experience in the analysis of eye tracking videos. The data of 22 participants was considered for analysis, as four data sets were incomplete.

The experiment was conducted in a one-factor within-subjects design (Huber 2009). Each participant analysed two videos showing two different scenes of a user-product interaction. One video showed the application from the mobile eye tracking perspective, whereas the other scene was presented from the third-person perspective. Balancing out the order of the presented stimuli prevented an order effect.

4.2 Stimuli

The stimuli were produced from one user-product interaction, which had been recorded simultaneously with a mobile eye tracking device and a conventional camera (Figure 4, left and middle). It showed a trial of a novice loading a powder-actuated fastening tool (Hilti DX 76 PTR) and driving a fastener nail into a steel plate. For instructions, the user filmed was allowed to consult the pictorial part of the manual. To load the fastening tool four steps have to be performed (Figure 4, right). First, loading the fastening strip (a) in the magazine (b). Second, inserting the cartridge strip (c) in the cartridge strip guideway (d). Third, pushing the cycling grip (e) backward toward the rear of the tool and then forward to its original position. Fourth, pressing the fastening tool against the working surface and pulling the trigger (f). Two different scenes have been extracted from the interaction, whereas both included usability problems. In the first scene (90sec) the user confused the fastening and the cartridge strip. In the second scene (50sec) the user didn`t load the cartridge strip. Instead he continues with the consecutive step and tried to push the cartridge strip guideway forward and backward instead of using the cycling grip. Thus he did not succeed in driving a fastener nail in the steel plate (50sec).

Figure 4. Eye tracking perspective; third-person perspective; fastening tool with fastening strip(a), magazine(b), cartridge strip(c), cartridge guideway(d), cycling grip(e) and trigger(f)

4.3 Task and procedure

The participants were asked to answer the following questions:

1. How did the user interact with the tool? How did the user approach the task?
2. Why did the user behave in this way? Which aspects of the usage did he understand and which not? What are possible reasons for the misunderstanding?
3. What are your suggestions to increase the usability of the product?

These questions were used to guide the participant to undertake a stepwise analysis of the user-product interaction in greater depth. Stimuli and tasks were presented on a 22’’ monitor (1680x1050 pixels). First the task was presented to the participants in order to guide their attention towards the relevant aspects. Afterwards the stimulus video was played twice. Consecutively, the task was presented again and the participant’s answer was recorded. This procedure was repeated for all three questions and identical for both scenes.

4.4 Evaluation

The answers of the participants were recorded and transcribed verbatim (Hoffman-Riem, 1980). For quantitative comparison of the content, sections of the transcripts were assigned to codes. Effects of the video perspectives on the participants’ analysis were assessed with the code frequency. The following list summarises an excerpt of the relevant codes.

- Scene description (overall)
  - Location of attention, e.g.: *“The user looked on the cycling grip.”*
  - Assumption concerning the location of attention, *e.g.: “Maybe the user looked on the cycling grip.”*
  - Action, e.g.: *“The user inserted the fastening nails.”*
- Cause of a problem (overall)
  - Visibility / recognisability of a design element, e.g.: *“The pictogram was misunderstood.”*
- Suggestions for improvement, e.g.: *“A pictogram on the guideway could explain its function.”*

4.5 Results

The description of the results is structured along the three main codes presented in section 4.4. The code frequencies are summarized in Table 1 at the end of the section.

Scene description: When analysing eye tracking videos participants described the scenes in significantly more details. The reason for that was that the location of the user's attention, e.g. *"the user looked on the cycling grip*" was mentioned significantly more often. In contrast to that, participants analysed the video from the third-person perspective mentioned significantly more assumptions about the location the user's attention is focused on. Furthermore, only observers of the third-person perspective described the user's position in the room and the description of the surrounding. They analysed that the user stood on a chair for a moment, that the chair was facing a window or that the workspace was cluttered (Figure 5, left and middle). There is no significance in this aspect as only few participants mentioned it. In addition to that the video perspective had no effect on the number of actions participants mentioned, e.g. *"the user manipulated the cycling grip"*.

Figure 5. Left: eye tracking perspective; middle: third-person perspective, user's position in the room and cluttered desk; right: pictorial part of the manual

Cause of a problem: Clearly incorrect assumptions were only made out of the third-person perspective, e.g., that the user did not see a pictogram in the manual, which indicated where to insert the cartridge strip (Figure 5, right). The eye tracking video proved this to be wrong. Several participants who analysed the eye tracking video mentioned the fact that the user looked at the pictogram. Furthermore, two observers of the third-person perspective mentioned the cluttered workspace as a cause for not loading the cartridge strip at all. Two participants analysing the eye tracking videos addressed this correct aspect as well, but much more precisely. They stated that the user had overseen the fastening strip on the table because it was partly covered by the manual. Overall participants described significantly more causes of problems when analysing eye tracking videos. Thereby, approximately 75% of these causes mentioned by the participants who analysed the eye tracking data addressed an insufficient visibility or recognisability of design elements of both manual and fastening tool, e.g. that the colour of the cartridge guideline was misleading.

Suggestions for improvement: Analysing eye tracking videos participants had the tendency to make more suggestions for improvement e.g. *"the cartridge strip should not fit in the magazine for the fastening nails"*. The suggestions did not vary in the level of detail depending on the presented perspective.

Table 1. Frequency of codes by video perspective

Code	Eye tracking	Third-person	
	M (SD)	M (SD)	t
Scene description (overall)	5.50 (2.35)	4.05 (2.03)	3.5*
Location of the user's attention	1.59 (1.53)	0.23 (1.43)	4.9*
Assumption of the location of the user's attention	0.05 (0.21)	0.23 (0.53)	3.2*
Action	3.80 (1.4)	3.60 (0.53)	0.4
Cause of problem (overall)	3.64 (2.06)	2.41 (1.10)	2.7*
Visibility / recognisability of a design element	2.73 (1.80)	1.86 (0.89)	2.1*
Improvement suggestion	2.27 (1.32)	1.82 (0.96)	2.0

*p<0.05

5 ANALYSIS OF MOBILE EYE TRACKING DATA (Q2)

In addition to the qualitative video analysis as performed in the laboratory experiment described in section 4, other approaches to structure the analysis of mobile eye tracking data can be used. This section addresses Q2 and introduces three case studies where mobile eye tracking was implemented in order to analyse the user-product interaction (Figure 3, right). The cases are extracted from development projects in the areas of peritoneal dialysis (section 5.1), manual assembly lines (section 5.2.) and overhead template routers (section 5.3). Each section describes the application, the development task, the type of analysis, the findings and the special value of mobile eye tracking.

5.1 Visibility and relevance of objects (peritoneal dialysis)

The first case deals with peritoneal dialysis, which is a renal replacement therapy. Patients with insufficiently working kidneys can perform this treatment at home by themselves. In an overnight process a device pumps 12 litres of a liquid through the patient`s body. Before the treatment can start a 40 min. preparation is necessary. The development task for the designer aimed at facilitating the preparation phase for the patients. For usability testing, patients were visited at home and the user-product interaction was recorded with a mobile eye tracking system. The observed users were approximately 70 years old and had more than one-year experience in performing the procedure.
In this case, *object-based eye tracking analysis* showed essential findings. Before the usability test conducted through this study discussions about the improvement of the therapy were always focused on the device itself. In fact, when observing the user-product interaction from a third-person perspective the patients' focus seemed to be dominantly on the device. However, the analysis of the eye tracking data showed that this assumption was mistaken. The accumulated fixation durations on different objects during the application pointed out that the patients looked only 5.5% of the time on the device itself, including display, buttons and housing (Figure 6, left). Actually, 31.3% of the time the patients were concentrated on connectors (Figure 6, right) or tubes and 24,8% on packaging material. While the fixations on the packaging material can be seen from a third-person perspective, the high amount of time visual attention was focused on the connectors was an unexpected result. The findings based on the eye tracking data formed the basis for a new development project to facilitate the periphery elements of the application.
This case demonstrates that the *object-based analysis* of mobile eye tracking recordings allows a better understanding of the (visual) relevance different elements have during the user-product interaction. The distribution of visual attention between single elements can help to decide where the development to improve the product should focus on. While an observation from the third-person perspective allows only assumptions about the user's focus, which could be misleading, eye tracking data is of meaningful value to enable a more objective interpretation of the scene.

Figure 6. Left: fixation on device; right: fixation on connector

5.2 Visual sequencing of procedure (manual assembly line)

This case is about a usability project that aims to improve an assembly line for a hand held power tool. The line is already in use and was built up due to the criteria of lean production. The line is operated in an one-piece-flow and most of the mounting steps are manually assembled. The development task was to improve certain elements of the line concerning their usability to create a more efficient mounting process. Two assemblers were recorded from two different perspectives: First-person perspective through mobile eye tracking glasses as well as third-person perspective by a conventional camera.

For this case a *sequence-based analysis* was performed. Therefore single sequences are defined as "simple actions that transform the state or place of an entity through manual manipulation" according to the categorization set up by Schwartz et al. (1991) and Schwarz et al. (1995). In reference to these action-based sequences the location of the visual attention was analysed. Land and Hayhoe (2001) found that the relations between gaze and action can be used to distinguish different kinds of user-product interaction (locating, directing, guiding, checking). According to this the *sequence-based analysis* of the mounting process of the assembly line showed three major relations. One example of each is presented in the following:

1. The action and the gaze are on the same object (guiding): e.g. when reaching for springs, which are hard to grab the visual attention stays on the same object during the action (Figure 7, left)
2. The gaze only directs the way to the object and moves further during the action (only directing, no guiding): e.g. when reaching for a damping element, which is easy to handle the visual attention shortly focusses on the dumping element. While acting the gaze already moves to the next object (Figure 7, right)
3. After finishing the task the gaze remains on an object, whereas no action or already the next action takes place: e.g. while already reaching for the next component the visual attention is still on the assembled sub group for a check.

Creating a sequence model of user-product interactions helps to understand the users' course of action to a higher degree. The relation between action and visual attention supports the evaluation of the single steps conducted and shows how they are linked to each other. Depending on how fast the gaze moves to the subsequent step the attention required for the current step can be indicated and hence the steps can be classified. For the development of the production line these results offer valuable conclusions about the order of single mounting steps and the position and the type of material supply.

Figure 7. Left: guiding, fixation of manipulated object; right: Directing, fixation on next object

5.3 Visual pattern (overhead template router)

In this case the initial use of two overhead template routers (Perles OF3-808, Triton 1010W) were compared. Routers are used to cut notches, adjustable in diameter and depth, into plates. Eight novices had the task to cut a defined notch in a wooden plate (0.7 mm depth, 15cm edge distance). The study aimed to compare the two routers and conclude, which tool was easier to understand for novices. Therefore a mobile eye tracking analysis as well as the INTUI questionnaire (Diefenbach et al., 2010), which evaluates on intuitiveness has been undertaken.

Whereas the questionnaire resulted in a rating of the whole task, the mobile eye tracking analysis pointed out single usability problems in detail. The eye tracking data was analysed on qualitative identification of *visual patterns*. The identification of visual patterns and their relation to a cognitive meaning through remote eye tracking is currently discussed in the community of design research (Lohmeyer et al., 2015). To analyse the fixation durations and their distances (saccades) were taken into account. Through the user`s gaze paths on the routers two dominant patterns, related to usability were found. (1) Visual search patterns, which are characterized by short fixations and long saccades on different design elements, appeared when users try to find a special function. This pattern was found for example, when users searched for the right way to mount the side lay on the router, while "scanning" for possible fastening elements (Figure 8, left). (2) Scrutinizing patterns in contrast are characterized by a high number of long fixations on the same design element. They appear when the user is strongly concentrated on a certain element in order to understand its function. This pattern was detected in different lengths depending on the tool and the user during the installation of the cutting heads (Figure 8, right). Holding the cutting head in the one hand and tightening the screw with the

other hand, whereby the router could not be placed in a stable position, required a high concentration of the user. The comparison of the number and the duration of the isolated usability problems showed that the Perles router has more usability problems. This finding goes along with the result of the questionnaire.
With this case study it is shown that the gaze point allows the manual identification of search and scrutinizing patterns. The analysis of the eye tracking data concerning visual patterns helps to isolate single usability problems and to compare different products. However, search pattern are more difficult to isolate, because their pattern are similar to very fast and intuitive usage. Hence the body language has to be taken into account as well. The potential of visual pattern has to be investigated in further experiments in order to clarify how they could be detected precisely based on the data.

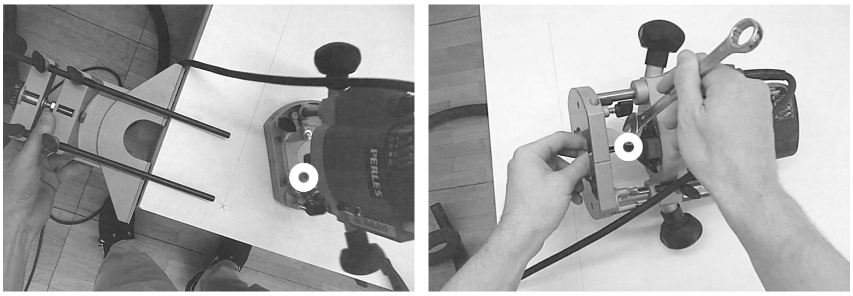

Figure 8. Left: one frame of search pattern; right: one frame of scrutinizing pattern

6 DISCUSSION AND CONCLUSION

The question, whether mobile eye tracking analysis adds value to usability testing of physical products performed by designers was approached in two steps.
First, a laboratory experiment was performed. It aimed at investigating the impact mobile eye tracking data has for the designers' qualitative video analysis of a user-product interaction. The results showed that participants who watched the mobile eye tracking perspective were able to describe the scenes in significantly more details, especially concerning the location of the user's attention. In contrast observers of the third-person perspective could only assume where the user was focusing on. Furthermore the information given by the gaze location led to a significantly higher amount of statements concerning the causes of problems, which were in this case based on a lack of visibility or recognisability of design elements. From the third-person perspective the user's position in the room and his posture could be determined more easily. Hence a better overview of the scene was given and ergonomic aspects could be evaluated more easily. No difference could be found concerning the description of the actions the user carried out. It can be concluded that the qualitative video analysis of mobile eye tracking data promises added value compared to videos from the third-person perspective. However, only the initial use of a single application with a high number of manual usages has been investigated until now. In the future different applications and a more detailed coding scheme should be the basis to draw broader conclusions.
Besides qualitative video analysis, which was applied in the first step the second step investigated in further types of mobile eye tracking analysis. Three case studies have been performed whereas each case focusses on another type of analysis. In the home dialysis case an *object-based analysis* was performed, which allows the designer to get a clearer view on the parts of the product most relevant for the user-product interaction. In the second case a manual assembly line was analysed by a *sequence-based approach*. The relation between action and visual attention supports the designer´s evaluation of single mounting steps as well as their influence on subsequent steps. In the last case the initial use of a router has been analysed by focussing on *visual patterns*. Search patterns and scrutinizing patterns were identified manually, whereas the number and the lengths of isolated patterns set the basis for a comparison of two tools. The exemplification of the three analyses types showed their potential to evaluate usability aspects. However, the different types of mobile eye tracking analyses need further detailed investigation for a deeper understanding and explicit methodologies to structure the process of analysing mobile eye tracking data should be developed in the future.
Overall the investigations showed that mobile eye tracking has the potential to add value to the usability tests of physical products conducted by designers. Depending on the aim of a usability study,

various approaches to analyse the eye tracking recordings may be suitable. The combination of mobile eye tracking with conventional video recording from a third-person perspective is advisable to engage in a comprehensive picture of a user-product interaction.

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