Mobile Eye Tracking

Visualizing eye movements in exhibitions

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Introduction

The medium of the exhibition is intrinsically connected to the gaze. The exhibition is organized by the curators' gaze and it is through the gaze of the visitors that it is explored. Being visual systems, exhibitions use their selective mode of presentation to show certain things, while omitting others. Furthermore, specific regimes of vision have come to be embodied in exhibitions, when Tony Bennett (2006), for example, speaks of the requirement of a *civic seeing* in the course of the establishment of modern museums as civilizing institutions. For centuries, the *male gaze* was also the status quo, with women appearing in museums almost exclusively as subjects of male artists (Nochlin 1971). Within the historical distinction made by the West between art and ethnographic museums, as well as the 'other' framing of non-European cultural artefacts, criticism was also voiced against the Eurocentric gaze (Bal 2002, Schade and Wenk 2011). Nowadays, museum studies are intricately involved with the deconstruction of regimes of vision and apparatuses of representation through discrimination-critical and decolonial discourses (Kravagna 2013, Morawek 2017, Mulvey 1996, Rito 2017).

While critical academic discourses locate the gaze as an abstract concept in a specifically temporal way, the question arises what the real viewing behaviour is about. For a long time, the compositional logic of buildings, spaces, objects and paintings was used to explain the focus and sequence of the gaze (Rosenberg 2011, Rosenberg and Klein 2015). In exhibition research, too, there are a number of studies that examine inherent visiting and visual regimes through the way displays are presented (Klonk 2009, Muttenthaler and Wonisch 2003, Staniszewski 1998). It was only since the invention of eye tracking at the beginning of the 20th century and first experiments in art and image viewing (Buswell 1935, Stratton 1902, 1906, Yarbus 1967) that it was possible to trace eye movements empirically (Wade 2010). For a long time, however, experiments on viewing behaviour were conducted almost exclusively in the laboratory and with digital image reproductions. However, com-

parative studies have shown that the context is crucial for the aesthetic experience since art viewed in a museum, for instance, sparks more interest and appeal than in a laboratory setting (Grüner, Specker and Leder 2019).

First attempts to record the viewing behaviour in museums and exhibitions in situ have been carried out since the 2010s. Even though Milekic (2010) already then postulated that "eye tracking may prove to be the most powerful tool for museum studies", the first eye tracking studies in exhibitions were frequently designed on similar lines as an experimental set-up in a laboratory due to technical challenges: in the beginning, standardized settings with few works of art, static viewers, a limited number of participants or insufficiently precise viewing data were characteristic in museum studies with stationary as well as mobile eye tracking devices. Heidenreich and Turano (2011), for example, were only able to record four participants looking at abstract and figurative paintings at the Baltimore Museum of Art with mobile eye tracking (henceforth MET). Quiroga, Dudley and Binnie (2011) conducted a MET study at Tate Britain with just six participants who viewed only one painting, *Ophelia* by John Everett Millais. Bachta et al. (2012) instructed twenty-two employees at the Indianapolis Museum of Art to sit in front of a stationary eye tracker to map eye movements to an Edward Hopper painting, unfortunately with insufficient data quality.

In more recent MET studies, both the technical set-up and the thematic range of applications in the exhibition context have been further refined and expanded. Various art genres were examined (Pelowski et al. 2018, Reitstätter et al. 2020, Stein, Jossberger and Gruber 2022), as were the influence of the display (Rainoldi, Yu and Neuhofer 2020, Reitstätter et al. 2020), orientation and colour perception (Fontoura and Menu 2021, Linden and Wagemans 2021), engagement with interactive and digital media (Al-Baddai et al. 2017, Eghbal-Azar 2016, Eghbal-Azar et al. 2016, Mokatren, Kuflik and Shimshoni 2018), the use of exhibition texts (Garbutt et al. 2020, Reitstätter, Galter and Bakondi 2022) as well as differences between spectators based on age (Mesmoudi, Hommet and Peschanski 2020, Walker et al. 2017), expertise (Stein, Jossberger and Gruber 2022) and disabilities (Tymkiw and Foulsham 2020). While to date, traditional art exhibitions and various art genres have been the focus of eye tracking studies, in recent years, (natural) history, ethnographic, science and technology museums have also increasingly gained attention (Greenslit, Price and Malone 2021, Krogh-Jespersen et al. 2020, Parra Morantes et al. 2016, Raffi 2017, Sherman, Cupo and Mithlo 2020).

A methodological comparison of the most recent MET studies shows that technological advances and the resulting simplified application procedures now make it possible to ask more specific research questions (from aesthetic experience to usability) in more natural exhibition settings (without prescribed paths or viewing times) and to examine far bigger samples (with up to several hundred participants). Owing to the still high equipment costs and the relatively large amount of time re-

quired for data collection and, in particular, data analysis, MET studies have so far been conducted almost exclusively in university-based basic research and have made few inroads into practice-oriented exhibition or evaluation research.

Aim of the method

When using MET in exhibition research, the primary aim of the method is to record the behaviour of visitors at the level of their eye movements. Where do they look, when, for how long, in what sequence and in what rhythm? The eye is in constant motion, and gazes result from the alternation of fixations and saccades. Fixations, which have a duration of around 100 to 500 milliseconds, describe the gaze that lingers on a point where we see something (Groner and Groner 1989). Saccades are leaps between fixations in which the eye is blind. They usually last twenty to forty milliseconds (Ditchburn 1973). The temporal and spatial sequence of fixations and saccades form eye movement paths, so-called scan paths (Kübler, Kasneci and Rosenstiel 2014). Due to their complexity, eye movements can only be assumed from body and head posture in free observation, but not assessed with any accuracy. While the general aim of using MET is to obtain detailed eye movement data, the specific aim in exhibition analysis is geared towards a specific research interest, as illustrated in the following step-by-step guideline and in the case study of the *True to Life* study.

Step-by-step guideline

The following guideline is arranged based on the typical phases of an empirical investigation, from defining the research questions to data analysis, which in practice also overlap or can be applied repeatedly:

1. Defining the research questions

Research questions that can be answered with MET examine the viewing behaviour in exhibitions in relation to different visitors, spatial constellations, exhibits, presentation formats, media resources etc. In terms of their objective, these questions can be both basic research-oriented (for instance, examining general viewing patterns in exhibitions) and practice-oriented (for example, evaluating particular exhibition displays).

2. Choosing methods

If you are interested in viewing behaviour in exhibitions, it is possible to use MET exclusively. If you are also interested in exhibition contexts (institution, space, presentation etc.), visitors' background (socio-demographics, motivation for visiting, opinions etc.) or the social and sensory exhibition experience (visiting conditions, interaction, multimodality etc.), a combination of methods is recommended (Eghbal-Azar and Widlok 2013, Mayr, Knipfer and Wessel 2009). More specifically: Say you want to examine the connection between institutional framings and viewing patterns, you can, for instance, choose a method combination with *Context Analysis*. If you want to uncover individual processes of meaning-making, a combination with *Social Meaning Mapping* would be an option. For recording physical practices and social interactions, a combination with *Video-Based Ethnomethodological Conversation Analysis* is well-suited (Reitstätter, Pesen and vom Lehn 2025).

3. Data collection

When preparing for data collection, it is necessary to determine the hardware and software, depending on available equipment and financial resources. At present, there are several providers of MET equipment that differ considerably in pricing, accuracy and usability (Holmqvist et al. 2023, MacInnes et al. 2018, Onkhar, Dodou and de Winter 2023). MET glasses usually function according to the same principle: a scene camera films the environment in the viewing direction, while the eye movements are recorded by infrared sensors that track the pupils. Once the participants have been recruited, informed about the study including filling out a consent form,[1] and the equipment has been customized, the glasses are calibrated while the participant is wearing them (Fig 1). This involves the participants fixating one or more points, so that the software can align the position of the pupil with the point targeted. Participants can visit the exhibition according to their own preferences, while their eye movements are registered using the provided recording device and corresponding software (Fig. 2). When the MET equipment is returned afterwards, it is advisable, in the interest of a comprehensive documentation, to enquire about usability experiences and to document the accuracy of the collected data, technical

1 If necessary, the MET glasses must also be adjusted to the user's vision in this step. Most manufacturers offer a small selection of corrective lenses that can be inserted into the MET glasses. However, most of them are limited to a maximum diopter of +5/-5, which means that visitors with a more severe visual impairment are automatically excluded. Furthermore, there are practical difficulties for visitors who have strabism or drooping eyelids that partially cover the pupils.

anomalies, or also contextual information from the conversations with the participants.

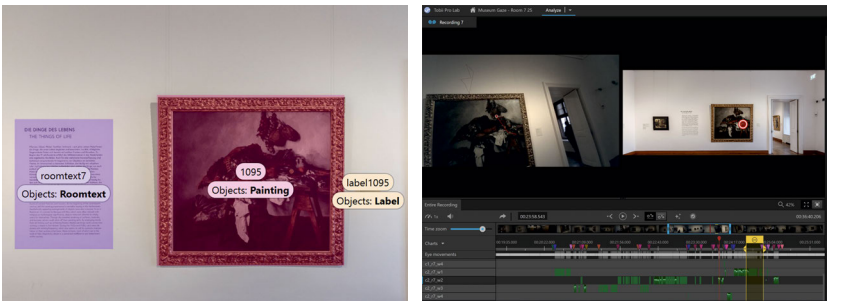
Fig. 1–2: Calibration of the MET glasses and participants on their self-guided tour of the exhibition, © Photos: Karl Pani, Department of Art History, University of Vienna.

4. Preparing the data

After recording the data, it is necessary to prepare the data in order to analyze them. In a first step, the collected MET data can be exported as a standard video format. These videos show the shots of the scene camera and a visualization of the viewpoint (Fig. 3). Such a video can already suffice for qualitative analyses. In a second step, however, it is necessary to identify the objects in the exhibition space in the raw video data. This is a highly labour-intensive step. While AI-supported image recognition procedures can already be applied, they still require extensive manual corrections as well as powerful computers in the current state of art. After the annotation, individual objects such as artworks or labels that are part of the research interest can be further processed, for instance, by dividing them into smaller areas of interest (AoI), such as particular figures or sections of text (Fig. 6–7). In case of method combinations, it is necessary to prepare further data in order to enable complementary data analyses.

Fig. 3–5: From the visualization of a person's point of view to cumulative heat maps and scan paths of a participant's sample, © Screenshots: Tobii Pro Lab, Seda Pesen.

Fig. 6–7: Selection of AoIs (Areas of Interest), automated annotation of fixations from the video to the respective snapshots, © Photos: Screenshots: Tobii Pro Lab, Seda Pesen.



5. Analyzing the data

The transitions from data preparation to data analysis are fluid and partly take place in alternation, for instance when initial findings during data preparation trigger more in-depth data analysis. Using analysis software (from the hardware provider or as an external programme), it is possible to calculate and visualize, among other things, heat maps of fixations (Fuhl et al. 2018, Kübler et al. 2015, Fig. 4) or scan paths of individual or cumulated viewers (Kübler et al. 2017, Fig. 5), as well as produce statistical data such as, for instance, the duration of fixations or the length of saccades. These enable numerous conclusions to be drawn about the distribution of visual attention, viewing sequences of exhibits and other elements such as texts or also the focus and paths of gazes within an individual object (Rosenberg and Groner 2022). From a humanities perspective, it is also desirable to aim for qualitative-interpretative analyses of the video data, for instance, in order to analytically document phenomena such as habitual viewing or joint meaning-making in the exploration of gaze patterns (and of further data) when conducting in-depth individual case studies.

Considering all five phases of an MET study presented here, it becomes clear that the greatest time and personnel investment is required for data preparation. Data collection lasting a few days is generally followed by data preparation lasting several months, while data analysis can be either relatively brief or very detailed, depending on the research interest. In addition to assigning at least one, but preferably several field researchers to collect the data, one should ideally allow for a larger team and a longer turnaround time for data preparation. Data analysis, too, should be conducted in a team, in order to make use of different technical and content-related expertise as well as perspectives when engaging with the material.

Case study

The transdisciplinary research project *The Museum Gaze* (2022–2026) conducts basic research on seeing in the museum, combining the expertise of the University of Vienna (Laboratory for Cognitive Research in Art History), the Technical University of Munich (Human-Centered Technologies for Learning) and the Austrian Gallery Belvedere (with the four collection departments of Medieval, Baroque, 19th and 20th Century and Contemporary Art). The first study *True to Life* (2022), which here serves as a case study, took place in the eponymous collection exhibition which highlighted the style of realism with works from the middle of the 19th to the middle of the 20th century. The study focused on research questions regarding the influence of hanging practices and the relational gaze between works and exhibition texts (labels). While the first part of the study (condition 1) examined the exhibition in its original setting, the following interventions were carried out before the second part of the study (condition 2): works of condition 1 were exchanged with works by popular artists (Gustav Klimt, Vincent van Gogh), replaced with contemporary art (Lisl Ponger), rehung within the room, or completely removed from the exhibition. Labels were expanded by increasing the number of words, rewritten following different narratives or supplemented for all the works in the room.

To assess viewing behaviour and visitor experience, we employed a method combination of MET, *Video-Based Ethnomethodological Conversation Analysis* (in collaboration with researchers from King's College London), *Questionnaires* and interviews. This combination of methods allowed us to contextualize the focal points of attention visible in the MET, video recordings of the interaction in the room, interview responses and background information from the questionnaire. Data collection took place in both conditions for one week each in October 2022 and entailed the following procedure: after inviting regular museum visitors to participate in the study and letting them fill out a consent form, the participants were fitted with MET glasses, given a small shoulder bag for carrying the recording device, and had their glasses calibrated. The participants were free to tour the exhibition

according to their own preferences. Afterwards, the MET recording was terminated, the equipment returned, and the participants were given a questionnaire on a tablet. The final step was to conduct a stimulus-based interview to reconstruct the exhibition experience and record it on video.

Initial findings from data evaluation (N=212, c1 n=108, c2 n=104) show that the usability of the MET equipment as well as the validity of the MET data can be considered relatively high. 85,4% of the participants stated that the glasses did not obstruct their vision, 79,7% stated that they did not find the glasses uncomfortable. Nevertheless, 50,5% stated that at no time had they not forgotten about the glasses, 43,4% that they had forgotten about them after one to ten minutes, and 6,1% that they had forgotten about them immediately, indicating that the participants' awareness that they were taking part in a study has to be taken into account, as in every non-covert survey situation. The evaluation of the exhibition's hanging practices revealed that the participants – following the conventional display of paintings hung mainly in a single row – exhibited a linear viewing behaviour and oriented themselves from one centre of a painting to the next. However, it was possible to interrupt this linear viewing behaviour by curatorial interventions: exchanging the landscape painting *Herbstsonne am Attersee* (Autumn Sun at the Attersee) (1917) by Olga Micheli with Lisl Ponger's photograph *Out of Austria 2000* (2000), which criticizes colonialism, prompted participants to stop abruptly and dwell in front of the work for a longer period of time, stimulated interaction between couples, and generated a strong response in the interviews. The evaluation of the use of labels revealed that with more text available in the room, both reading times and art viewing times increased on average. While participants with a high affinity for reading also perceived longer object descriptions in full length, there was a continuous decline in readers across all participants. Around half of the participants read labels with hundred words and only a quarter read labels with 200 words to the end.

Method reflection

In summary, MET is a novel and currently still complex method of exhibition analysis. However, the following potentials argue in favour of its utilization: by examining the exhibition from the perspective of the person experiencing it, understood as a spatiotemporal event, the application of MET literally achieves a methodological integration of the visitor's view. The exhibition is accessed through the gaze, individually and processually and thus materializes itself as an ephemeral medium through the activity of viewing. Another strength of MET is its use as a mobile method (Büscher and Urry 2009), since viewing in exhibitions often does not take place while standing, but in motion, and objects are viewed via repeated gazes from different vantage points (Carbon 2017, Reitstätter 2015: 129–139, Reitstätter, Galter

and Bakondi 2022). In this visually complex appropriation behaviour of exhibition visitors, MET provides comprehensive, accurate and valid data, with MET data already being able to be recorded with an accuracy of 0.1° (Schneider et al. 2009). Sufficient data validity is also supported by the fact that the MET equipment tends to impair the exhibition experience only minimally (Mayr, Knipfer and Wessel 2009, Santini, Fuhl and Kasneci 2018). In addition, recordings of over one hour are meanwhile possible, enabling the analysis of an entire exhibition visit, including potential changes of gaze patterns over time.

At the same time, the recording of viewing behaviour with MET is subject to limitations: too expensive, technically complex and thus poorly accessible – would be a brief summary of the major current constraints. Thus, in the further development of MET, the affordability of hardware and software must be ensured, and data preparation, particularly in automatic image recognition, needs to be optimized to simplify the method's use. MET provides an accurate measurement of viewing behaviour via physiological parameters such as fixation and saccades. However, whether and to what extent these parameters shed light on the production of insights and meaning in the viewers is not an objective conclusion but depends on the interpretation of researchers (Doering and Pekarik 2010, Garbutt et al. 2020, Mayr, Knipfer and Wessel 2009). To avoid being accused of taking a behaviourist approach, it is essential to undertake a theoretically sensitive data interpretation that considers the complexity of cultural artefacts and practices. Combining methods also helps to counteract the limitation of MET as a means of collecting eye movement data in isolation from the viewing body and without insights into introspective processes of meaning-making. MET generates products of viewing (in long export tables and visualizations such as heat maps or scan paths) that need to be integrated into the process of *embodied seeing* and also further decoded in the context of meaning-making, also in the interaction with other persons on site.

Besides further technological development, the combinations of methods and the theoretical sensibility are crucial to preclude simplified conclusions by means of a reflected interpretation of eye movement data with contextual embedding. In particular, the multimodal, sensory significance of MET can be considerably expanded when linked with additional methods, allowing the gaze to be also located in space, on the body and in social interaction. A theoretically sensitive approach with reference to current critical discourses on discrimination and decolonization, in turn, can open MET to the critical social sciences and situate ways of seeing in exhibitions in their respective cultural contexts. We see the potential in using MET as a method of exhibition analysis – beyond the current focus on art museums and individual aesthetic experience – in taking a closer look at other exhibition venues, cultural artefacts as well as sensory and social modes of perception.

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