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METHODOLOGY

Setup guidelines for eye tracking in child and teenager research in the context of learning by interacting with a tablet

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ABSTRACT

The growing use of tablet-based applications in education increases the importance of testing them in an effective way. Eye tracking devices can now be used to serve this purpose, but these evaluations require valid ecological testing contexts that can affect data quality and validity. The focus of this paper is to propose setup guidelines that will maximize data quality and validity by optimizing the trade-off between steadiness of the visual attention data and natural interaction of the child with a digital educational product. The guidelines are based on three different eye tracking educational studies conducted with children participants.

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1. Introduction

The usability evaluation of an educational application (digital product) is a crucial step of its development. In user experience research, a commonly used method of usability evaluation is the usability test. It consists in developing a realistic product usage scenario which must be performed by prospective users (Hartson & Pyla, 2012). Given the growing usage of tablet based educational application, it is important to perform high quality usability testing during their development (Donker & Reitsma, 2004). Educational applications draw national education departments' and local schools' attention because of their positive impact on learning outcomes (Masood & Thigambaram, 2015). Usability testing is thus crucial in this context, because it allows one to measure the effectiveness of educational approaches, to adapt user interface design for different ages and to resolve design debates at an early stage of product development (Hanna, Risden, & Alexander, 1997).

Conducting usability testing with children is difficult as children may not be willing or able to provide explicit feedback on their experience. Thus, methods capable of measuring unobtrusively the experience of the children bears many benefits (Barendregt & Bekker, 2003). Recently, educational researchers' attention is drawn to eye tracking due to an increased ease of use of this technology (She & Chen, 2009). It is a powerful tool to measure visual attention during realistic usage scenarios and allows one to determine where users look the most, what catches their attention first, and how their visual exploration patterns are deployed (Johansen *et al.*, 2011). Poole and Ball (2006) have summarized various guidelines on the usage of eye tracking technology on adults. They mention the importance of the right positioning of the person, of the calibration procedure and participants' selection considering eye trackers' sensitivity to hard contact lenses, bifocal and trifocal glasses, very large pupils or the "lazy eye" phenomenon. It is also important to have well-defined tasks and minimize non-test related visual distractions to avoid data contamination (Goldberg & Wichansky, 2003).

However, to our knowledge, very few studies have been done to propose guidelines on the usage of eye tracking technology on children and teenagers (Kooiker *et al.*, 2016). While performing usability tests on children, it is crucial to study their natural interactions with educational technology which affects motivation and performance, to isolate their physiological feedback on the digital product features (Read, 2015). It means that testing environment and eye tracker positioning, in particular, have to be tailored to children's natural developmental level (Hanna *et al.*, 1997) to maximize data validity. This paper describes lessons learned from three different eye tracking studies: on elementary school children, on teenagers taking digital notes and lastly on children solving pedagogical robotics problems. We conclude by formulating additional eye tracking setup guidelines for usability tests on a tablet.

2. Literature review

2.1 Eye tracking

Eye tracking is a technique which measures eye movements to indicate where a person is looking at a given moment and the sequence in which eyes are moving from one location to another (Poole & Ball, 2006). Most commonly used eye tracking devices are infrared corneal reflectors. Infrared light is projected on the eyes, where it is reflected twice on the cornea and twice on the lens. Once reflected, the light is recorded by infrared sensitive video cameras. The four different reflections allow to calculate the position and direction of both eyes, even if one eye is usually enough. A calibration procedure is necessary to adjust for anatomical differences among participants (Wipfli, 2008). However, other configurations are also used. Feng (2011) compares the technical differences among remote stationary eye trackers described above and head-mounted systems that allow free movement of the subject, but are not adapted to children and require longer coding.

The results are interpreted based on the eye-mind assumption. In general, eye fixation location reflects attention and eye fixation duration reflects processing difficulty and the amount of attention. The longer the information is fixated, the more complex it is or the more deeply it is processed (Just & Carpenter, 1980). To sum up, eye tracking allows one to understand visual and display-based information processing by the user, as well as factors that may impact system interface usability (Poole & Ball, 2006).

Eye tracking on tablets bears unique specificity. When conducting an eye tracking study in a browser on desktop, the recording software is capable of recording events in the interface, such as the opening of a new web page, in real time. These events are used for analysis to aggregate stimuli across users. Current eye tracking technology is unable to detect those events when the recording is made on a tablet. On such devices, a screen capture is done by the eye tracker and the recording becomes a dynamic scene. A similar limitation exists for mobile eye tracking with lenses. Thus, conducting an eye tracking study on a tablet requires substantial manual coding to obtain those user events essential for the analysis.

2.2 Eye tracking in child and teenager research

Eye tracking is a tool used in various research contexts such as user experience (UX), education and development pathologies. Masood and Thigambaram (2015) investigated the importance of UX in user interface design of mobile educational applications designed for 4- or 5-year-old children. They analyzed eye tracking glasses' data to evaluate interface design of the educational application based on the children's mental model and the quality of learning experience. Eye tracking technology is also known for contributing to find altered gaze patterns across the eyes and the mouth and a failure to orient to biological motion among toddlers with Autism Spectrum Disorder (ASD) (Flack-Ytter, Bolte, & Gredebäck, 2013).

The youngest population studied using eye tracking is 3-month-old babies. The authors suggested that where infants look limits the information input and, therefore, influences the development of the concept of object. Using eye tracking glasses, researchers concluded that some children appear to perceive objects as a whole and others did not (Johnson, Slemmer, & Amso, 2004). Eye tracking technology is also commonly used to help children and adults with impairments. It allows communication operated only by movements of the eyes without using any additional input device such as a keyboard or a mouse (Karamchandani *et al.*, 2015; Poole & Ball, 2006).

In a learning context, eye tracking techniques have the potential to reveal learning processes and problem-solving strategies as well as opening a wide range of research opportunities (Jarodzka *et al.*, 2017). For example, it provides information about which parts of the material are attended to and the length of their processing (She & Chen, 2009; Yen & Yang, 2015). Computer game learning experience (Alka & Cagiltay, 2007) and color coding effects on retention and learning performance have also been studied using eye tracking devices (Ozcelik, 2009).

2.3 *General eye tracking guidelines*

Most of the studies that used eye tracking on children mention the particular difficulty of the calibration. A child's head is usually anatomically smaller than an adult's and it is hard for a child to limit their head movements during longer usability tests (Gredebäck *et al.*, 2009; Oakes, 2012). It is important to limit a child's head movement not only to get a successful and precise calibration, but also to maintain good quality of the data all over the experiment without losing track of his or her eyes. Sasson and colleagues (2012) mention that seating must allow for vertical adjustment to position a child within eye tracking range regardless of their height and posture. Distance of the chair from the display must be adjusted for the size of the screen and standardized for all participants. The child's eyes must be positioned in the middle of the window to minimize data loss when the child sways, straightens or slouches (Sasson *et al.*, 2012). Researchers suggest using an adjustable-height office chair, a Rifton chair or a car seat (Gredebäck *et al.*, 2009; Sasson *et al.*, 2012). For very young children and for those that are not able or willing to sit straight by themselves, it is preferable to use a portable system such as eye tracking glasses over the stationary one (Oakes, 2012), even if the coding procedure is much more complex.

Hanna and colleagues (1997) have also formulated general children usability testing guidelines. Those include adapting the technology used in the lab to what children are used to manipulate at home, using laboratory equipment in an effective and unobtrusive way, such as using smaller microphones, avoid placing the child in front of the camera or one-way mirror, and allowing particularly young children to manipulate the computer before the test to warm-up. It is important to emphasize that actual positioning guidelines are limited and do not guarantee natural expression of children's behavior while ensuring quality and consistency of the collected data at the same time.

3. Eye tracking in a mathematics learning context (Study 1)

The first study's objective was to study visual attention in a mathematics learning context among 5- and 6-year-old children (Léger *et al.*, 2017). We were interested in the amount of cognitive load reflected by pupil's diameter (Tsai & Meng-Jung, 2013) and the efficiency of the design of an educational application prototype. The task implied choosing an assignment, solving a simple mathematical problem and clicking, using only one hand, on the right answer among several options. To test multiple hypotheses, an eye tracker *Tobii x60* (Tobii Technology AB, Danderyd, Sweden) and a facial expressions analysis software, *Facereader 6* (Noldus, Wageningen, The Netherlands), were used. To consider children using their fingers to count, we also filmed the participant's face with a webcam, his hands with a camera on an articulated arm to capture the moments of clicking on the screen and track his eyes' movements with minimum interruption.

The first setup that was tried was the one originally recommended by Tobii, the manufacturer. The eye tracker was positioned on a triangular prism metallic base with a tablet horizontally on the front face (see figure 1). Even if this positioning is natural from the user's perspective, the upper side of the tablet partially blocked infrared light emitted by the eye tracker, therefore the child's eyes could not be tracked properly. The metallic base allowed adjustment, but the quality of the calibration was poor.

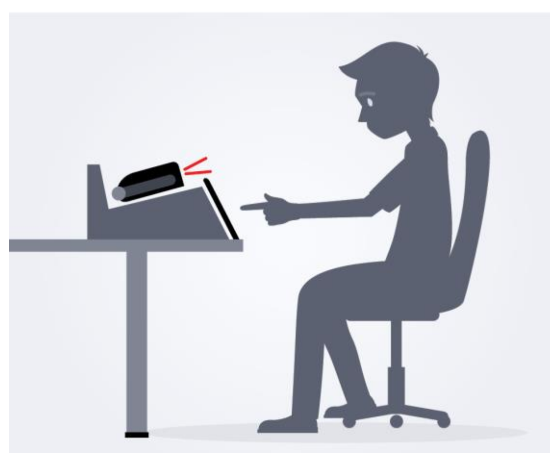

Figure 1. Setup recommended by the manufacturer

For the next iteration, the tablet was fixed to the table with an articulated arm by Manfrotto (Gentec International, Markham, Ontario, Canada). The usage of articulated arms helps to fix the tablet in a natural position. Unfortunately, the quality of eye tracking data was still poor. It was due to the angle of infrared light projection. When the participant looked at the bottom of the tablet, especially when they had long and voluminous eyelashes, the eye tracker lost his eyes. Generally, with the eye tracker placed in this particular position, the tracking box is restricted. The initial setup being rigid and ineffective, a second articulated arm was added. This time, the eye tracker was fixed with this second arm under the table, below the tablet (see figure 2). This setup allowed us to have the tablet a little closer than the eye tracker and the infrared light was projected more efficiently. The tracking box was bigger and eye tracking data was steadier over the length of the experiment given that children had trouble staying in place without moving their head or looking around. In fact, we succeeded to track at least one eye for 40.8 minutes out of 50, an average computed among 22 participants. In other words, we compare the eye tracking device indication of a weighted gaze of 68% to a maximum needed of 83%, for a task that takes 50 out of 60 minutes of eye tracking recording. The 10-minute difference corresponds to the moments the child receives instructions, turns his head to ask a question and a break between assignments.

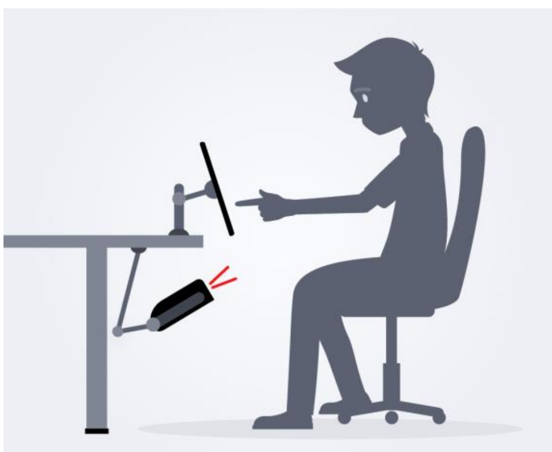

Figure 2. Table and eye trackers fixed to articulated arm

The child has to be placed in an ergonomic chair. For the three studies presented in this paper, we used a chair provided by ErgoCentric (Mississauga, Ontario, Canada). Ideally, it should be an ergonomic chair designed specifically for kids. Eyes must be at a minimum distance of 60 cm from the eye tracker. Setup parameters must be adjusted in the Tobii software interface and the child's eyes must stay in the tracking box. An assistant must remind the child to keep a good posture and avoid unnecessary head and hand movements if they are too agitated. This setup allows a maximum efficient trade-off between context authenticity and eye tracking data quality.

4. Eye tracking in note-taking context with teenagers (Study 2)

The second study's objective was to study visual attention in digital note-taking context among 14- to 17-year-old teenagers. We were interested in the emotional state of the student, the amount of cognitive load generated by the activity and note-taking effectiveness. The task implied reading an informational text while highlighting certain texts and annotating the others. In this case, the corpulence of teenagers versus young kids and the task itself added challenge to the setup because note-taking implies using both hands, therefore the risk of blocking the eye tracker was higher.

Since we had success collecting good quality data with the final setup of the previous study, it was the first setup tried for this one (see figure 2). However, when the teenager was taking notes, their hands blocked infrared light emitted by the eye tracker (in the first study, it was not a problem because participants only had to touch the screen once to answer the mathematical question). They reported also being very tired after the first 30 minutes of the experiment, and therefore started to lean towards the tablet and press their head on their hands making not only the eye tracking, but *FaceReader* data unusable too. The eyes were captured 35% of the overall length of the 90-minute experiment.

Given the ergonomic complexity of the task, *SMI Eye Tracking Glasses 2* (SensoMotoric Instruments, Berlin, Germany) were tested. This measurement instrument usually allows faster calibration and steady data collection. However, when we tested it in the note-taking context, important drawbacks were revealed. First, data can not be analysed by creating areas of interest as the scene is dynamically moving with the head of the participant. It is also impossible to see the recording of the bottom of the tablet since the participant was sometimes lowering their eyes without moving their head. Moreover, facial expression recognition software does not work because eye tracking glasses hide contractions of facial muscles such as procerus and orbicularis oculi.

Continuing the iterative process, we manufactured a table with a hole under which the eye tracker would be placed (see figure 3). A portable eye tracker *SMI RED250mobile* (SensoMotoric Instruments, Berlin, Germany) was tried first and results were unsuccessful.

Figure 3. Table with a hole and the eye tracker positioned under the table

Keeping the idea of the tablet placed directly on the table, we fixed the *Tobii x60* eye tracker directly under the table with strings first, then with a plastic storage cube for greater stability and safety (see figure 4). The issue was that the participant's arms and legs could not only damage the costly instrument but also block infrared rays emitted from the ends of the device. The solution we came up with implied using red markers placed on the bottom ends of the tablet not to be crossed by the participant's hands and asking the participant to keep their legs apart. This setup was tested on five teenagers and contrary to first impression, these restrictions did not bother them. However, the quality of eye tracking data was not steady across participants. For those who were taller, the calibration process took longer, and eyes were found by the eye tracker, on average, during 23 out of 60 minutes. Taller participants also had more discomfort trying to keep a good posture with this setup.

Figure 4. Eye tracking under the table with table in flat position on the table

Finally, for data collection in note-taking context, we kept the setup with articulated arms for both the tablet and the eye tracker (see figure 5). Only few adjustments are required: the tablet must be positioned a little closer to the participant, and a little higher as well, to avoid unnecessary leaning and improve posture. The virtual keyboard of the tablet must be split in two so that the hands do not block the eye tracker, and also for additional comfort. The eye tracking data is very steady (at least one of the participant's eyes is tracked, on average, 56 out of 60 minutes, following previous study eye tracking quality measurement logic) and the positioning is most natural. Participants concluded that this setup is very close to their natural use of a digital tablet with a stand.

Figure 5. Final setup with eye tracker closer to the participant

5. Eye tracking in educational robotics with children (Study 3)

LEGO Education WeDo Construction Set is a robotics hardware and software platform designed to initiate children from 5 to 8 years old to programming and engineering. The task implies completing an assignment on the tablet to, step by step, build and, in parallel, program a robot. For example, the learner constructs a crocodile and then makes it move forward using a visual programming language. While the student is performing the task, a teacher interacts with him, asking questions about his progression and monitoring him. The goal of this study was to gain deeper understanding of assisted learning in educational robotics.

Given that two stimuli of a different nature, the tablet and the robot, share the child's attention, eye tracking glasses have been used for both the child and the teacher. They follow the participants' eyes without any physical restriction. The main challenge of this study is to capture data in a way that would optimize its analysis.

Part of the proposed analysis is the construction of heat maps that indicate where the child looked the most and what parts of the stimuli have been processed with more depth on both stimuli, the tablet and the robot. Since the robot is a 3D item, the heat maps must be created by manually transferring the data collected by the eye tracking glasses, fixation by fixation, on each of its faces to be able to interpret and visualise it.

In the case of the tablet, it is important to fix it in front of the child using an articulated arm, so the child does not have to hold the heavy device in their hands and constantly move it (similar to the set up in figure 2).

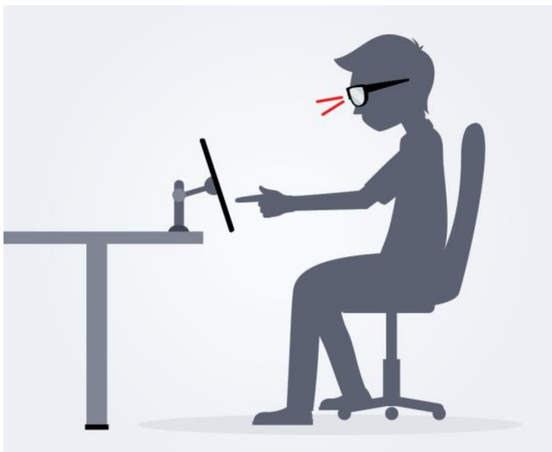

Figure 6. Eye tracking with glasses

It is better for the surface of reference to be stable to keep the analysis feasible and interpret the data correctly. Parts that are used to build the robot must be placed close to the tablet, ideally on the right or left side from the tablet depending if the child is right- or left-handed. The overall positioning must be comfortable for both the teacher and the student, and both have to clearly see the tablet. Not only will this ensure ecological validity of the data, but it will also allow one to analyse mutual gaze patterns by synchronising eye tracking data of the student and the teacher.

A sufficiently large corner desk would be an ideal solution to avoid unnecessary movements that will not only make the experience longer but also increase the amount of data to be filtered and analysed. It is also important to position the person who has the role of the teacher in a way that allows them to clearly see the tablet and child's manipulations. The child's chair should allow rotation to increase the child's comfort and allow fluid movements.

5. Discussion

Eye tracking is a powerful tool to study the visual attention of learners by identifying their eye movements and the depth at which they process the information (Hyönä *et al.*, 2002; Yen & Yang, 2015). Eye tracking data has the potential as a tool to assess the effectiveness of educational software and approaches (Hanna *et al.*, 1997) and research avenues have recently been proposed (Jarodzka *et al.*, 2017).

However, to take advantage of it properly, it is important to optimize its potential. First, it is crucial to carefully select an eye tracking device appropriate to the task or the software being tested. A proper positioning of a child maximizes the probability of tracking their eyes steadily, but should also recreate an authentic and ergonomic environment to ensure data quality and validity. Building upon the three studies described in the previous sections, we are able to formulate additional guidelines to those already existing in the literature.

Guideline #1: Choosing the appropriate eye tracking device category

As for any eye tracking study, it is important to adapt the choice of the eye tracking device to the task that is being tested. With children, their height and posture depart from the manufacturer's assumption in their guidelines. Eye tracking glasses are more adapted to a context that requires movements, such as walking and moving the head, but will necessitate manual coding and reduce precision. Remote eye trackers such as *Tobii x60* that we used are more adapted to tasks that require manipulating a tablet, reading, and other types of subtle eye movements. The portable remote eye trackers such as *SMI RED250mobile* are usually more suited for tasks on a desktop computer or laptop. Based on our experience, placing the eye tracking device below the tablet leads to more precise results with children.

Guideline #2: Ensuring acceptable calibration with remote eye trackers

First, manufacturers provide specific calibration instructions for the eye tracking device. There is often a minimum and a maximum distance between the eyes and the instrument. Being able to move the eye tracker back and forth provides the required adjustment range for the initial setup; the use of articulated arms for both the eye tracker and the tablet is thus suggested. The eye tracker should be placed under the table below the tablet to maximize the tracking box (see figures 2 and 5). The tablet should stand out a little. Once an acceptable calibration is successfully obtained, the setup must remain fixed during the data collection part of the study to facilitate the analysis of visual attention data, while chair dimensions should be adjusted for each participant.

Guideline #3: Ensuring eye tracking data steadiness

If the nature of the task represents a risk for eye tracking data steadiness, as it was the case in the study of digital note-taking where both hands were used and could potentially obstruct the infrared light emitted by eye tracking, precautions should be taken. This is often an issue when it comes to using remote eye trackers. In Study 2, a split digital keyboard has been enabled as the tablet settings so that the hands of the participants avoid interfering with the eye tracker. As participants were teenagers, their longer legs had to be kept apart too. In the first study, hands movement was not a concern since the task implied using only one hand to click on an answer. In this case, the natural flexion of the elbow joint was not a concern for data steadiness.

Another issue in usability testing with young children is their inability to avoid unnecessary movements and concentrate on the tablet. It is essential to make them understand the importance of looking at the tablet and maintain a good posture without leaning forward or leaning backwards and to remind them about it during the experiment if needed. In our experience, they should also be reminded to keep their hands away from their face at regular intervals.

Guideline #4: Optimizing ecological validity

The measurement dilemma being difficult to solve, researchers must make sure an authentic context for efficient usability and hypothesis testing is reproduced as closely as possible. This principle applies to all the guidelines presented above.

Children should be as comfortable as possible and the setup itself must interfere minimally with the task being tested. It is suggested to use a sufficiently large desk and an ergonomic chair designed for children, and to position the tablet in a way that avoids holding the heavy device or leaning towards it to be able to perform its task. The eye level should be the reference.

A comfortable setup will avoid any unnecessary movement that could damage data steadiness and complicate the analysis. Finding the right setup may require a series of tests and iterations.

6. Conclusion

Research that leverages neuroscientific measures such as eye tracking data has potential in education (Jarodzka, Holmqvist, & Gruber, 2017). However, it is important to find the optimal setup of the eye tracker to measure visual attention with a high degree of validity and reliability. The aforementioned specific guidelines should help researchers in developing research protocols allowing to recreate these ecologically valid contexts to properly and efficiently measure visual attention when children interact with educational applications.

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