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The Role of Eye Tracking in UX Research: A Meta-Analytical Review of Usability Studies

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Abstract

Human-Computer Interaction (HCI) has grown in importance as digital systems have become integral to daily life, increasing the need for interfaces that support a positive user experience (UX). Eye tracking has therefore become an important methodological approach in UX research, as visual information processing plays a central role in users' interactions with software. It provides detailed insight into attention patterns and user strategies during task completion, thereby enabling a more precise evaluation of how interface elements support or hinder efficient interaction. The theoretical section of this article presents the evolution and major milestones of eye-tracking technology, with a focus on its applications and evaluation possibilities within HCI (including heatmaps, scan path visualisations, and related quantitative indicators). The empirical section offers a meta-analysis of previous case studies to demonstrate the applicability of desktop-based eye tracking in assessing both general-purpose and UX-specific software. This article provides practical guidance for those intending to use desktop eye tracking, outlining the technology's advantages and limitations to support future researchers and UX professionals.

Keywords

eye tracking, UX research, usability studies, meta-analysis

1 Introduction

Human-Computer Interaction (HCI) gained significance in the 1980s due to the growing prominence of personal computers, which made technology more accessible to individuals without technical expertise. As computing transitioned from scientific and military applications to homes and workplaces, a growing need emerged to develop user-friendly interfaces. This meant that the HCI discipline gained greater importance with the emergence of graphical user interfaces, which replaced complex command-line interactions with more intuitive visual systems (MacKenzie, 2024). Today, as digital products increasingly permeate everyday life, HCI remains a key area in contemporary discourse due to the rapid evolution of technology, which has given rise to novel interaction paradigms, including touchscreens, voice interfaces, virtual and augmented reality, and systems driven by artificial intelligence. Given the growing demands of society on software products, it is crucial to prioritise user experience (UX) in information technology (IT) projects as a central aspect of HCI (Pushpakumar et al., 2023).

UX encompasses the emotions and perceptions that users encounter while interacting with software (Tang and Herrli, 2025). This indicates that user UX is significantly shaped by individual human perception, which is inherently subjective. Based on on the widely accepted definition of UX, also adopted by Tang and Herrli (2025) in their chapter published a recent HCI handbook, it can be maintained that all software entails some form of UX – whether positive or negative. However, software development practitioners can only increase the likelihood of achieving a satisfactory user experience. To this end, UX experts employ a broad range of research methodologies, which help them ensure that the software products they design provide sufficient ergonomic quality and UX for users (Szabó and Hercegfi, 2023).

In today's highly competitive IT market, a high level of UX is crucial for securing market share, improving employee motivation and performance, and significantly influencing end-user wellbeing (Inan Nur et al., 2021). The evolution of HCI has provided a diverse array of

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UX research methodologies to organisations. These approaches enable organisations to develop software that achieves ergonomic quality and delivers an optimal UX for their users (Sikorski, 2021).

One possible method for gaining a detailed understanding of user behaviour in UX research is eye tracking, which can be applied as a supporting tool in usability studies. Since individuals process environmental information through multiple sensory channels, with vision being the predominant one, examining visual attention enhances our understanding of how people perceive information in different contexts (e.g., during software usage).

Expanding on this methodological possibility, this article examines the use of desktop-based eye tracking through a meta-analysis of usability studies, investigating both the advantages and limitations of the technology in UX research.

2 Theoretical background

2.1 Technological developments in eye tracking

In the early stages, the study of eye movements relied on direct observation to obtain a precise understanding of the reading process. In 1879, Louis Émile Javal employed mirrors to empirically demonstrate that ocular movement during reading is not continuous; rather, it consists of discrete jumps (saccades) interleaved with pauses (fixations) at multiple points along each line of text (Gheorghe et al., 2023).

During the initial basic eye-tracking research, participants read with one eye. Javal estimated eye movements by attaching a microphone to the eyelid of the closed eye, as the end of each saccade was clearly marked by the moment when the convex part of the cornea struck the microphone. Moreover, the participants' eyes were illuminated with a strong light source, and they reported the position of the resulting afterimage to indicate the approximate location of their fixations (Kasprowski, 2024).

Because this observation-based method was relatively inaccurate, researchers in subsequent years aimed to improve measurement accuracy using various invasive techniques. Delaberre, for instance, replaced the observational approach by anaesthetising the eye with cocaine, attaching a small handle to it, and capturing the resulting eye movements with a kymograph (Macele and Mueggenburg, 2024).

The first technique that was not only non-invasive but also contactless – meaning that the measuring device did not touch either the eye or the eyelid – was introduced in 1901. Developed by Dodge and Cline (1901), this method relied on the photographic recording of light reflected from the cornea, providing a basis for subsequent innovations in eye-movement measurement (Hessels et al., 2024).

Because participants were required to keep their heads completely motionless during measurement, the technology was initially unsuitable for studying everyday activities. Consequently, for many years, researchers focused on investigating static activities, such as reading aloud, viewing images, or reading musical notation (Fletcher et al., 2022).

A significant breakthrough in the history of eye tracking, enabling limited head movement, occurred when Mackworth and Thomas (1962) developed a system that simultaneously recorded both the participant's field of view and the corneal reflection (Li et al., 2021). Despite this innovation, the device remained heavy, imprecise, and constrained by a narrow field of view. Consequently, during the 1960s, eye-tracking measurements experienced renewed interest in invasive methods, after researchers recognised that Delabarre's approach could be advanced by attaching various structures to the eye using suction. Yarbus (1965) employed a small valve to drain fluid from beneath the contact lens, while Fender (1964) demonstrated the usefulness of sodium bicarbonate, which diffuses through ocular tissue and generates osmotic suction (Lawand, 2024).

In these techniques, reflections were recorded with tiny mirrors mounted on the lens. Later, the mirrors were suspended in front of the eye to prevent tear droplets, induced by ocular irritation from the mirrors, from blurring the recordings. In this configuration, different types of light sources (small lamps or luminous radioactive tritium) were suspended from the mirror-supporting rods to generate corneal reflections.

By 1969, a non-optical technique for recording eye movements was introduced using a magnetic coil embedded in a contact lens. In this method, pairs of field coils were affixed to the head to induce current in the small coil placed on the eye, thereby providing information about eye position. A significant limitation was that this specialised contact lens could only be applied after local anesthesia (*via* eye drops) and could be tolerated for only 30–60 min, which restricted its use primarily to animal studies (Martinez-Marquez et al., 2021).

In the 1970s, new avenues of measurement emerged, involving the recording of eye movements using video cameras and the electronic extraction of relevant features. Because these methods required high contrast, they depended on detecting the corneoscleral boundary between the iris and the sclera. When the system's photosensitive sensors were positioned near this boundary, the output signal changed in relation to the illumination of the sclera (Nitschke and Nakazawa, 2018). With this technique, horizontal eye movements could be determined immediately. In contrast, vertical movements were more challenging to detect, as the eyelid frequently obscured the large scleral area during blinks.

This alternative measurement approach no longer depended on reflections from the pupil, creating difficulties for individuals with dark eye colours due to the low contrast between the iris and the pupil. When the pupil is directly illuminated – using a light source aligned with it – the light reflected from the back of the retina becomes sharply visible and therefore more easily detected by video cameras (Richardson and Spivey, 2008).

Although these methods were well-suited for determining eye movements relative to the head, accurate estimation of gaze direction in the visual scene still required the head to remain nearly motionless. A few years later, an innovative approach was introduced that overcame this measurement constraint, allowing simultaneous monitoring of two optical characteristics of the moving eye. Using the Pupil Center Corneal Reflection (PCCR) method developed by Merchant et al. (1974), it became possible to determine both the pupil contour and the brightest point on the cornea. Since the position of this point remains fixed relative to the pupil center during head rotations – while moving in concert with the eye – the direction of gaze can be estimated accurately even in the presence of small head movements (Sigut and Sidha, 2011).

An alternative method, also based on the light reflection from the eye's optical surfaces, involved the analysis of Purkinje images. Upon illumination, four distinct reflections can be observed: from the anterior corneal surface (P1), the posterior corneal surface (P2), the anterior surface of the crystalline lens (P3), and its posterior surface (P4). Of these, the relative displacement between the P1 and P4 reflections could be measured using a mirror system controlled by servomotors. Depending on the computational resources available for image processing, this system was capable of sampling at rates between 300 and 1000 Hz, although the head still needed to remain stationary during measurement (Wu et al., 2023).

While current eye-tracking techniques are predominantly based on video-oculography (VOG), electro-oculography (EOG) also permits precise determination of eye position (Estrany and Fuster-Parra, 2022). EOG measurements exploit the detection of electrical potentials arising from physiological processes within the body. The retina's high neuronal density results in the eye being polarised; consequently, shifts in eye position induce measurable potential differences in the surrounding structures, enabling inference of gaze direction (Estrany and Fuster-Parra, 2022). Due to its relatively intrusive nature, however, EOG is employed primarily in clinical and medical contexts – for example, to record rapid eye movements (REM) during sleep. It is therefore unsurprising that VOG-based methods have emerged as the predominant approach for the measurement of eye movements across most research domains (García and Cano, 2022).

VOG techniques can be categorised according to several criteria, including the type of illumination employed during measurement. Systems may utilise light within the visible spectrum or rely on infrared illumination. Since video-based processing captures the visual features of the eye – primarily the iris and/or pupil contours – and subsequently infers gaze direction from their movement, measurement accuracy is highly dependent on lighting conditions. Under suboptimal illumination, determining the orientation of the eyeball becomes more challenging and less precise. Whereas natural light represents a passive approach, exploiting ambient reflections from the eye, infrared illumination actively illuminates the entire visible portion of the eye. Because near-infrared light does not interfere with the user's vision – typically remaining invisible – most modern eye-tracking devices employ infrared light sources (García and Cano, 2022).

Overall, infrared illumination serves as the technological basis of eye tracking, and its widespread adoption has been facilitated by advances in computing, particularly in video camera technology. From the 1980s onwards, commercially available video cameras became progressively more compact and lightweight, allowing for natural head movements during eye-tracking studies. This development enabled detailed investigations of everyday activities. Consequently, supported by ongoing technological innovation, eye tracking now supports a broad spectrum of applications, encompassing both basic research and applied development across numerous scientific domains (Szabó, 2020).

In basic research, eye tracking supports the understanding of visual and cognitive processes, as well as the mechanisms underlying reading, writing, learning, and communication. It also plays a key role in studies of aviation, driving, and virtual reality. In assistive technology, eye tracking primarily serves to facilitate and enable user interaction in situations where conventional input devices (keyboard, mouse, touchscreen) are difficult or impossible to use. In marketing research, it provides detailed insights into consumer behaviour, attention, and decision-making, particularly when assessing the effectiveness of packaging, advertising, and online content. Moreover, it contributes valuable information to general product development by supporting the in-depth evaluation of diverse prototypes and enabling the human-centered refinement of market-ready products through a more comprehensive understanding of user behaviour (Chinyere Onyemauche et al., 2021) (Table 1).

2.2 Data obtainable from eye tracking studies

In UX research within HCI, eye-tracking–based usability testing enables the analysis of users' gaze patterns, the duration of their attention on specific interface elements, and potential disruptions in visual focus (Novák et al., 2024). As a complementary method, eye tracking enhances the execution of usability studies by providing objective and quantifiable evidence of of user behaviour (Table 1). The resulting eye-tracking data inform design improvements, contributing to more intuitive and user-centred interface solutions (Li et al., 2021).

Several types of eye movements can be distinguished, with fixations and saccades being the most observed. Fixations typically last between 200 and 600 ms and represent periods during which actual information intake and cognitive processing of visual stimuli occur (Conklin et al., 2018). Saccades are rapid, ballistic eye movements that link consecutive fixations, allowing the gaze to move from the peripheral visual field to the fovea. During saccadic movements, the visual system does not acquire new information; this process, called saccadic suppression, is an active neural mechanism through which the brain performs complex computations based on information gathered during fixations to assemble a coherent visual representation (Blake and Sekuler, 2006).

Table 1 Different domains and research opportunities regarding eye tracking

Domain	Research opportunities
Basic research	Understanding the fundamental cognitive mechanisms of vision and the brain (Pajkossy et al., 2017); understanding writing and reading (Katona, 2021; Weiss et al., 2016); exploring and supporting learning processes (Szabó et al., 2022a; Ujbanyi et al., 2019); examining communication and information-processing behaviour (Józsa and Hámornik, 2012; Kovari et al., 2020); studying aviation (Allsop and Gray, 2014) and driving (Doshi and Trivedi, 2009); virtual reality research (Köles et al., 2014).
General product development	Usability and prototype testing (Babicsné-Horváth et al., 2018); creating improved product versions (Trautmann et al., 2022).
Assistive technology	Developing assistive technologies that support interaction beyond conventional input devices (Biswas and Langdon, 2011; Pulay, 2015).
Marketing research	Examining the quality of packaging (Hámornik et al., 2013) and advertisements (Korpás and Szabó, 2019); understanding consumer behaviour in online environments (Gombos et al., 2026; Korpás and Szabó, 2019; Szabó et al., 2022b); conducting in-store research (Huddleston et al., 2015; Koren et al., 2019); analysing advertising videos (Szabó and Szederkényi, 2020); performing neuromarketing research (Cuesta et al., 2020; Horváth, 2021).
Human-Computer Interaction	Supporting usability testing evaluations (Babicsné-Horváth and Hercegfi, 2023; Lenzner et al., 2014; Megyeri and Szabó, 2024).

An eye tracker is a device that uses near-infrared illumination and optical sensors to collect highly accurate data on gaze direction and eye movements. Most eye-tracking devices rely on the corneal reflection technique (Stuart, 2022). Microprojectors emit infrared light to create reflections on the eyes, which are registered in real time by optical sensors. Image-processing algorithms then determine the characteristics of the user, the eyes, and the reflections. The precise position of the eyes and the direction of the gaze are subsequently calculated using mathematical mode (Tobii, 2024) (Fig. 1).

In various HCI studies, eye-tracking devices allow for the precise recording of gaze direction, enabling the identification of fixation locations and their durations. If required, the magnitude and velocity of saccades between fixations can also be measured. These metrics provide insights into task difficulty; for example, more demanding tasks generally elicit faster saccades.

Data extracted from eye-tracking systems can be classified into movement, position, latency, distance, and numerosity categories (Holmqvist et al., 2011).

Movement indicators describe the key characteristics of eye movements, including direction, amplitude, duration (temporal length), speed, and acceleration. These indicators allow for determining the direction and extent of eye movements, their duration, as well as the speed and acceleration involved (Holmqvist et al., 2011).

Position indicators relate to gaze direction and primarily refer to cases where participants focus on a specific location, along with the properties of such occurrences.

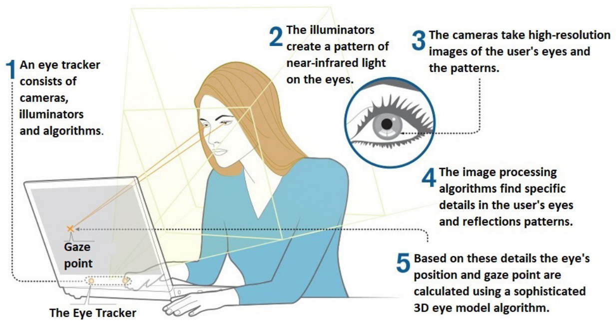

Fig. 1 Operation of the eye-tracking system (Source: Szabó (2020); Tobii (2024))

Positional data include measures of exact location, dispersion, similarity, duration of fixations, and the pupil diameter during fixation (Józsa, 2010).

Latency and distance indicators can also provide valuable information about eye movements. Latency measures, for example, can determine the time elapsed after the presentation of a stimulus until an eye movement occurs or until the pupil begins to change in size. Distance indicators provide values such as the disparity between the fixation points of the left and right eyes or the distance from the mouse cursor (Holmqvist et al., 2011).

Recording and analysing the indicators in the categories described above requires precise measurement and thorough evaluation. Due to the need for such accuracy, these studies are typically conducted under controlled laboratory conditions.

In UX eye-tracking research, the simplest and most used method for quantifying the momentary data collected during measurements is to count the frequency of indicators relevant to the experiment. In practice, these readily quantifiable eye-tracking measures typically include the number, proportion, and frequency of fixations in predefined areas of interest (AOIs).

Because eye-tracking software allows for the manual or automatic (cluster-based) definition of AOIs, the numerosity of eye-tracking indicators deemed relevant for the study can be readily retrieved for specific target areas. User-defined, manually selected AOIs enable researchers to examine regions considered particularly important, allowing precise determination of fixation locations, durations, and the number of returns within these areas. Consequently, the most frequently employed AOI indicators are the number of fixations and visit counts, as these reflect the subjective importance of predefined regions within the software (Hámornik et al., 2013).

Eye-tracking data are not only available in numerical form but can also be visualised (Duchowski, 2007). The most common form of visualisation is the heatmap, in which aggregated user gaze data are overlaid on the stimulus material: the most viewed points – where total fixation durations are longest – appear in warmer (red) colours, whereas less viewed areas appear in cooler (green) tones. Another widely used visualisation is the scan path (also known as the gaze plot). In this representation, saccades are depicted as thin lines, while fixations are represented by numbered circles of varying sizes, with larger circles indicating longer fixations. This visualisation clearly shows the order in which participants' gaze traversed the stimulus, and different colours typically represent different users (Szabó et al., 2022a).

3 Aim of the research and methodology

This article aims to present the applications and potential of eye-tracking technology, to identify its advantages and limitations, to position the methodology within the context of UX research, and to define its boundaries of use. The topic is examined through a meta-analysis of six previous eye-tracking case studies.

3.1 Meta-analysis

A meta-analysis is a research method that compares the results of multiple scientific studies. Meta-analysis is suitable for systematically comparing the results of different case studies, identifying relationships or discrepancies between them, and uncovering other relevant connections within the context of processing and interpreting multiple studies (Rothman et al., 2008). The primary advantage of meta-analysis is that it enables more comprehensive conclusions by aggregating information, surpassing the scope of individual case studies (Lipsey and Wilson, 2001). Meta-analysis can be conducted when several case studies address the same question – in this case, the use of eye-tracking technology.

The meta-analysis summarises the insights of six case studies in which eye-tracking technology was applied during usability evaluations of various software products (Megyeri and Szabó, 2024; Szabó, 2020; Szabó et al., 2021; Szabó et al., 2022a). If, in certain cases, this resource-intensive and complex methodology proves worthwhile to apply even in corporate practice, it demonstrates that eye tracking, as a tool supporting usability testing, is a valuable component of the UX methodological repertoire and can effectively contribute to the accurate identification of development priorities within HCI.

3.2 Overview of the case studies included in the meta-analysis

Half of the analysed products were custom-developed online stores, while the other half consisted of desktop and mobile native applications, including a graphic or layout editing program and a mobile banking application. Some studies aimed to identify general usability issues, whereas others focused on predefined, specific research objectives (Table 2).

All case studies were conducted under controlled laboratory conditions using a Tobii T120 desktop eye-tracking system for data collection and Tobii Studio (2017)

Table 2 Basic information on the case studies included in the meta-analysis

ID	Software category	Type of the case study	Aim of the case study
1	Online store	General	Identifying usability issues
2	Online store	General	
3	Layout editing software	General	
4	Graphic program	Specific	Comparing onboarding solutions
5	Banking mobile applications	Specific	Comparing the usability of mobile applications
6	Online store	Specific	Comprehensive measurement of psychological pressure

software for data recording and analysis. The examined software products were fully functional in each case, with the exception of one study (ID6), in which the accommodation-booking website was replicated in a Figma environment with limited interactivity. In this particular study, an electrocardiogram (ECG) was also employed to obtain a more comprehensive assessment of mental effort.

A common characteristic of the case studies is that each involved between 5 and 18 participants. Studies that focused on a single software product (ID1, ID2, ID3) included 5–6 participants, whereas those comparing multiple product variants involved 10–18 participants (ID4, ID5, ID6). This sampling strategy ensured that each product variant was evaluated by an equivalent number of participants (Table 3).

Although a larger number of participants would be required to statistically identify both severe and minor usability issues with high confidence, it is generally accepted in HCI that five participants are sufficient to qualitatively uncover basic usability problems (Alroobaea and Mayhew, 2014; Nielsen, 2000). Empirical studies by Faulkner (2003) indicate that with five participants, a minimum of 55% and an average of 85.55% of usability issues can be detected. Nielsen and Landauer (1993) note that this value is influenced by multiple factors. Naturally, fewer issues are likely to be identified when users encounter a product after multiple testing and redesign iterations. Additional factors highlighted in the literature include the evaluation methodology, the nature of tasks in the test protocol, the evaluator's expertise, and participants' personalities (Vassar, 2012). Alroobaea and Mayhew (2014) concluded that five potential users can reveal the main aesthetic ("cosmetic") problems of a user interface, as well as structural and content issues. The related study recommends involving 16 ± 4 participants for comprehensive empirical testing; however, this approach is often time-consuming and costly in industrial practice.

Table 3 Methodological details of the case studies included in the meta-analysis

ID	Number of participants	Think-aloud technique	Applied physiological channel	Additional methods applied
1	6	CTA	Eye tracking	Web analytics, post-task interview
2	6	RTA		Web analytics, post-task interview
3	5	CTA		Post-task interview
4	18	CTA		Post-task interview, SUS
5	10	CTA		Post-task interview, SUS, NPS
6	12	RP	Eye tracking ECG	Pre-task interview, post-task interview

In four studies, participants employed the Concurrent Think-Aloud (CTA) technique, verbalising their thoughts while performing tasks (Cooke, 2010). In two studies (ID2, ID6), a Retrospective Think-Aloud (RTA) protocol was implemented, in which participants reviewed video recordings of task performance as visual cues and retrospectively evaluated their actions (Table 3).

In both techniques, participants performed self-observation, analysing their experiences and emotions based on their thoughts and reasoning (Alshammari et al., 2015). In CTA, some users may behave unnaturally when required to verbalise their thoughts continuously, which can lead even holistic users to act and think more analytically. In contrast, RTA does not require such demands during software use, resulting in more natural behaviour. However, RTA nearly doubles the time required for testing, thereby increasing costs and participant burden. A variation of RTA, known as Retrospective Probing (RP), allows the moderator to select only the most relevant task segments for participants to review and comment on, significantly reducing the time needed for review (Szabó et al., 2022a). This RP technique was employed in one study (ID6) (Table 3).

Some studies began with web analytics (ID2) or preliminary questionnaires (ID6), and all concluded with post-task interviews. In two cases (ID4, ID5), quantitative questionnaires supplemented the interviews. One of the questionnaires was the System Usability Scale (SUS), and the other was a single-item measure of support level, known as the Net Promoter Score (NPS) (Table 3).

The SUS is one of the most widely used questionnaires in both academic research and industry for quantifying subjective usability. It was originally developed for comprehensive evaluation of complex systems but is also applicable to websites and software products. The questionnaire comprises 10 items, each rated on a five-point Likert scale, measuring users' attitudes toward the system's usability. The SUS includes an equal number of positively phrased and negatively phrased statements, producing a score ranging from 0 to 100 (Lewis, 2018).

The NPS is a single-item questionnaire commonly employed to assess customer satisfaction. Respondents answer the question, "How likely are you to recommend this company or organisation to friends or colleagues?" using a 0–10 Likert scale. Based on their responses, customers are classified as promoters (9–10), passives (7–8), or detractors (0–6). The resulting NPS score ranges from −100 to +100, reflecting the level of loyalty or support for a company or product (Fisher and Kordupleski, 2019).

4 Results

Section 4 presents the conclusions drawn from general-purpose and specific eye-tracking-based usability studies separately, as this structure enables a more precise interpretation of the findings.

4.1 Results of meta-analysis in the case of general-purpose usability studies

In the meta-analysis, the usability testing tasks in the ID1 and ID2 e-commerce case studies focused on the most common activities performed on the respective websites. Accordingly, the tasks addressed the visibility of the newsletter subscription option, the findability of the registration function, the modifiability of profile data (e.g., password changes), the structure of the menu system, and the adequacy of the final steps of the online shopping process. Similarly, in the ID3 case study, the tasks evaluated how potential users managed the core functions of the software.

In these general-purpose usability studies (ID1, ID2, ID3), eye tracking served as a supplementary technique alongside traditional, observation-based usability evaluation. Most of the issues identified in these studies could have been detected even without eye tracking – through direct observation, think-aloud protocols, and post-test interviews. However, the gaze-based visualisations revealed additional opportunities for improvement that would not have become apparent from task performance alone.

4.1.1 Examples from the results of the ID1 and ID2 eye tracking studies on online stores

In the case of Fakopáncs (2012) online shop, a latent issue was identified through the heatmap, indicating that users did not notice the warning message displayed in the upper-right corner regarding the change in the shipping cost (Fig. 2).

The visualisation clearly demonstrates that, while completing the associated task, users searched for products in the left-hand menu but failed to notice the warning message indicating that they had reached the free shipping limit. This message is located outside the main shopping area and is displayed in a colour consistent with the company's visual identity, allowing it to blend into the overall design. Although this issue could theoretically be identified through analytical inspection, it would not have been uncovered in the present study without eye tracking. During think-aloud task completion, participants did not mention this problem; instead, they made several observations regarding the illogical structure of the menu system. This finding is of particular importance from a business perspective, as it indicates a potential issue that could affect sales if users are unable to locate products *via* the menu.

In the general-purpose e-commerce case studies (ID1, ID2), the identified issues could have been observed without eye tracking. In the ID1 case, a further example is the insufficient visibility of the centrally displayed confirmation message during password modification. Several participants entered the new password three or four times as instructed, as clicking the "Save" button provided no clear feedback indicating whether the operation had been successful (Fig. 3).

Fig. 2 Heatmap illustrating users' failure to notice the warning message regarding the change in the shipping fee (Source: Fakopáncs (2012) website, edited in Tobii Studio (2017) (Szabó, 2020))

Fig. 3 Heatmap illustrating the insufficient visibility of the confirmation message indicating successful data modification (Source: Fakopáncs (2012) website, edited in Tobii Studio (2017) (Szabó, 2020))

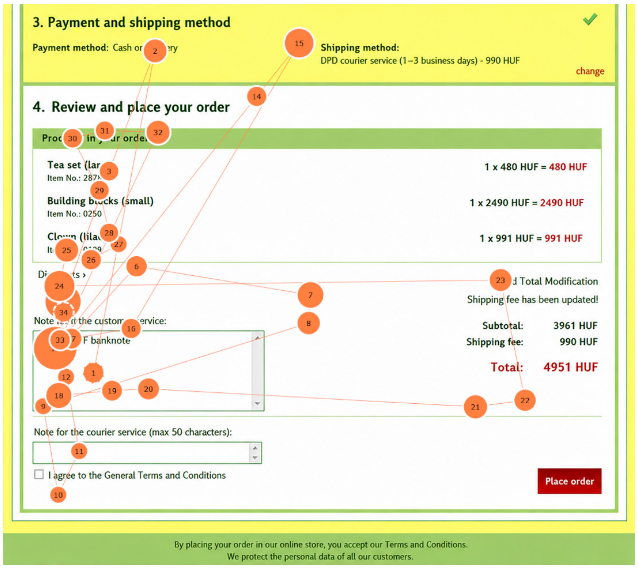

Fig. 4 Scan path visualisation related to the incorrectly executed task (Source: Fakopáncs (2012) website, edited in Tobii Studio (2017) (Szabó, 2020))

This behaviour can also be observed in a traditional usability test and typically results in longer task completion times. However, the heatmap provides visual confirmation of the issue, thereby highlighting the need for product improvements. Beyond heatmaps, scan path visualisations are also valuable in general-purpose studies, as they help explain the reasons why users performed specific tasks incorrectly. For instance, in the ID1 case study, during the finalisation of the checkout process, almost all participants failed the task requiring them to leave a message for the courier service. Instead, they wrote their note to customer service, as that text box was larger and more visually prominent. User behaviour is guided by design elements, but the scan path highlights the visual conditions of task execution, thereby substantiating the need for further refinement of the product (Fig. 4).

In the case of the ID2 website, locating the registration option and the newsletter subscription feature proved particularly challenging. During the registration task, several participants struggled even to find the online store itself, as it was placed under the "Online store" section of the homepage. Since most users expected to encounter the registration option directly on the homepage, they spent considerably more time there than necessary. After eventually locating the webshop, participants encountered further difficulty in noticing the registration link next to the "Login" button. Participants' mental models assumed that this element should be in the upper-right corner of the interface, so they initially searched there. Consequently, they only identified the "Not registered yet? You can do it here!" prompt – located on the left side of the page – at a later stage. The scan path visualisation generated during this task indicates that participants' mental models did not match the website's actual structure, noticeably affecting task completion (Weinschenk, 2011).

Newsletter subscription was available only to registered users through the "Personal Information" settings menu. Several participants were unable to complete this task successfully because the option was difficult to locate on the registration page. Even when participants located the subscription option, the system did not provide confirmation that the action had been executed. The scan path visualisation indicates that participants experienced difficulty in locating the subscription option. After clicking the "Save changes" button, participants' gaze scanned the entire interface in search of a confirmation message indicating successful completion of the action (Fig. 5).

In the case of ID1, the "Registration" option blended into the homepage design, resulting in very short fixation durations in the AOI analysis (Table 4).

Table 4 also shows that, in an extreme case, clicking on the registration option required up to 66 s. As this is an older case study, registration represented a particularly critical function because shopping as a guest user was not yet possible. The AOI analysis thus provides numerical evidence that the registration option should be visually highlighted – while remaining consistent with the site's design – to ensure that it effectively attracts users' attention.

In the ID2 case study, the AOI analysis similarly proved useful: the quantitative data confirmed that certain functions

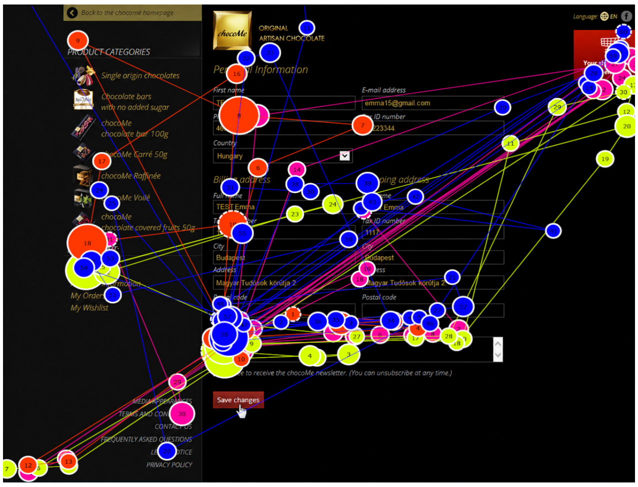

Fig. 5 Newsletter subscription option and gaze behaviour while searching for the confirmation message (Source: ChocoMe (2015) website, edited in Tobii Studio (2017) (Szabó, 2020))

were difficult to locate on the web interface. A Mann-Whitney U test statistically demonstrated that users fixated significantly more often on the "Points of Sale" label while completing the information-seeking task, even though the required information was located under a different submenu.

4.1.2 Examples from the results of the ID3 eye tracking study on the use of graphic software

In the general-purpose usability evaluation of the ID3 software products, eye-tracking visualisations proved useful in highlighting task execution difficulties resulting from the software's complex functionality.

For example, in the task where participants were required to create a document in a different format based on an existing one, most users completed the task relatively quickly by accessing the required function from the "Pages" menu in the toolbar (see the left side of Fig. 6). However, one participant experienced difficulty locating the function necessary to complete the task, requiring more than 1,000 fixations before identifying it (see the right side of Fig. 6). This behaviour clearly reflects increased mental effort at the cognitive level.

Thus, in the case of a non-intuitive software product, eye-tracking visualisations can effectively reveal cognitive difficulties arising from the product's complex functionality. The differences in fixation counts for the same tasks, as shown in the scan path diagrams, can support the identification of challenges encountered among different users during product interaction.

Table 4 AOI metrics for the registration button and time to click (participants P1–P6)

ID	Time to first fixation	First fixation duration	Total fixation duration	Number of fixations	Time to click
P1	14.39	0.27	1.92	2	15.23
P2	7.69	1.23	2.97	2	9.04
P3	0.91	0.07	0.39	3	6.52
P4	N/A	N/A	N/A	N/A	N/A
P5	8.02	0.04	4.95	12	24.31
P6	4.47	0.15	1.95	4	65.51

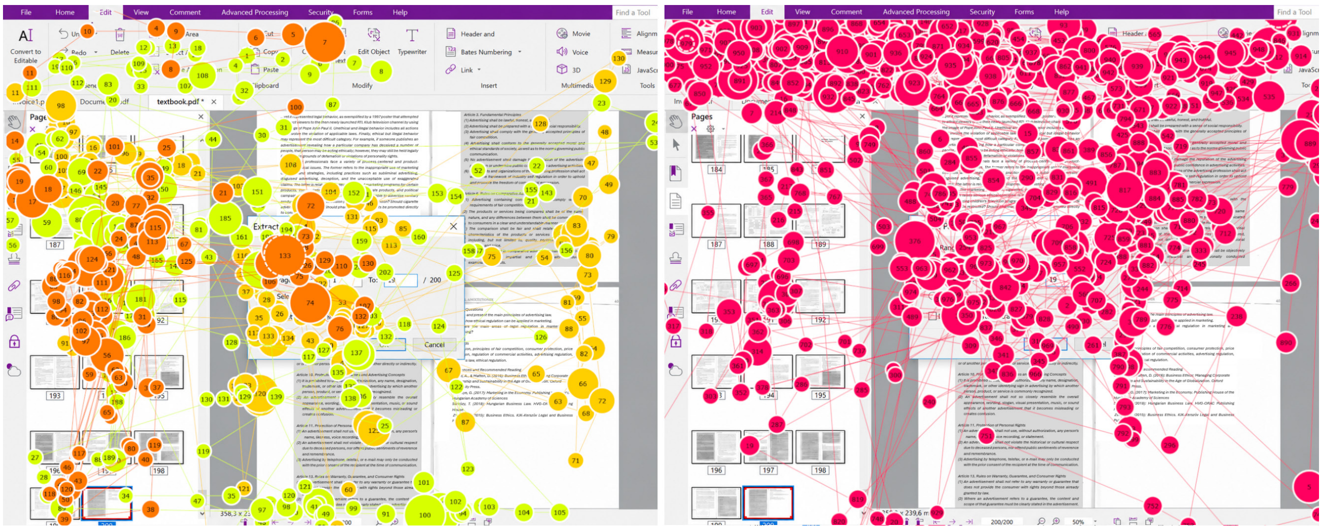

Fig. 6 Scan path visualisations illustrating differences during task completion (Source: PowerPDF (2019) interface, edited in Tobii Studio (2017) (Náray, 2019))

4.2 Results of meta-analysis in the case of usability studies with a specific purpose

In the case studies with a specific purpose (ID4, ID5, ID6), usability tests were conducted not only to identify general usability issues but also to address specific research questions. In ID4, differences in software usage were examined between versions without onboarding and those with video-based or interactive onboarding solutions. The ID5 case study aimed to compare the usability of mobile applications, whereas ID6 assessed the effects of different types of online sales messages on users' decision-making during accommodation booking.

4.2.1 Examples from the results of the ID4 eye tracking study on onboarding to support initial software use

The ID4 case study employed heatmaps to visualise the effectiveness of onboarding solutions using a graphic editing program as an example. During the usability tests, onboarding solutions designed to support initial learning promoted more deliberate task performance for specific tasks, particularly those considered critical, such as rotating and moving an inserted 3D shape (a fish) in three dimensions. Based on the reference group's results (left side of Fig. 7), the icons surrounding the designated 3D shape, which could have been used to complete the task, received very little attention. Instead, participants searched for the solution in the top and right menu bars. This behaviour can be explained by users' mental models, which had been shaped by a previous version of the Paint 3D (2018) software, in which they had learned to locate these functions elsewhere.

In contrast, the visualisations in the other two groups indicate that users spent considerably less time searching the top and side menu bars (middle and right sides of Fig. 7). When using the onboarding solutions, participants learned that the shape could be rotated using the icons appearing around it; accordingly, most fixations were concentrated on the canvas rather than the menu bars.

This observation can be quantitatively confirmed using AOI analysis: the number of fixations on the top and side menus (analysed with the Mann–Whitney U test) demonstrated that the onboarding solutions promoted more deliberate task performance. As a result of the onboarding methods, participants fixated significantly less on the top menu ($U = 1$; $Z = -2.727$; $p = 0.006$ and $U = 0$; $Z = -2.903$; $p = 0.004$) and the right-side menu elements ($U = 2$; $Z = -2.242$; $p = 0.025$ and $U = 0$; $Z = -2.887$; $p = 0.004$), as they understood that the rotation of the 3D shape could not be performed there.

4.2.2 Examples from the results of the ID5 eye tracking study comparing banking mobile applications

In the ID5 study on banking mobile applications, eye-tracking visualisations effectively illustrated differences that provide clear and actionable insights for designing an optimal banking app. As an example, a crowded menu system resulted in increased cognitive load, as reflected by a higher number of fixations (Fig. 8, right side).

This cognitive load can be explained by the limited capacity of short-term memory, typically 7 ± 2 items, meaning that menu sections exceeding this limit impair successful information processing. In contrast, the user interface shown on the left side of Fig. 8 supports more intuitive use, which is associated with fewer fixations during interaction.

The quantitative results also demonstrated that task completion was significantly faster when using navigation solutions with a lower menu. In the ID5 case study, similar eye-tracking visualisations provided additional valuable insights, enabling the collection of best-practice principles for designing an optimal and user-friendly banking application.

4.2.3 Examples from the results of the ID6 eye tracking study measuring the psychological pressure of online sales messages

In the ID6 case study, eye-tracking visualisations and AOI analysis clearly demonstrated that users allocated

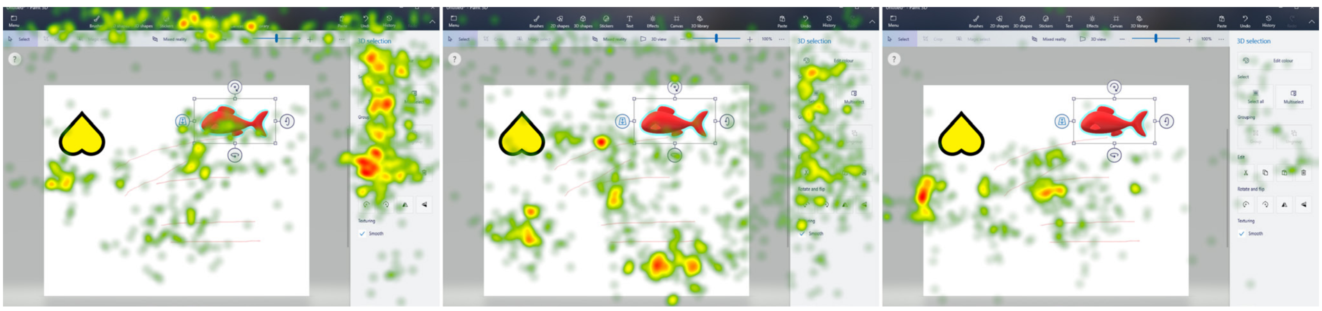

Fig. 7 Heatmaps of the rotation task: without onboarding (left), and with onboarding solutions (middle and right) (Source: Paint 3D (2018) interface, edited in Tobii Studio (2017) (Megyeri and Szabó, 2024))

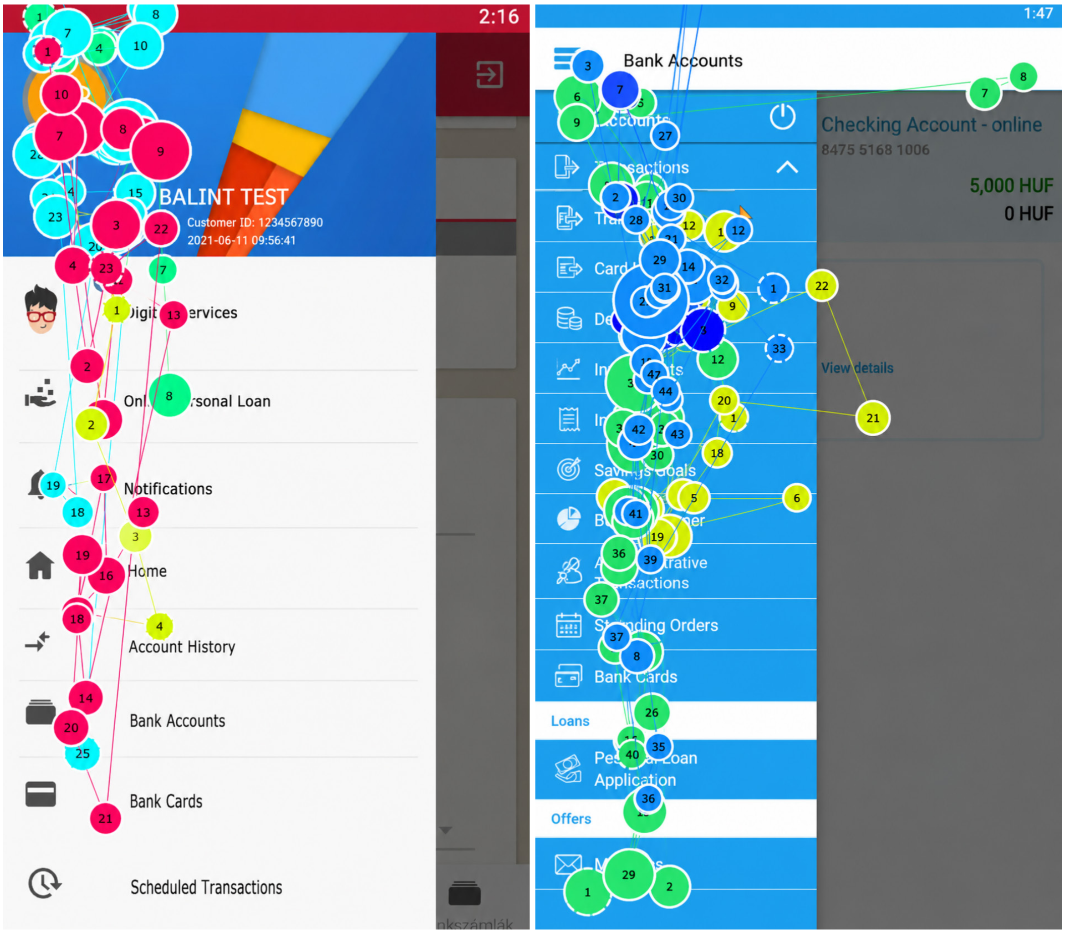

Fig. 8 Scan path visualisations illustrating the increased cognitive load caused by an overcrowded menu system (Source: Screenshots from commercial banking applications (MKB and K&H based on Szabó et al. (2021)), edited in Tobii Studio (2017))

minimal attention to the online sales messages. The heatmaps confirm that, while viewing the accommodation listing results, users focused primarily on the left-hand filters as well as on the accommodation names, descriptions, and prices. This pattern was observed both before and after scrolling on the page (Fig. 9). Simultaneously, the visualisations indicate that displayed messages, such as "–20% last-minute discount" and "5 bookings in the last 2 days" (highlighted by red dashed outlines), received minimal attention (Fig. 9).

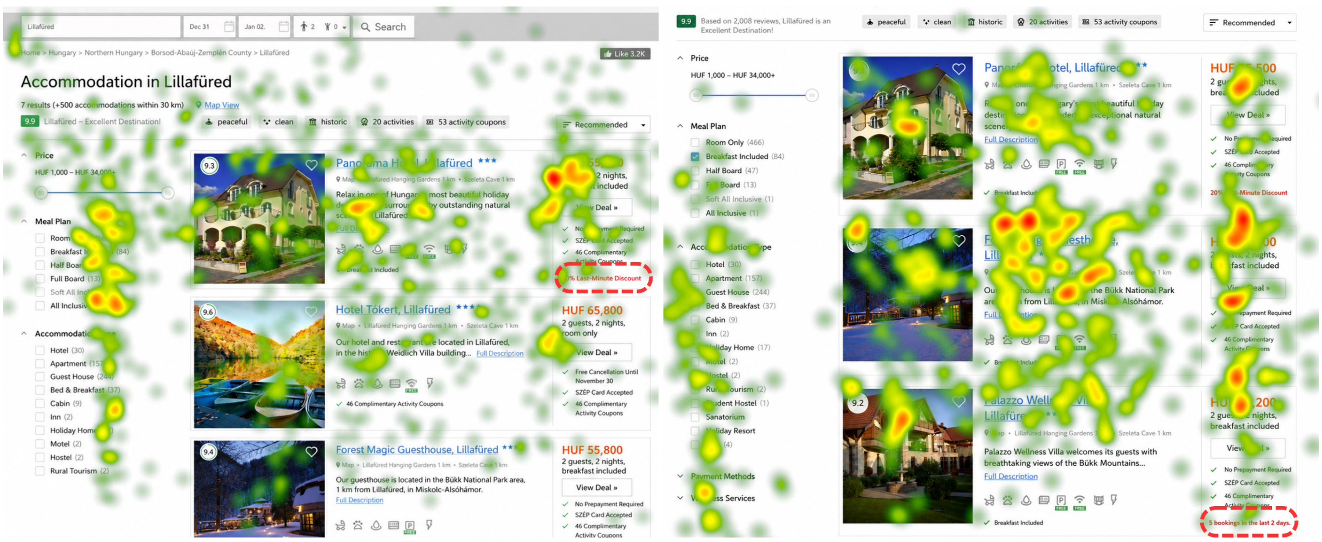

Fig. 9 Heatmap showing users' aggregate fixations on a booking accommodation webpage containing online sales messages (highlighted by red dashed outlines) (Source: Szállás.hu (2020) website, edited in Tobii Studio (2017) (Szabó et al., 2022a))

On the accommodation results page, by defining different offers as AOI regions and analysing the corresponding quantitative data, it is possible to determine whether the sections containing online sales messages received increased attention from participants. The middle offer did not include any stress-inducing elements (designated as the "Reference" AOI), whereas the areas above and below it, where various sales messages appeared, were labeled as AOIs "1" and "2" (Fig. 10).

Based on the number of fixations recorded for the AOI regions, the “Reference” area received an average of 31.2 fixations per second. In contrast, the regions containing stress-inducing elements received considerably fewer fixations (16.3 and 16.7). A similar pattern was observed for visit counts: the "Reference" AOI attracted attention on average 10.9 times, whereas the other two areas were revisited only 6.6 and 7.6 times. Considering the small sample size (n = 12), these data were analysed using the Wilcoxon signed-rank test, a non-parametric statistical test used to compare eye-tracking metrics recorded for different AOIs within the same participants. This analysis indicates that the difference between the accommodation without stress elements and AOI "1" is statistically significant. Accordingly, the central offer without online sale messages was more engaging to participants according to these metrics than the option above it ($Z = -2.524$; $p = 0.012$ and $Z = -2.684$; $p = 0.007$). However, AOI "2" did not differ significantly from the reference area in terms of attention.

A trend observed during the study was that participants spent more time on the accommodation results pages, revisiting them multiple times, than on the individual subpages. On the subpages, users focused primarily on images, price, rating, and booking period verification, whereas stress-inducing elements (for example, the "5 guests viewing" label located to the left of the orange "Book Now" button in the centre of the page) appeared to be consciously or semi-consciously ignored (Fig. 11).

Thus, a form of banner blindness is evident for online sales messages on subpages (Benway and Lane, 1998). Overall, the eye-tracking results suggest that online sales

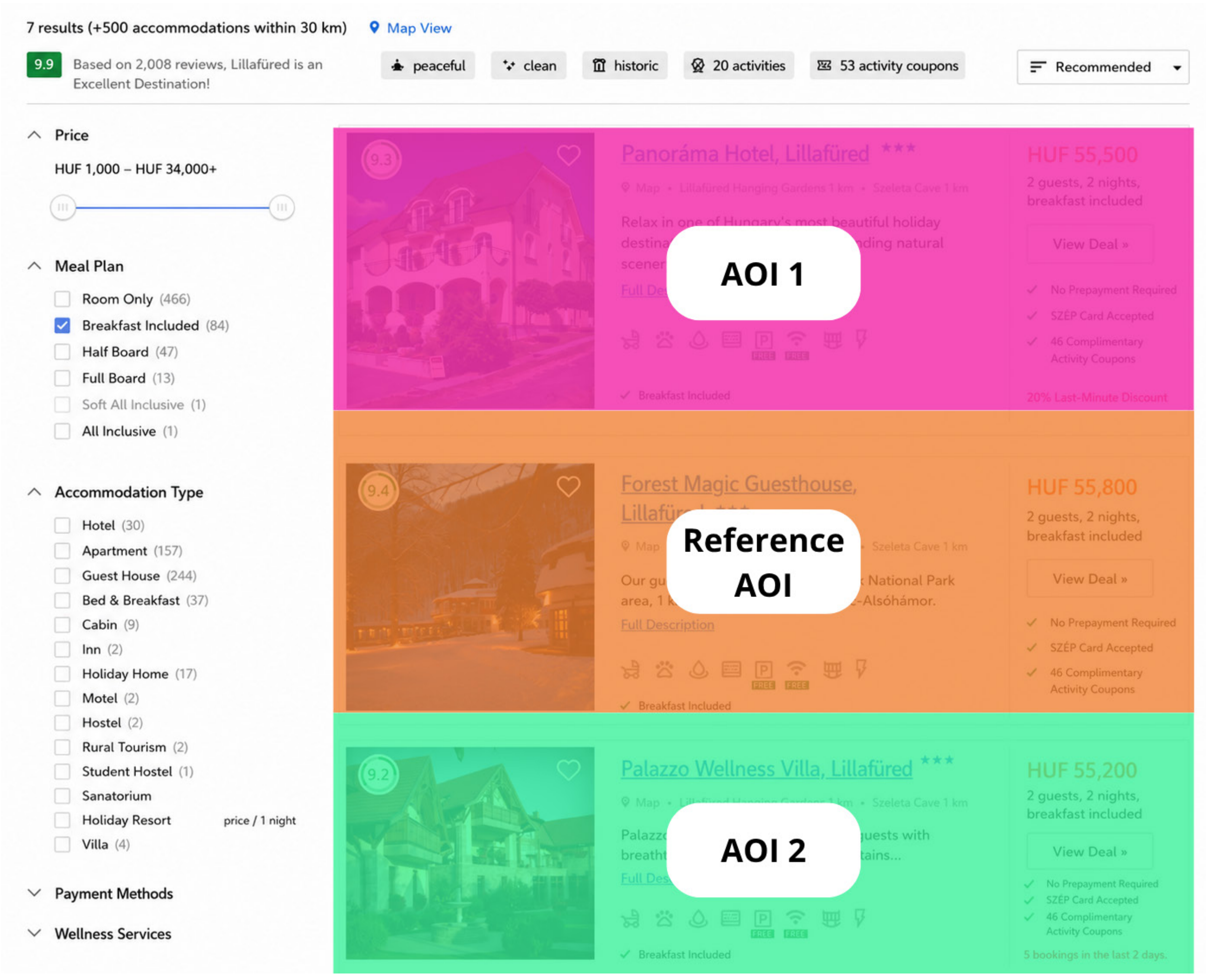

Fig. 10 AOI selections on the accommodation results page (Source: Szállás.hu (2020) website, edited in Tobii Studio (2017) (Szabó et al., 2022a))

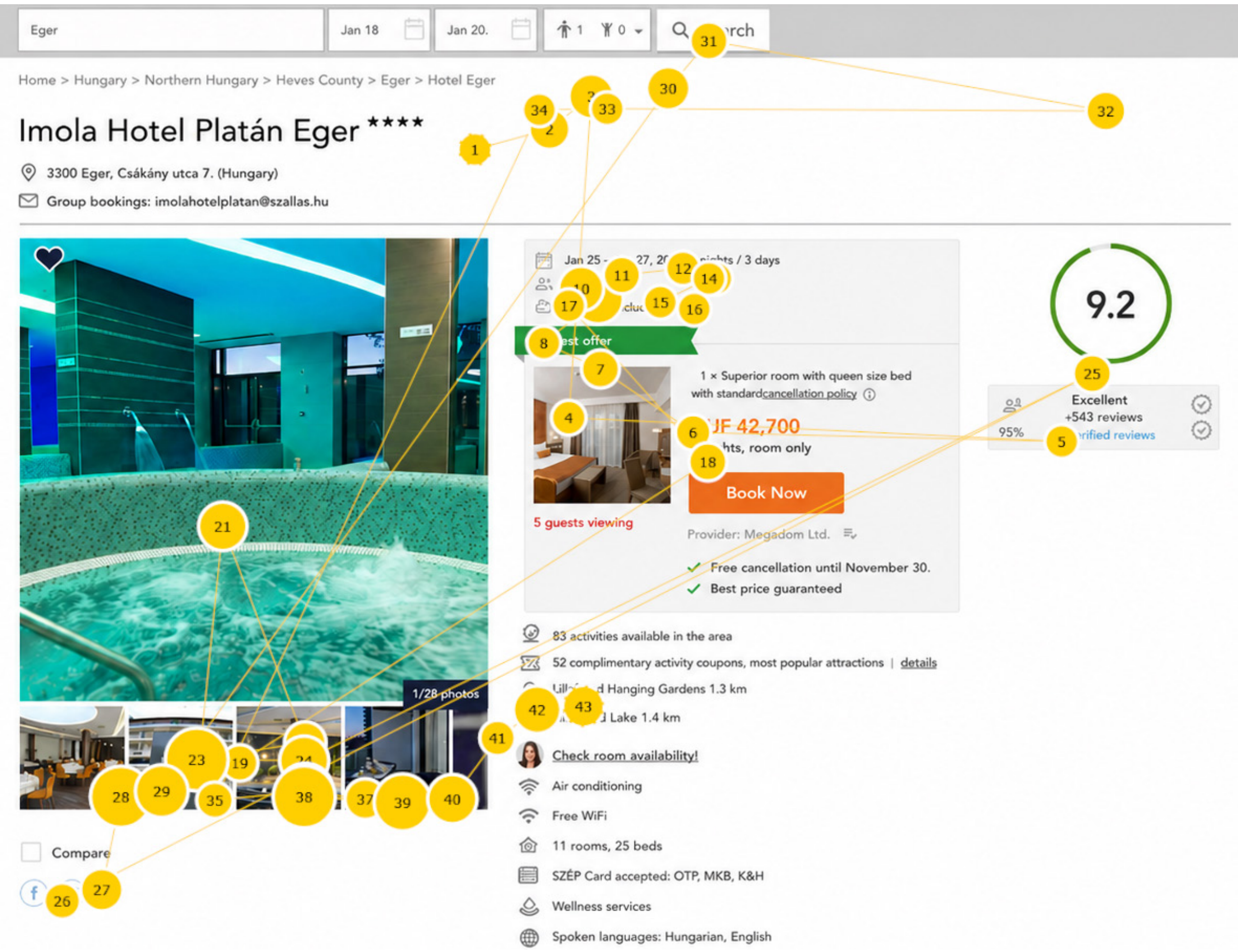

Fig. 11 Scan path visualisation illustrating participants' neglect of online sales messages on subpages (Source: Szállás.hu (2020) website, edited in Tobii Studio (2017) (Szabó et al., 2022a))

messages on the accommodation results page attract more attention than those on subpages, yet neither receives focused attention from users.

5 Discussion

The results of the meta-analysis reveal several recurring patterns regarding the role of eye tracking in usability evaluation, particularly when comparing general purpose usability studies with studies conducted for a specific research objective. Across the analysed cases, eye tracking consistently functioned as a complementary method rather than a standalone usability evaluation technique, but its contribution differed substantially depending on the purpose of the study.

In general-purpose usability studies, most usability problems could already be detected through observation, think-aloud protocols, and post-test interviews. However, eye-tracking visualisations provided additional explanatory power by revealing the visual and cognitive background of user behaviour. Heatmaps, scan paths, and AOI metrics made it possible to identify latent usability issues that were not verbalised by participants, such as unnoticed warning messages, visually weak interface elements, or mismatches between the users' mental models and the actual structure of the interface. These findings suggest that, in such studies, the main added value of eye tracking lies not in problem detection itself, but in the deeper interpretation and validation of usability problems.

A recurring pattern observed in several case studies is that eye-tracking data help to explain performance differences between users by revealing variations in fixation count, search behaviour, and visual attention distribution. In complex software environments, a higher number of fixations often indicated increased cognitive effort, and eye-tracking visualisations can serve as a valuable tool to demonstrate the presence of elevated mental workload during interaction. In such cases, scan path diagrams and fixation patterns provide visual proof that users encounter difficulty while locating functions or interpreting the interface structure. Similarly, AOI-based quantitative analysis can provide objective and measurable evidence when certain interface elements are difficult to locate or fail to attract sufficient attention. By supporting qualitative observations with numerical data, AOI metrics make it possible to justify design decisions with statistically interpretable results.

Another recurring finding across the analysed studies is the strong influence of users' mental models on visual search behaviour. Participants frequently searched for functions in locations where they expected them to be based on prior experience, even when the actual interface structure differed. Eye-tracking visualisations made these mismatches visible, thereby providing insights that are difficult to obtain with traditional usability methods alone. Similarly, in the analysis of online sales promotion messages, eye-tracking results provided clear evidence for the presence of banner blindness. Heatmaps, scan path visualisations, and AOI metrics consistently showed that users allocated minimal visual attention to online sales messages, even when these elements were visually prominent on the interface. This finding confirms that users tend to ignore interface components that they do not consider relevant to their current task. Such results underline the importance of eye tracking in studies where the objective is not only to determine whether users complete tasks successfully, but also to understand how visual attention is distributed during interaction, and which interface elements remain unnoticed despite deliberate design effort.

Overall, the results suggest that the effectiveness of eye tracking strongly depends on the research context. In exploratory usability testing, the method primarily supports interpretation and validation, whereas in hypothesis-driven or comparative studies it becomes a key measurement tool. This distinction may explain why the perceived usefulness of eye tracking varies across studies, and it highlights the importance of clearly defining the research objectives before selecting the method.

These findings also indicate that eye tracking can contribute to higher-quality usability analysis when it is applied in a targeted and methodologically justified manner. By combining qualitative observation with quantitative gaze data, researchers and UX practioners can obtain a more comprehensive understanding of user behaviour, which may lead to more reliable design decisions and better-grounded product improvements.

6 Conclusion

Beyond the practical implications discussed above, this meta-analysis provides a systematic contribution to the UX and usability research literature by synthesising empirical findings on the application of eye-tracking methodology across different types of software usability studies, thereby offering methodological guidance for researchers and practitioners regarding when and how the technology can be applied effectively. While previous studies typically report results from individual experiments or case studies, the present review identifies recurring conditions under which eye tracking provides meaningful added value compared to traditional usability evaluation techniques.

The findings indicate that eye tracking is most beneficial when the research requires objective measurement of visual attention, detailed interpretation of user behaviour, or comparison between alternative interface solutions. At the same time, the method involves considerable preparation time, specialised expertise, and financial cost, meaning that its application should be carefully justified within the constraints of software development projects.

The analysis suggests that in general usability evaluations, eye tracking primarily serves as a supporting method that strengthens the interpretation of observed usability problems, while in studies with a specific research objective it can function as a central measurement tool. Its use is particularly recommended when a product undergoes substantial redesign, when interaction takes place in complex or real-world environments, or when precise attention-based metrics are required to answer clearly defined research questions.

Overall, this review contributes to UX eye-tracking research by clarifying the methodological role of the technology and by outlining practical decision criteria for its application in usability studies. By providing a structured overview of its advantages, limitations, and appropriate contexts of use, the paper supports more informed method selection and may foster higher-quality usability evaluation in both academic research and industrial UX practice.

6.1 Limitations

The six case studies were selected for convenience, as the author had full access to all raw data necessary for interpreting the visualisations from the Department's usability laboratory, which is advantageous for a controlled analysis, although it imposes inherent limitations on the broader applicability of the findings. In addition, the Tobii device used in these studies operates at a lower sampling rate and employs a square monitor, whereas more modern eye-tracking systems provide higher-frequency measurements and support widescreen (16:9) displays. This technological difference may have influenced users' visual behaviour, as some interface elements could have appeared differently than they would in a natural usage context, potentially affecting the ecological validity of the research.

6.2 Future research

Within the framework of future research, collaboration with other universities could enable the inclusion of a broader range of case studies using modern high-frequency eye-tracking devices with widescreen displays. Such studies would allow examination of whether the observed patterns hold across different types of software, thereby improving the transferability and ecological validity of findings in UX and usability research.

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