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Published in:
Electronic Journal of E-Learning

Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Magnussen, R., Zachariassen, M., Kharlamov, N., & Larsen, B. (2017). Mobile eye tracking methodology in informal e-learning in social groups in technology-enhanced science centres. *Electronic Journal of E-Learning*, *15*(1), 46-58.

Mobile Eye Tracking Methodology in Informal E-Learning in Social Groups in Technology-Enhanced Science Centres

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Abstract: This paper presents a methodological discussion of the potential and challenges of involving mobile eye tracking technology in studies of knowledge generation and learning in a science centre context. The methodological exploration is based on eye-tracking studies of audience interaction and knowledge generation in the technology-enhanced health promotion exhibition PULSE at a science centre in Copenhagen, Denmark. The current study is part of the larger PULSE project, which aims to develop innovative health promotion activities where a science centre exhibition is a key setting. The primary target groups were families with children age 6–12 years and school classes with students from 4th to 6th grade. The main purpose of the study was to understand the methodological potential and challenges mobile eye tracking comprises during the different stages of research on informal e-learning in a science centre context utilising digital platforms to enhance informal learning and interaction. The paper presents how eye-tracking methods influence research on: 1) an interventional level: what role eye tracking and eye-tracking equipment plays in interventions; 2) a data level: what new types of data eye-tracking methods specifically contribute; and 3) an analytical level: how analysis of eye tracking can supplement and contribute to other analytical approaches. Finally, the article discusses how the methodological approach presented invites consideration of other ways of understanding how users experience technology-enhanced exhibitions.

Keywords: Mobile eye tracking methods, visitor studies, health promotion

1. Introduction: Eye tracking and studying exhibition visitors

The study of exhibition visitors is a broad field that still lacks a common language (Macdonald, 2007). The research goals of museum exhibition studies vary, covering a range of topics stretching from learning outcomes (Falk & Storksdieck, 2005), to visitor behaviour along the exhibition route (Bollo & Dal Pozzolo, 2005) to interpreting the experience of a museum space (Schorch, 2013). Museums and science centres have both an academic and commercial interest in how visitors experience and interpret the exhibitions presented. The academic interest involves intellectual dimensions that have to do with the science centre as a place where the main purpose is to disseminate science and promote science literacy (Friedman, 2007). The commercial interest concerns the science centre as a place in need of visitors to legitimise its existence and to a certain degree as a source of necessary income. Visitor studies, for example that involve investigating audience behaviour and satisfaction, are necessary in order to create activities that visitors find worthwhile to spend their leisure time and resources on (Dean, 2002). Thus a variety of different methods are applied and experimented with in the pursuit of exploring different aspects of the museum and science centre exhibition experience.

Eye-tracking technology, which involves recording and analysing the gaze of a study subject, is evolving rapidly. There is an ongoing need to explore how best to apply mobile eye tracking (MET) methods in natural environments. The first studies of eye movements began more than 100 years ago (see e.g. Huey, 1908), but it is only in recent years that lightweight mobile devices allow subjects to walk around freely with the eye-tracking device (Hayhoe & Ballard, 2005). Eye tracking has been shown to have strong potential in combination with other methods, e.g. interviews and observations of social interaction, and in comparison to using conventional methods alone, for instance in multimedia learning studies (Jamet, 2014). Recently the possibilities of eye tracking in the study of visitor experiences in exhibitions have been explored (Eghbal-Azar &

Reference this paper as: Magnussen R et al, "Motivational Gaps and Perceptual Bias of Initial Motivation Additional Indicators of Quality for e-Learning Courses" *The Electronic Journal of e-Learning Volume 15 Issue 1 2017*, (pp46-58) available online at www.ejel.org

Widlok, 2013). Mayr, Knipfer and Wessel (2009) point out the potential of revisiting the respondent's experience when applying MET in an exhibition context. And Eghbal-Azar and Widlok (2013) argue that a more detailed view of the exhibition experience is possible when MET is applied as a research method.

This paper explores the potential and challenges of eye tracking as a method for studying knowledge generation and learning in a science centre setting. The methodological discussions are based on studies of families in the health promotion exhibition PULSE at the science centre Experimentarium in Copenhagen, Denmark. The study is part of the larger PULSE project, which aims to develop innovative digital health promotion activities where a science museum exhibition is a key setting. The primary target group is families with children age 6–12 years and school classes with students from 4th to 6th grade.

The current methodological study focuses on understanding the potentials and challenges MET comprises during the different stages of research in informal e-learning in a science centre context utilising digital platforms to enhance informal learning and interaction. Based on these studies we present how eye-tracking methods influence research on an interventional, data and analytical level.

2. Background: Exploring user experience in the complex setting of an exhibition

As mentioned, studies of museum and science centre visitors remain a wide research area lacking refinement in common practice and language (Macdonald, 2007). Hooper-Greenhill (2006) argues that the overall foci of studying museum and science centre visits has shifted from: "thinking about visitors as an undifferentiated mass public to beginning to accept visitors as active interpreters and performers of meaning-making practices within complex cultural sites" (p. 362). This has led to a variety of methods in the study of visitors. A classical way of studying visitors is through the use of surveys e.g. on satisfaction (Loomis, 1988) and/or test scores to investigate learning outcomes (Falk, 1997). As with any other context that involves using surveys, the answers are confined to the respondents' interpretation of the questions. It remains difficult to be exploratory and thorough if investigating an exhibition solely by means of a survey or questionnaire. Other research activities in exhibitions focus on the varying amount of time users spend in the exhibitions and they observe and interpret their behaviour at a distance (Bollo & Dal Pozzolo, 2005; Barriault & Pearson, 2010). However this method of purely observing the user can limit the research findings as the behaviour of the visitors can be due to many non-exhibition factors (e.g. a child having a bad day or staying in one spot for a long time while your mind is preoccupied with what to make for dinner).

Other studies investigate the visitor experience in a more exploratory way, e.g. by walking along with a group of visitors in the museum and playing an active part in the experience by asking questions as the subjects explore (Lykke & Jantzen, 2013). It can be argued that following subjects around intrudes on the behaviour and discussion in the group. Conversely, with just observation or video recording, researchers miss out on the opportunity to ask about aspects of the exhibition visit in situ. There is a long history of interest in the use of video recordings when studying visitor behaviour, mostly focused on patterns of visitor navigation or verbalization (Vom Lehn, Heath & Hindmarsh, 2002, pp. 2-4). When video recording, either by following the group around or with a fixed camera, researchers obtain data that renders the group or person from a third-person point of view. It can be difficult to hear verbalization depending on the distance and quality of the video equipment. the methodological potential and challenges mobile eye tracking comprises during the different stages of research on informal e-learning in a science centre context utilising digital platforms to enhance learning and interaction.

This paper focuses on the methodological potential and challenges of applying eye tracking in the study of social groups in a technology-enhanced science centre exhibition. Exhibition studies employing MET are challenging the view of coherence between the observed time a visitor spends at an exhibition and the individual's interest in the exhibition and/or its theme (Eghbal-Azar & Widlok, 2013). MET is not only interesting in terms of presenting a new way to analyse new types of data (e.g. heat maps). Eye tracking is also interesting in that it presents the possibility of looking through the visitor experiences through their eyes, from a first-person point of view, with a clear recording of their verbalisations in correlation to what or who they are observing. Other studies have accounted for some attending issues, such as the limited validity of the interpretation of eye movements and cognitive processing (Hayhoe & Ballard, 2005) and the limitations of the interpretation of eye fixations in relation to the attention span and processes of the participant (Treisman, 2006). Mayr et al. (2009) argue that one of the implications of this in a science centre is that:

> *... while a participant's eye is fixating a specific exhibit, he may actually be attending to the whole exhibition wall without devoting attention to the fixated exhibit itself, or he may be thinking about something completely different while his gaze still lingers on that specific exhibit (2009, p. 6).*

To the best of our knowledge very few MET studies similar to ours that take place in a museum or science centre setting have been carried out. Some focused on the enhanced level of detail that can be obtained from data, e.g. due to the ability of MET to track how participants scan an exhibition (Eghbal-Azar & Widlok, 2013). Others were more practical and design-oriented, exploring how MET can be an integral part of getting information about the exhibition based on where the subject's gaze is resting (Toyama, Kieninger, Shafait & Dengel, 2012). Both Mayr et al. (2009) and Eghbal-Azar and Widlok (2013) focused on using MET in a natural museum setting and allowed participants to walk around freely with no agenda other than their own curiosity. Both of these studies advocated the use of MET in combination with other methods such as interviews. Eghbal-Azar and Widlok (2013) point out that MET data alone are not enough to get information about how the participants perceive the exhibition. Likewise, both of these studies focused on a single participant at a time and the interaction with the exhibition. However, it is widely acknowledged in the museum community that a visit to a museum is a social activity, and that a visitor's: "interaction with their companions is an important aspect of their museum experience" (Coffee, 2007, p. 377).

To limit the factors of disturbance Mayr et al. (2009) restricted their study to only one person at a time to explore the exhibition they investigated. This may have provided more clear data, but it also compromised the exploration of the museum experience in its natural environment, as the participant neither had companions nor other visitors to observe.

The current study explores the possibilities and limitations of MET in the natural setting of a science centre with a social group of visitors. The study takes place in the PULSE exhibition, which was designed as an active social experience, with family groups as the main target group. As a result, it represents a good example for studying MET in a highly social science-centre setting that uses a high degree of digital platforms and feedback. We highlight how/if the glasses used to track eye movements interfered with the subjects, who were active during the exhibition, and how/if this affected the other group members. We also describe the new types of data MET can record from the first-person perspective of subjects interacting with digital platforms in science centres. The main focus of the paper is thus to develop a methodological understanding of how to conduct MET studies at the: 1) interventional, 2) data and 3) analytical level in social groups in technology-enhanced exhibitions.

3. The PULSE exhibition and data collection methods

The PULSE project is a large-scale project that was created in collaboration between the Danish science centre Experimentarium and the research institute Steno health Promotion Centre. The project began in 2012 and the core outcome is a technology-enhanced exhibition, with the goal of health promotion. The core target group of the exhibition is the family unit, building on studies that demonstrated how museums could introduce children to science as an academic discipline (Crowley & Jacobs, 2002). The exhibition focuses on the family as a social unit and the notion that parents will see the visit as positive if the children achieve deeper insights by playing games and engaging in various activities (Falk & Dierking, 1992). The project builds on health promotion theories and action competencies that include a number of subcomponents such as knowledge, commitment, visions and action experiences (Jensen, 2000). The exhibition, which opened to visitors in March 2015, was also evaluated through visitor surveys (Zachariassen & Magnussen, 2016). In short the exhibition consists of eight different activities in which participants are active as a team consisting of two to five members. The activities resemble places in the home, for example, a kitchen, where balancing skills are put to use, a bathroom, where cleaning it involves dancing.

3.1 Data collection setup and methods

This paper's methodological design is based on a study of visitor knowledge generation in the PULSE exhibition (Magnussen, et al., 2016), with a specific focus on developing methodological approaches for MET studies on group interaction in the informal e-learning context of a science centre exhibition context. Conducted in late 2015, the study comprised eight families with children 6-12 years of age visiting the science centre and two groups of sixth graders. The respondents were chosen from the visiting audience based on how well they

matched the project's target groups. The study was conducted by applying MET methods and by conducting short qualitative interviews with participants after they saw the exhibition. Our research specifically looked at the possible implications of the method on the interaction of subjects in the exhibition context and worked to identify new knowledge and types of data derived from the first-person perspective MET, also in combination with other methods, such as interviews. The groups were invited to participate in the eye-tracking study before their first visit to the exhibition. After the eye-tracking interaction in the PULSE exhibition, group members participated in short un-structured group interviews (Kvale, 1996) with questions about the perceived theme of the exhibition and the perceived knowledge-gain from interacting with the installations. Interview data were categorised in a grounded theory process (Corbin & Strauss, 2008). Eye-tracking glasses recorded audio, video and gaze point from the test subject's point of view during the group's interaction in the exhibition. Data from the eye tracking were applied to investigate how interaction with a specific exhibition installation could be related to knowledge building. Findings of the study have been reported on and published elsewhere (Magnussen, et al., 2016).

3.2 Eye-tracking method

In the eye-tracking study, one adult in each family group and one child in each school group was invited to wear eye-tracking equipment. The use of eye tracking in this context relies on the idea that human physiological capacity to obtain, or sample, visual information from the surrounding environment is inherently limited by the structure of human eyes, which can only receive high acuity visual information from a very narrow visual angle at any given point (Land, 2014). Perceptual processing capacity is also inherently limited and, consequently, there is a high correspondence between the locus of overt attention and the direction of the gaze. Thus, tracking where a person is looking on a moment-to-moment basis provides rich information about what material is being sampled and used in visually guiding the activities that people are engaged in as well as in situated learning and social communication processes (Lauwereyns, 2012). In this study, we implemented eye tracking using MET glasses (SMI ETG 2w 60hz, SensoMotoric Instruments GMBH, Teltow, Germany). The MET device uses non-invasive recording technology that illuminates the eye with safe-intensity infrared lamps and tracks the position of the moving eye using an infrared camera. The SMI ETG 2w system is built into sports glasses (about the size and weight of ski goggles) and uses a smartphone with custom software to record data. The system was worn by participants in the same way as sports glasses are worn and the data recorder was worn in a small belt pouch. Thus, the system provided high mobility, allowing participants to move freely and interact with the surroundings in a nearly unrestricted way (apart from the slight limitation of peripheral vision by the eyeglass frame and the limited conscious effort on the part of the participant to avoid damaging the equipment). The output data were a gaze overlay colour video with 1280x960 pixel 24 fps of the subject's point of view (the camera was positioned approximately between the eyebrows) with the position of the gaze indicated by a marker in each frame. Gaze position was estimated by the eye-tracker firmware from a 60hz recording of the eye position matched to the position of the gaze within the recorded field of view. Gaze overlay video also contained an audio track recorded via a microphone mounted in the glasses, thus recording what the participant was saying and some surrounding sounds (e.g. what another person standing close said in a conversation). Recordings using eye tracking began with explaining the equipment to the participant, fitting and calibrating the eye tracker and starting the recording, after which the participant moved freely around the exhibition until deciding to stop participation (40 minutes on average, which was the amount of time needed to see most of the PULSE exhibition). Data were qualitatively analysed by reviewing the gaze overlay videos and matching the locus of overt visual attention with the participants' utterances, following procedures described in Holmqvist et al. (2011).

4. Methodological results: Three levels of understanding eye-tracking methods

The eye-tracking studies described in this section were conducted with families and grade-school students visiting the science centre Experimentarium in Copenhagen, Denmark. The current study specifically focused on developing methodological approaches for MET studies on group interaction in the informal e-learning context of a science centre exhibition. Our research specifically looked at the possible implications of the method on the interaction of subjects in the exhibition context and worked to identify new knowledge and types of data derived from the first-person perspective MET, also in combination with other methods, such as interviews. Next, we present how the eye-tracking methods influenced the research on the: 1) interventional 2) data and 3) analytical level.

4.1 The interventional level: Eye tracking as an intervention in the intervention

The interventional level concerns the role eye-tracking equipment plays in knowledge building in informal settings, in this case, in the test person's interaction with the exhibition. As described in the methods section, one adult in each family group and one child in each school group were asked to wear eye-tracking equipment during their visit, before entering the PULSE exhibition. Adults were chosen primarily based on the assumption that the equipment would be less of a distraction for them. They were provided with information and shown how what they were looking at would be visible on a computer screen. Notably, no one declined to participate after receiving an explanation about the study and the equipment and many expressed excitement about being in the study. We did a short interview after each group was finished with their visit to obtain qualitative data on their thoughts about the themes of the exhibition.

With regard to the interventional aspects of the glasses, it turned out that not following the groups around ourselves also provided useful data. The glass wearer or others in the group commented on the glasses when we were not nearby and we were able to hear these comments in the recordings. This allowed us to gain additional articulations from among the participants in the social groups. The recorded dialogue provided insight into how the physical presence of the glasses was perceived, how the knowledge of measurement affected the participants and how the glasses, as a foreign object, affected a social group.

4.1.1 The physical presence of the equipment

One of the ways the glasses interfered with the experience was by the sole issue of wearing them. While visiting the exhibition, a father in one family said: "I don't want to have these glasses on anymore. I want to take them off now." Even though he had been informed that he could take them off at anytime, he did not come to a researcher to have them removed and went through another activity before asking to have them removed when a researcher came to calibrate them. In the post-exhibition interview he said that getting used to wearing the physical equipment affected him the most. Interviewer: "What was it like to wear them? Were you affected by it?" Father (with glasses): "No, you had to get used to wearing them but otherwise I certainly think it was fine" (Magnussen, et al., 2016). Hence, the subject stated that, for him, the intervention had more to do with wearing the physical equipment than the awareness that his gaze was being tracked. When asked, one of the school students also emphasised the physical discomfort of wearing the glasses, but not the intrusion of having their gaze tracked. Interviewer: "How does it work to have these glasses on?" Student (with glasses): "So, it's fun, but actually it hurts a little bit, but it's fun (laughs)" (Magnussen, et al., 2016). In general, the groups spent a fair amount of time in the PULSE exhibition, many spent up to an hour. One mother said several times to her family that the bag holding the smartphone and battery for the glasses was hot but she did not ask for assistance either (Magnussen, et al., 2016). This is a possible indication that using eye tracking in exhibitions for an extended period requires clearly explaining that participants are more than welcome to have the glasses removed or adjusted. We told the participants that they welcome to get the glasses off at any time but few of them did so before finishing the exhibition. Most people were quite enthusiastic about the research and technology, their belief in the necessity of gathering complete data perhaps allowing them to better tolerate the heat from the bag or skin irritation from the glasses. When asked by the researcher, the families and students did not report any self-awareness or discomfort about the fact that their gaze was being tracked. However, as will be demonstrated in the following, the subjects made statements to other group members that indicated a sense of self-awareness about this.

4.1.2 Obtrusiveness of measurement

Another interventional quality of the glasses is the self-awareness that one's gaze is being tracked. Mayr et al. (2009) argue that the obtrusiveness of measurement was not a relevant factor in their study, as only one participant (the one wearing the glasses) was allowed in the exhibition at a time. However, they recognise that this might be a factor in a more natural setting, especially considering the highly social aspects of visiting a museum (Mayr, et al., 2009). In the PULSE exhibition only one participant at a time wore glasses, but they saw the exhibition in groups, while other visitors were simultaneously present. The intrusiveness of the glasses was evident in some dialogues in the data. In a school group of three girls, the girl wearing the glasses talks with a classmate about the embarrassing fact that the direction of her gaze is being monitored while waiting in a queue for an activity. Student (with glasses): "It's embarrassing that they can always see who I'm looking at and stuff." Classmate: "Yeah, if you look at someone's butt or something." Student (with glasses): "Yeah." Thus the knowledge of having her gaze tracked made her uncomfortable and potentially careful about where she looked. In one family, the mother stated that there was a correct, or intended, way for the husband (wearing

the glasses) to look around. Mother: (laughs) "Now you have to look in the right directions." Father (with glasses): "Well, where should I look? I can only look where I usually look. Should I take a look at you and your nose?" (laughs) (Magnussen, et al., 2016). As opposed to the mother the father said that he can only look where he usually looks. His wife, however, even though she was not the one wearing glasses, demonstrated an awareness of the fact that the gaze of a person in the group was being monitored, which overlapped with the social facts described in the next section. Thus, the argument that the obtrusiveness of measurement would indeed be present in a natural social museum visit is confirmed in the context of the present case study (Mayr, et al., 2009).

4.1.3 Foreign object in a social group

Another interventional factor of the glasses occurred with the other members of the group experiencing the exhibition along with the participant who was wearing the glasses. In the family groups, it was mostly the children who asked the parent about the glasses during their visit. In another family, a girl about seven years old showed discomfort about her father appearing differently:

> *Girl: "Dad, when are you going not to have those [the glasses] on?"*
> *Father (with glasses): "How about in ten minutes? Don't you like them, Silvia?"*
> *Girl: "No, I'm not used to seeing you with something like that on."*
> *(About six minutes later her sister also asks him when he will get them off.)*
> *(Transcripts from eye tracking recordings of Family 3 interacting with the PULSE exhibition)*

Another girl of around five years of age in a family group had a more curious approach and asked: "Why are you wearing that thing Dad?" Father (with glasses): "It's because I'm helping them make an experiment." When using eye tracking, the presence of equipment is more obvious when the recording device is literally on the participant's face in comparison to a more subtle camera mounted in a corner (Mayr, et al., 2009); the children in particular pointed this out. Not all children expressed concerns about the glasses and those who did were often the youngest ones. In the school classes, many of the teams knew each other and walked around the exhibition simultaneously. This meant that, unlike the family groups, the student groups were not only familiar with their own team members, but also with other teams crossing their path. One group of school boys were so conscious of the glasses that they generated very little data that did not involve statements like "look at me." or interacting with the glasses (attempts to make the wearer look at specific places). For instance, one boy wearing the glasses stated: "I mean it, they [the glasses] are very fun to wear, something scientific (...)", while in the middle of an activity. Likewise, when walking by classmates he said, for example: "It's seriously fun this with these [the glasses] on; it's seriously weird." The classmates would try to get him to look at them and comment: "Nice glasses!" when passing by, thus overtly noting the presence of the glasses (Magnussen, et al., 2016). Overall the two groups of school students, to a much higher degree than the eight family groups, mentioned and interacted with the glasses. The high level of attention given to the presence of the glasses could have been influenced by age. In Denmark, sixth graders are about twelve years old putting them in early adolescence, a period of greater self-conscious than adults (Larson & Richards, 1994). Likewise, the glasses could work as a way to get attention from their classmates. However, the higher number of statements about and interaction with the glasses in the school groups could indicate that the more participants know each other, the more they will talk about and interact with the person wearing the glasses. It is possible that a group of strangers would interact less with the glasses, as the person wearing them would not look as different to a stranger. The school students and the family groups knew each other very well, hence the glasses looked unfamiliar or unusual.

The PULSE exhibition was designed to stimulate a high level of active physical interaction, and we expected an increased awareness of the glasses might lead to the fragile equipment being dropped. However, no data indicated that this was an intruding factor and the glasses never came close to being dropping. Moreover, the study demonstrated that the use of MET in a natural museum setting had to consider the science centre visit as a social and active experience – especially for families (McManus, 1987). As we shall discuss later, MET in a social group had advantages, but the glasses can also affect the participants who are not wearing any, creating focus on e.g. a parent looking unusual or a way to gain attention from the rest of the group.

4.2 Data level: Detailed knowledge from the participant's point of view

The second level focuses on the opportunities for acquiring additional data that occurs when tracking the participant's gaze. In this study, we have far from fully explored and analysed the large amount of available data. Our interest in the project focused on the kind of information the participants acquired from the exhibition and on from what or who they obtained the information (Magnussen, et al., 2016).

The data level involved focusing on understanding what new types of data eye-tracking methods can contribute to studies of knowledge generation in informal settings. In the current study the eye-tracking equipment recorded audio and visual data during the interactions and dialogue, similar to an audio recorder or video camera but, in contrast to these traditional methods, it also recorded data on the direction of the subject's gaze. This type of visual data provided new knowledge about visitor interaction.

One example was recordings of a group of 12-year-old students playing a ball game at an installation. Data from the student wearing the eye-tracking equipment showed that additional information for the game was visible only from her point of view. The activity involved throwing balls in holes that light up on two opposite sides, causing the team to work together. The teammate wearing the glasses yelled, "Freja there's light over there!" even though the lit-up hole was on the teammate's side and not her own side. Looking at where the participant's gaze rested allowed us to see that, at her height, she could look directly through the holes on her side, which allowed her to scan the holes on the opposite side when she had finished her own without success (see figure 1).

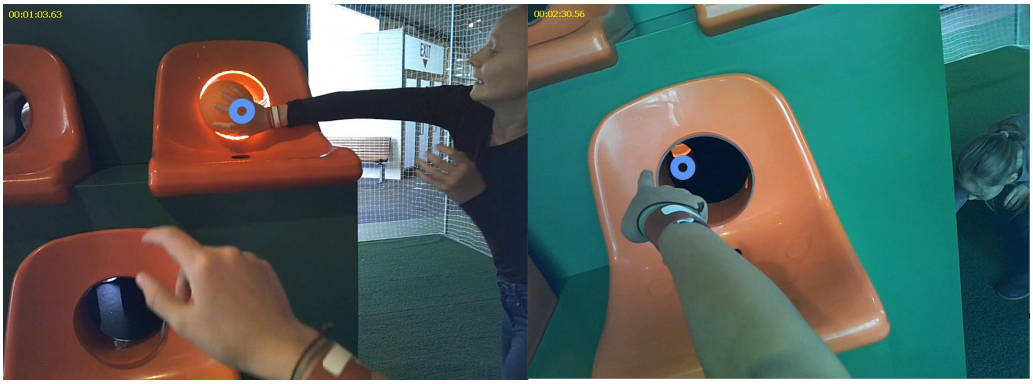

Figure 1: The eye-tracking data revealed that the girl playing the game was able to look through the holes on her side of the activity, enabling her to tell the teammate to throw the ball in the lit-up hole on that side.

Hence, tracking the gaze point allowed us to discover that some participants played the game watching both sides and told their teammate(s) on the opposite sides where the light was if the teammates did not initially find it themselves. As a result, the glasses provided additional data on the direction of gaze and revealed other types of visual input the students could build knowledge on.

Mayr, et al. (2009) point out that one of the benefits of gathering data with MET in the museum context is the added level of detail obtained. The current case study focused on information and knowledge gained by the participants and, likewise, we found that details about how the participants sought and found knowledge were rendered clearer through MET. One example was a participant who walked toward a new activity in the PULSE exhibition and asked: "What are we supposed to do here?" In the gaze recording it was clear that for a short time he looked directly at a sign on the wall of the activity and it is very possible that he was seeking the information about what to do on the sign (see figure 2.).

Figure 2: Participant gazing at a sign that explains how to sign up as a team and not the information he said he was seeking. The text on the sign says: "You must be logged in as a team to use the activities. You can create a team in the MIDDLE.".

Several factors about the setup made this kind of data information possible. First, we allowed the museum visit to be a highly social context in a natural environment. While others have chosen to restrict the visitors to one-at-a-time in an exhibition while using MET (Mayr et al., 2009), this exhibition could only be used in teams, thus every participant wearing MET was accompanied by a team. If the person in figure 2 had been alone he would most likely not have wondered out loud about what to do in the activity. Hence, the social context of the group provided additional auditory data about navigation and rationalisation in the exhibition. Video recordings have been a widespread method for conducting visitor studies (Vom Lehn, Heath & Hindmarsh, 2002), but linking the question of what to do with the gaze point on the sign was only possible with video containing the first-person point of view and basically is not possible with the other method due to the brevity of the gaze. He does not find the information that he sought on the sign and proceeded to the activity with his family, where they spent the beginning of the activity talking about what to do. This information allowed us to present additional findings to the developers of the exhibition by pointing out how to better provide information on finding the way in rather complex activities.

One practical challenge was the difficulty in ascertaining who was talking if the MET participant was not looking directly at them, possibly compromising the analysis of group dynamics of interest. One solution would be to give all participants a microphone and to have an additional camera filming the group from the outside. This approach would, however, add to an already time-consuming pool of data.

4.3 Analytical level: Relationship to traditional qualitative analytical approaches

On an analytical level this paper aims to understand how eye-tracking data analysis can contribute to traditional social science analytical approaches. In the case study, all members of the family and student groups were subsequently interviewed to understand how the group experienced the exhibition, what they saw as the thematic focus and if they thought they had gained new knowledge from the activities (Magnussen et al., 2016). The interview data was analysed drawing on a grounded theory approach and resulted in the following categorisation of various themes to describe the participant perspective on the topic of and the knowledge presented in the PULSE exhibition:

- Collaboration
- Exercise/fitness
- What the body is capable of:
    - Knowledge about the body on the inside
    - A physical activity previously assumed to be impossible to achieve, e.g. how high one can jump and how fast one is

    - For example, how to jump high and dance
- Family and community
    - Trying things in the family, doing things together not normally done in the family

The grounded theory analysis of the interviews created what can be defined as an analytical map of focus points that the further analysis was based on. In a second analysis, gaze points were analysed to determine how they correlated with the specific themes the participants identified. The eye-tracking data thus provided more background information on the participant's focus compared to what would have been possible with more traditional analytical methods with regard to the categories defined. Data available from an interview helped define the theme "What the body is capable of":

> *Interviewer: "If everyone had to try to explain what this exhibition is about what do you then think it's about?"*
> *Girl: "I think it's about technology and what you're like inside your body."*
> *Interviewer: "What are you like inside your body?"*
> *Girl: "Yeah, you find out what you're like inside."*
> *Interviewer: "Can you try to explain what you mean?"*
> *Girl: "Well, for example, what you can do that you weren't aware of, like that thing with cycling and heart rate for a minute and things like that."*
> *(Transcript from interview with Family 2 after visit to PULSE exhibition)*

To investigate the experiences that influenced the girl mentioning knowledge in relation to understanding her own body, data from the family's visit to the bicycle installation (see figure 3) was reviewed to identify the possible sources of information. The family cycled together on four adjacent exercise bikes equipped with sensors in the handlebars to measure their heart rates. In front of the bikes was a large screen showing a film simulating a family bike ride to the beach. Participants were instructed to cycle and then to rest to see how fast their heart rate decreased to a resting rate. Information about who took the lead and the different member's heart rates was also displayed. The eye-tracking studies on Family 2 focused on understanding what influenced building knowledge about the body on the inside and "what you can do that you weren't aware of". Family 2 had three members: a father and two girls, one 6-7 years old and the other 9-10 years old.

Figure 3: Screen shot from eye-tracking studies of Family 2. The father in Family 2 (wearing eye-tracking glasses) watches another family use the Bike Shed while waiting with his daughters to try it. The text on the screen says "Bike Shed" shows the biking time (0:20) and says "Feel your body and see your PULSE fall." The digits represent the different family members' (various colors) heartrate per minute. The boxes also indicate who has the lead in the virtual bike race.

> *Father (with glasses): "It looks fun." (Bike Shed)*
> *(Watching the family in front of them.)*
> *Father (with glasses): "Should we try this one girls, or should we try something else?"*
> *Youngest girl: "I'd like to!"*
> *Father (with glasses): (Still watching other family.) "See it's the pulse, it shows the rate at which your heart beats per minute. See, his heart beats 167 times a minute."*

(…)(Family gets on the bikes.)
Youngest girl: "When should we start?"
Father (with glasses): "It reads the pulse. See, it reads our pulse."
Father (with glasses): "Great, you're in the lead. Where are the others? It says you have more power. It says give it all you've got! Come on! Yes!"
[00: 15: 34.08] Father (with glasses): "See, it's our pulse."
(…) (Interview right after Family 2 tried the Bike Shed.)
Youngest girl: "I'm sweating!"
Interviewer: "I can see why."
Father: "There's nothing intellectual about it. It was very physical."
Girl: "Try to feel how much I am sweating!"
Interviewer: (laughs)
Father: "Yes, it's wonderful." (laughs)
(Transcript, eye-tracking studies of Family 2 testing the Bike Shed installation in the PULSE exhibition)

In the above situation the girl and her family acquired useful information from various sources. Before getting on the bikes they saw how to use the installation by watching another family. The father mentions just one of the people in front of them to help explain what is being measured: "His heart beats 167 times per minute". The interaction between the father and the girls at this installation focused on him physically challenging the girls by encouraging them to bike faster. This is perhaps what the girl referred to later when she said she had gained new knowledge about "what you can do that you weren't aware of." After the activity, the girl stated that she was sweaty, referring to what could be called embodied information. She also mentioned new knowledge concerning finding out about the body on the inside.These experiences were covered by the first category, concerning knowledge about effects, in this case the bodily effects the surrounding environment caused that the respondents in Family 2 mentioned. An analysis of how the bike installation supported this understanding showed that the interaction between the bike, the screen and the people biking is focused on providing the audience with technical data about their heart rate and about challenging them to race against each other. This represents a self-monitoring technology that provides feedback on the individual performance compared to other competitors (Magnussen & Aagaard-Hansen, 2012).

In our studies, the grounded theory analysis and resulting themes led to a map of focus points for our studies. In combination with this, the analysis of the eye-tracking data contributed detailed information about sources of knowledge that could be coupled to themes defined based on grounded theory analysis. The eye-tracking data analysis provided an indication of what aspects of the exhibition influenced audience knowledge. Analysis of eye-tracking data allowed us to triangulate self-reported data on the expressed audience experiences from interviews with results from gaze points and audio recordings of dialogue recordings from the eye-tracking glasses. In the analysis we were able to pair results from the grounded analysis of interview data with results from eye tracking on both how participants received information about how to use the installation and what kind of information the installation provided them with as part of the interaction.

5. Discussion and conclusions

The aim of the current study was to methodologically explore the possibilities and limitations of MET for studying visitor experience and learning in the setting of the health promotion exhibition PULSE at science centre Experimentarium in Copenhagen. MET has been widely applied to studying the interaction with an exhibit of a single individual at a museum (Mayer et. al. 2009). This has, however, been criticised for compromising the study of what visitors experience at a museum and their social interaction, which is an important part of the natural environment of exhibitions and the museum experience (Coffee, 2007). This paper described the methodological potential and limitations of MET when applied as a method for studying informal e-learning in family and school groups in an authentic exhibition setting. Based on the findings of a previous study (Magnussen, et al., 2016), we divided the methodological reflections into three levels: 1) interventional, 2) data and 3) analytical.

At the interventional level we presented how, in the social setting of the PULSE exhibition, MET becomes an intervention in the intervention. In contrast to what Mayr, et al. (2009) reported, the results in the current paper showed that various test persons or group members interacting with test persons said they were aware that their gaze was being monitored.

The MET equipment intervened at both the individual and social level. Comments from visitors on what it was like to wear the eye-tracking glasses were possibly connected, in part, to the context of the studies. PULSE is a highly interactive exhibition focusing on activities that require a high degree of physical activity. The eye-tracking glasses became an intervention in the interaction with the exhibition, which involved jumping, dancing and cycling. One possible means that can be employed to minimise the perception of the glasses as an intervention is to reduce 30 to 60 minute intervals spent in the PULSE study. Socially, the intervention resulted in positive and negative responses, specifically in family groups. Comments by participants not wearing the glasses indicated that the glasses affected them because, for example, the parent looked unusual or they drew extra attention from the rest of the group. The obtrusive aspect of the method is difficult to minimise when working with family groups with younger children, who may react more to them as a foreign, unfamiliar object. The glasses and visual data on gaze point were thoroughly introduced to the various family members before the adults wearing them did the test. Our results indicate that the obtrusiveness of the MET measurement is more present in an authentic social museum context compared to more controlled studies, where the test person wearing the equipment visits the exhibition on his or her own (Mayr, et al., 2009). Based on the implications of the cases presented, we argue for a continued study of how to minimise the intervening factors of MET equipment, including the reactions of family members, especially younger children, to the parents or guardians wearing the unfamiliar equipment.

At the data level, this paper examined how the MET method can contribute new types of data and perspectives on analysing how audiences develop the knowledge mentioned during their post-visit interview. At the data level it became clear that the MET method can offer new types of detailed data on sources of knowledge from the visitor's point of view that would potentially not be available with other data collection methods. Being able to track the test person's gaze and direction provided valuable knowledge only visible from the first-person perspective. The method also revealed detailed information about what sources of knowledge visitors overlook, for example, vital information on PULSE exhibition signs. Due to its ability to provide this type of detailed data, the methodology is well suited for conducting future research on exhibition screens and digital platforms. The methodology thus offers great potential for future studies of visitor interaction with various types of learning technology in exhibitions due to the fact that it is possible to follow actions such as reading and other information processing in detail. One of the difficulties in the social groups, however, was that it was difficult to distinguish respondents from one another if the test person wearing the MET glasses was not looking directly at the person speaking. Future studies should taken this into consideration when determining how to develop the method.

At the analytical level, the study showed that the methodological choices in the combined interview and eye-tracking data collection also have implications for the analytical approach and generation of results. At the analytical level we discuss the approach for analysing and connecting findings from the different types of data in the study. In the current study short group interviews were conducted after each group was finished with its visit to the PULSE exhibition. The aim of the interviews was – in addition to and separately from the eye-tracking data – to understand what knowledge the audience gained from the exhibition. This allowed us to pair interview data with the eye-tracking data to investigate what interaction and activities led to the knowledge described in the interviews. Eghbal-Azar and Widlok (2013) report on conducting interviews with participants after the visit while simultaneously showing them the recording of their gaze points during their visit, thus providing the opportunity for participants to comment on actions at specific times and places. In accordance with Mayr et al. (2009), our analysis of eye-tracking data clearly shows that just because participants are looking at a fixed point, it does not mean their attention is focused on that specific exhibition item, for example, when visitors overlook information about exhibition features even though they looked at it. One way to improve the data and expand the analysis of whether the object and the visitor's attention coincide would be to do more extensive individual interviews with questions on knowledge gained and specific gaze points during interaction with the exhibit installations. The MET approach generates a large amount of varied data that can be useful in analysing a large variety of issues. Apart from gaze data, hours of accompanying audio recordings can serve to indicate the general focus of the test person's attention, making it possible to analyse their utterances and interaction with the people near them in relation to research themes of interest.

Overall the study contributed new knowledge to understanding the methodological potential of the MET approach in an authentic social science centre context at all levels of visitor research. At the interventional level, MET equipment becomes an intervention in the intervention in a social context, where both subjects wearing the equipment and the group members they interact with are highly aware of the gaze being

monitored. Future studies involving MET methods should focus on this interventional factor and develop study designs to minimise it. The MET approach, however, also provides new types of data and valuable new knowledge, specifically due to the fact that it records the gaze from the first-person point of view, leading to new types of analyses concerning what aspects of digital platforms and physical surroundings contribute to informal e-learning in the social exhibition setting. Our study thus showed that the MET method allows an analysis of specific areas based on tracking, in detail, knowledge and actions such as reading on screens and interaction with other learning technologies in exhibitions. The methodology, however, also proved to have limitations, specifically due to the interventional aspects of the MET equipment. As a result, future studies should further explore the analytical potential and interventional implications to a greater degree.

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