To See or Not to See: Exploring Inattentional Blindness for the Design of Unobtrusive Interfaces in Shared Public Places

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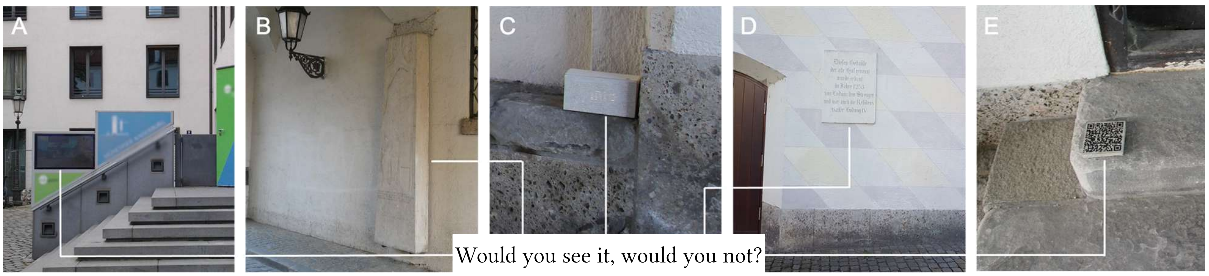

Fig. 1. Comparing the IB toward five interfaces, a screen (A), a flagstone (B), a translucent concrete box (C), a historical sign (D), and a QR code made from concrete (E), in a real-world context. Table 3 shows each in detail.

People visit public places with different intentions and motivations. While some explore it carefully, others may just want to pass or are otherwise engaged. We investigate how to exploit the inattentional blindness (IB) of indirect users in the design of public interfaces to apply to such diverse needs. Beginning with a structured literature study in the ACM Digital Library on IB, we analyzed 135 publications to derive design strategies that benefit from IB or avoid IB. Using these findings, we selected three existing interfaces for information presentation on a large public square and created two additional interfaces ourselves. We then compared users' perceptions through a self-reported photography study ($N = 40$). Participants followed one of four scripted profiles to imitate different user intentions, two for direct and two for indirect users. We hypothesized that direct users would recognize the interfaces, while indirect users would experience IB and ignore them. Our results show that direct users reported up to 68% of our interfaces, whereas indirect users noticed only 16%. Thus, IB can be exploited to hide interfaces from indirect users while keeping them noticeable to direct users.

CCS Concepts: • **Human-centered computing → Ubiquitous and mobile computing design and evaluation methods**; **Empirical studies in ubiquitous and mobile computing**.

Additional Key Words and Phrases: inattentional blindness, public and historical places, unobtrusive interfaces

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1 INTRODUCTION

In public urban areas, we typically find a heterogeneous group of people [27]. For example, historical places are frequently visited by both tourists and residents and provide different individual functions to these groups: Some may take a lunch break, others search for a new apartment in the neighborhood, and some may simply explore different historical sites. All of these people closely observe their environment, however, with different intentions. While an apartment-hunter is merely scanning the neighborhood for potential disturbances, a tourist is actively discovering the surroundings and is looking for additional information about the space. Public displays, whether digital (e.g., screens) or analog (e.g., plaques or signs), can provide such information for a tourist. However, if not designed carefully, they can become obtrusive for people who only pass by on their way home or even negatively impact historical places' authenticity. This creates a distinct challenge for user-centered design in public spaces: Ideally, public interfaces should only present information to direct users and those interested in them but stay invisible for indirect users who feel disturbed by them [64, 103]. This poses the question of how we can design interfaces to be visible for direct user groups but remain easy to ignore by others or when not needed. For approaching this question, we explore the potential of inattentional blindness (IB), the perceptual phenomenon of being blind to something that is not the focus of our attention. Simons and Chabris [104] asked participants to watch a video of a group passing a basketball and to count the number of passes. 46% of their participants missed the person in the gorilla costume crossing the room. Thus, subjects can be inattentionally blind and miss out on important information when being involved in another task at hand [107, 108].

To inform our work, we first explored the use of IB in the field of Human-Computer Interaction (HCI), in particular for the design of unobtrusive public interfaces. We conducted a structured literature study in the ACM Digital Library, resulting in 135 publications. We analyzed the publications and looked for strategies to (a) overcome IB or (b) elicit IB on purpose. We found that IB was predominantly treated as a task-related phenomenon and that there is a research gap concerning user studies that investigate the application of IB for the design of public interfaces in a real-world context. Based on this, we derived a testable hypothesis:

H_1 Indirect users involved in a specific task are less likely to notice public interfaces not relevant to their task. They will notice interfaces less frequently than direct users to whose task the interfaces are relevant.

To test our hypothesis, we selected five public interfaces as our study control objects that, according to Leifer's scale for implicit interaction [69], vary in terms of their attentional demand and the user's required initiative. Three interfaces (a public screen, a sign, and a flagstone) were already present in the space we selected, which is a public square next to the first royal residency in Munich. We complemented this selection by two prototypes we designed, a QR code made from concrete and a translucent concrete box displaying text (see Figure 3).

We tested our hypothesis in a mixed-methods experimental user study ($N = 40$), asking participants to self-report interesting artifacts or scenes at the historical site using a picture-taking paradigm previously applied by Moore et al. [84]. To artificially avoid or induce IB, participants were randomly assigned to one of four user profiles: Two profiles, the one of a tourist and a person on a lunch break, were created to notice our control objects because they were task-relevant, while the other two, an apartment-hunter and an event planner, were designed not to notice them because they were not relevant to the respective task. We hypothesized that the different intentions when visiting the place would result in different attentive behavior and, therefore, different recognition rates of the surrounding interfaces.

Research leveraging IB for the design of unobtrusive interfaces is still scarce, especially in outdoor environments. Accordingly, we contribute a) a concise overview of the current understanding and the application of IB in HCI literature, b) insights into the role of IB for the design of unobtrusive public interfaces, as well as into c) the influence of IB on different (indirect) user groups sharing the same public place and d) the artificial induction and measurement of IB in an HCI field study.

2 RELATED WORK

This section gives a short overview of attention research, including current design guidelines and principles, followed by current attention guidance strategies in public places and an overview of unobtrusive interfaces in relation to calm technology.

2.1 Attention - Background, Principles, and Guidelines

Attention is a mechanism that functions as a selection process for perceived stimuli [83]. It supports a conscious perception and interpretation of our surroundings [16, 101]. In our work, we focus on visual attention, in particular, the bottom-up and top-down information processing of visual stimuli [26, 39, 68, 81]. Top-down processing is task-driven, depends on internal cognition, and draws on prior knowledge and executive control [37, 53]. Bottom-up processing instead is a reaction triggered by external, salient stimuli and thus does not depend on a certain task [41, 68]. Prior research mostly discusses design principles and guidelines for guiding attention [46, 79, 95, 102, 109], i.e., by highlighting a target object using contrast, color, shape, alignment, or movement [90]. These guidelines evoke bottom-up processing and are often based on increasing the salience of the stimulus [25].

2.2 Attention Guidance for Public Interfaces

The placement of attention-guiding and attention-catching cues is one of the main challenges in public environments [12]. Concerning top-down processing, prior research focuses primarily on the relevance of the gist of real-world scenes and thus semantic and cognitively relevant information [54, 113, 115]. Accordingly, a user's attention is guided not only by task-relevant information but also by task-irrelevant cues that convey a certain semantic meaning or seem of high personal interest [96]. Object co-occurrences further influence this; i.e., objects that are easier perceived, because they are expected to appear together or close to one another [123].

When looking at existing public interfaces, attention guidance has mainly been discussed for public displays by exploring different interaction and perception stages, from indirect passers-by to direct users of pervasive displays [17, 28, 116]. A key challenge in this domain is that potentially interested users might not perceive such displays as interactive and therefore ignore them [28]. Wang et al. [116], as well as Börner et al. [17] argue for unobtrusive, attention-aware displays that dynamically move from the periphery to the focus and consider different levels of implicit to explicit interactions. Attention-aware systems often track users' eye gaze to measure their engagement and concentration level [56, 122]. However, the tracking is still problematic in public contexts due to the complexity and dynamic of real-world conditions requiring alternative solutions, such as face presence [2]. Finally, there are design guidelines about proactive, provocative, and salient features that can draw people towards the display by social means, i.e., by observing others interacting [28].

2.3 Unobtrusive Interfaces and Calm Technology

Since technology is becoming so ubiquitous and a vivid part of our public environments, we need design strategies for calm technology and unobtrusive interfaces [19, 66, 97, 118]. This need is especially relevant in historical or emotionally sensitive places, such as a cemetery or historical monument [47, 48]. Typically, such technologies are attention-inviting, not attention-demanding, and may use, for example, subtle sounds to guide the user to the interface [91] or be adapted to the context [97]. This type of design reduces attentional overload [19] and information stress [63, 67] for users. Accordingly, such interfaces are placed rather in the periphery of perception and designed to not be disruptive but available when needed [4, 66].

This can be achieved by the seamless integration of interfaces into their physical environment. In *unobtrusive* designs, the user can typically switch between the periphery and the focus of attention [3, 119], while *obtrusive* interfaces are characterized by explicit sensory input appearing in the user's focus. The former approach can significantly decrease users' cognitive workload and make technology disappear when not in use [3, 19, 62, 119], thus making it a desirable design strategy for technology when bottom-up processing, e.g., through a salient display, is not desired [47, 48]. For determining the level of unobtrusiveness, Gil et al. [44] applied a framework by Leifer [69] to their interfaces. The framework considers implicit interactions and ranks system behaviors on a scale from proactive to reactive (initiative) and from being in the foreground to being in the background (attentional demand) [69]. However, the relevance of the interaction for the task at hand can also influence the level of obtrusiveness [97]. We considered all of these aspects in the design phase of our prototyping process and in our selection of control objects for the field study.

In summary, we argue that there is a research gap for connecting concepts of perceptual psychology with the design of unobtrusive interfaces for public areas. We try to bridge this gap by exploring IB in particular and test its potential when designing for different user groups of real-world interfaces.

3 LITERATURE REVIEW

We conducted a literature study to assess how prior work investigated IB in HCI and what design strategies were related to it. We aligned our approach with the methodology of prior surveys conducted in HCI (e.g., [55, 111, 124]). This means that we focused on the application of technology and its effect on human perception, and we only included publications from the HCI domain.

3.1 Initial Paper Selection

We first defined the scope of our literature analysis: Using a keyword search for "inattentional blindness", we retrieved every research paper that included the string[1] in any part of the publication (title, abstract, keywords, or body) in the ACM Digital Library, in particular, the ACM Guide to Computing Literature. This includes a great variety of publications from more than 50 top tier journals, including but not limited to IMWUT, PACMHCI, TAP, TiiS, or TOCHI, as well as proceedings of more than 170 conferences, symposia, and workshops, for example, CHI, CSCW, or MobileHCI. Our initial query resulted in 231 publications, which we further narrowed down by excluding those which were not available in English or did not undergo a double-blind peer-review process (workshop paper, lecture notes, etc.). The resulting data set contained 147 publications (75 full papers, 16 short papers, 51 journal articles, 2 book chapters, and 3 books). This process yielded an extensive yet non-exhaustive set of literature, providing interesting insights into IB's different occurrences in the HCI domain.

3.2 Exclusion and Categorization

We grouped the publications into the following six categories:

(0) IB is evaluated in a psychological or neuroscience context but not applied in a system or application
(1) Keyword IB is put in context to benefiting strategies
(2) Keyword IB is put in context to overcoming strategies
(3) Keyword IB is mentioned with a short explanation
(4) Keyword IB is mentioned without further explanation
(5) Keyword IB only appeared in the reference list or appendix

[1] Originally, we also included *inattentional deafness*, a related construct referring to acoustical attention, as a potential additional phenomenon. However, the query yielded only four viable results. We then decided to exclude it from our analysis for stringency.

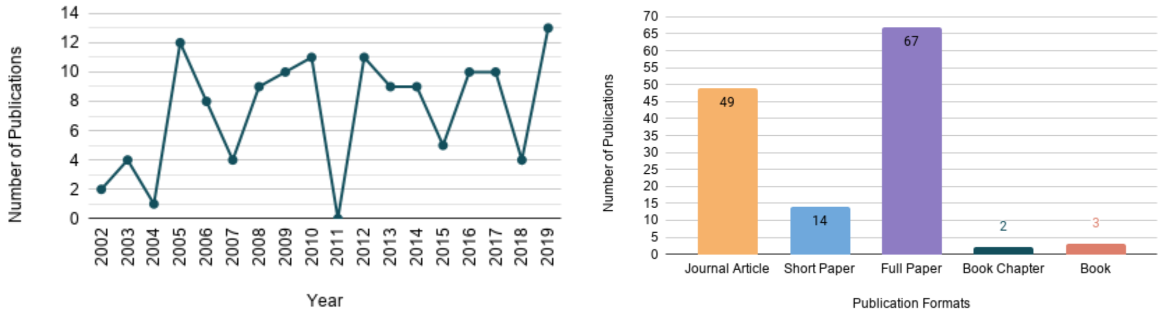

Fig. 2. IB in the ACM Digital Library: Distribution of the number of papers per year (left) and per format (right).

Two independent raters performed the categorization. To assure a non-biased categorization and evaluation of the content, we assessed our inter-rater reliability as proposed by Campbell et al. [18]. We randomly selected about 15% of our data set (20 papers) and double-coded them. The coding showed an agreement on 15 out of the 20 publications (inter-rater reliability score of 75%). The remaining disagreements on the categorization resulted mainly from different assessments of the papers' focus, particularly whether the discussion on IB was extensive and explicit enough to include it in our literature set. All disagreements were discussed in detail until consensus was reached, and the process was revised according to the results. For further evaluation, we excluded all publications of Category 5, in which the key terms only appeared in the appendix or reference section.

Our resulting condensed set contained 135 publications in total[2], including nine publications of Category 0, 23 publications of Category 1, 20 publications of Category 2, 45 publications of Category 3, and 38 publications of Category 4. We only discuss Category 0 papers if they describe strategies that can be generalized to the HCI domain. The evaluation's main focus lies on Categories 1 and 2, describing systems or tools to either overcome the effects of IB (2) or actively making use of IB (1).

3.3 Results

Our set of publications included work from the years 2002 - 2019 (cf. Figure 2). The most common publication venues were the Spring Conference on Computer Graphics (SCCG, N=10), the Journal Transaction on Applied Perception (TAP, N=9), the Journal on Cognitive Neuroscience (N=9), and the Conference on Human Factors in Computing Systems (CHI, N=7). Every publication mentions IB at least once. Only seven publications mention it 10 or more times in the full-body text ($M = 2.74$, $SD = 4.14$). The paper most frequently mentioning IB (37 occurrences) is a description of a study revisiting the invisible gorilla experiment by Gelderblom and Menge [43].

Next, we analyzed our resulting 135 publications according to six guiding questions: (A) *How is IB defined in this work?*, (B) *What is the application context of IB in this work?*, (C) *Is IB evaluated in this work? If yes - How was it measured?*, (D) *What are the reasons for IB described in this work?*, (E) *Does this work propose strategies to overcome the effects of IB?*, and (F) *Does this work propose a system, tool, or concept to exploit IB?* Below, we describe our evaluation of the publications guided by those questions.

3.3.1 Defining Inattentional Blindness. The majority of publications refer to the initial work by Mack and Rock [74] or Simons and Chabris [104] to define the phenomenon IB. While the concept is described in similar ways, we encountered slight differences in its definition. The majority of publications (58) defined IB as failing to

[2]The complete literature set can be found here: https://osf.io/q7h93/?view_only=43ddff99dbbf4ee88f361666503c2848, last accessed 15th November 2020.

notice or failing to perceive a visual stimulus, even salient (12) or unexpected features (18). Definitions can focus on visual (foveal) attention (e.g., [13, 21]) but also consider more general attention shifts or resource limitations (e.g., [70, 86]). Some definitions were more descriptive, stating that IB occurs due to a lack of capacity to process stimuli irrelevant to a given task (e.g., [42]). We found that the main reasons for IB were explained as due to participants being engaged in another task (20 occurrences), lacking attention (37), or focused attention (5). Limited capacity to process a stimulus or cognitive absence (2) can also cause IB.

3.3.2 Application Context. We further looked at the context of application in which IB was described in the respective publications. We found that the majority mentioned IB when explaining user behavior (48), e.g., arguing why users did not perceive a particular display or object even though it was displayed in plain view (e.g., [8, 73]). IB is further frequently noted when describing the design of a tool, system, or technique (40), in particular when evaluating the exploitation of IB (e.g., [23, 50]). We found that several publications mention IB in the application contexts of their research study setup (11) and their design approach (11). Several other application contexts occurred just once and were therefore omitted in the detailed description below.

3.3.3 Evaluation of Inattentional Blindness. All but one project evaluated IB in lab studies in which authors tested for IB in a task-oriented scenario asking participants about perceived aspects. Partly, eye-tracking data supported the qualitative results (e.g., in [9, 34, 51, 108]). One study by Bessa, Coelho, and Chalmers discussed IB in an outdoor context. The authors provided photos to participants and asked them to find and recognize locations in a city by looking at the photos. This novel task could reveal which contextual aspects are used to remember and recognize objects and which are ignored [10].

3.3.4 Strategies to Overcome Inattentional Blindness. In total, 18 publications in our set described strategies to mitigate or overcome IB. From those 18, 14 belong to Category 2 (explicitly describing overcoming strategies), three to Category 3, and one to Category 4. As many of the publications describe more than one strategy to mitigate IB, we extracted 19 strategies, grouped into six clusters (cf. Table 1). A frequently used strategy to redirect a user's attention when IB occurs is the usage of *visual cues or similar attention-grabbing mechanisms* (6). Especially on screens displaying rich information, cues can guide a user's attention and mitigate IB. I.e., the gaze of search and rescue operators is redirected to important information by applying these strategies [94]. Similar strategies can be applied to support the screening of web search results. Marcos, Gavin and Arapakis [76] evaluated different visualizations of snippets displaying meta-information from landing pages. In particular, they compared the richness of these snippets and their potential to attract attention, concluding that richness can influence user's behavior (higher richness sometimes resulting in higher attention) but does not dominate it [76]. Especially when designing interfaces for user groups with declining working memory and attention capabilities such as older adults, Nunes, Kerwin and Silva emphasize the need for careful visual presentation. One suggestion from their recommendations for TV interfaces is to center important information on the screen as this space is where users expect content to be displayed, thus, reducing the likelihood of IB [88].

Further, visual cueing can support users in search tasks in images [80], complex content [11], or videos [65]. For image searches, McNamara describes the usage of subtle gaze direction (SGD) to guide users' gaze without interrupting the viewing. This is achieved by carefully blending pixels in the peripheral vision with some amount of black and white color, resulting in improved performance without affecting the image perception [80]. When engaging with complex content, Blok investigates the usages of animations to highlight changes. However, she further discusses including a control that allows the user to adapt the rate of changes. This can be achieved either through the speed of presentation or the magnitude of change per unit in the animation, which is hypothesized to result in less overload when interacting with it [11]. To guide users' attention in video content, Kurzhals, Höferlin and Weiskopf propose four visualization techniques. They were able to show that using attention-guiding visualizations can help to distribute the attention more evenly between the objects of interest compared to no

Table 1. Clusters of publications concerning strategies to mitigate or overcome IB as well as their size (Occ.)

Strategies to mitigate and overcome IB	**Occ.**	**References**
Visual attention grabbing, cues, and gaze re-direction	9	[11, 29, 32, 65, 76, 80, 88, 94, 117]
Substitution of modalities for interaction and perception	5	[1, 15, 29, 98, 99, 114]
Outsource attention switching decisions	1	[38]
Increase number of observers	1	[75]
(1) rules (2) distributed knowledge	1	[110]
Slowing down perceptional process	1	[100]

Table 2. Clusters of publications concerning strategies to exploit IB as well as their size (Occ.).

Strategies to exploit IB	**Occ.**	**Publications**
Decrease rendering time (animations, 3D, VR, etc.)	21	[6, 9, 10, 20–24, 30, 34, 35, 50–52, 71, 72, 78, 85, 92, 107, 108]
Cross-modal effects - How audio influences visual perception	2	[58, 59]
Extend perceived space in VR environments	2	[105, 106]
Unnoticed manipulation of VR scenes	2	[60, 77]
Modeling human perception in agents	2	[45, 112]
Using IB for non-interrupting notifications	1	[36]
Indicator for brain malfunctions	1	[87]
Hiding non-task related information (e.g., fiducial markers)	1	[89]

visual support. A bounding box and grid visualization were subjectively preferred by the participants [65]. In his book, Ware [117] refers to a publication by Jonides [61], who describes two approaches to visual cueing, namely push and pull cues. In a pull cue, a new object is introduced that attracts the users' attention. A push cue is a visualization such as an arrow that indicates where the attention of the user should be shifted to.

In situations where the visual channel is already overloaded, crucial information can easily be missed due to IB. Four publications proposed a solution by *substituting visual information by a different modality* (e.g., audio), thus aiming to reduce IB's likelihood. Albrecht et al. [1] designed a navigation system for cyclists that uses spatial audio to guide users through the city. Similarly, in-car interfaces, tactile, auditory, or olfactory information presentation can reduce disruptions on the driving task [98].

3.3.5 Exploiting Inattentional Blindness. Almost a quarter of our literature set (32 out of 135) proposed or analyzed a system that exploited IB or was at least benefiting from this phenomenon. Thereof, 23 publications were in Category 1, meaning they are offering or evaluating systems exploiting IB. Further, nine publications belonged to Categories 2 to 4, meaning IB's exploitation was not the publication's primary focus. However, in this section, we report on the range of all 32 publications.

In the majority of research papers (20 occurrences), IB was utilized to *hide changes* in computer-generated visualizations. In particular, animations (e.g., [24]), 3D-models (e.g., [72]), and Virtual Reality (VR) environments (e.g., [92]) can be generated with *decreased rendering time* if areas, which are currently not in the focus of attention, are rendered in lower quality than the focus area. Similarly, IB can be exploited to hide unnatural changes or technical limitations in VR. I.e., in EyeHacker [60], Ito et al. were able to switch between real-time fluently and recorded virtual reality scenes, while participants could not perceive the switches at the very moment. Also, Marwecki et al. proposed Mise-Unseen, a VR system using gaze analysis to detect the user's focus of attention and performed unnoticed rearrangements in the virtual environment by exploiting IB [77]. Another example is provided by Sra et al. [105, 106] who investigated the use of IB to *create a natural walking experience* in VR by giving the impression of up to four times more space through imperceptible redirection. IB can further help to *hide non-task-relevant information*. Ouzts et al. [89] could show that using mobile eye-tracking devices usually requires the presentation of 3D fiducial markers. However, those markers, while irrelevant for the users, can influence the gaze behavior. In their evaluation, they showed that participants did not pay visual attention to areas where the marker was located when provided with a mentally demanding task. In a similar attempt, Esholz et al. [36] used a color-changing keyboard as an ambient display to *deliver notifications without interrupting* the user. They claim that colors are perceived even without full user attention. Thus, they exploited IB to deliver such notifications unobtrusively and without interruption.

Besides the exploitation of visual attention reallocation, Hulusic et al. [58, 59] investigated the use of auditory stimuli on visual perception. They presented first results on the influence of certain sounds on the perception of animations' smoothness, thus exploiting IB across modalities.

Finally, we discovered two alternative applications for exploiting or benefiting from IB. One work by Neymotin et al. [87] discussed the phenomenon of IB in regards to corrupting neural networks. They state that IB in a network with a greater degree of independence or isolation could indicate brain diseases [87]. The other, by Gu et al. [45], discussed incorporating IB as a *cognitive imperfection of an intelligent agent* or the virtual human. They aimed at creating a computational model for an agent who shares the shortcomings of human perception, thus, improving its social acceptability and the interpersonal interactions between people and animated human agents. Thilakarathne further added to it by using IB to generate a model for agent-based applications [112].

3.4 Methodological Limitations

In our literature review, we focused on the in-depth analysis of publications dealing with IB. We discovered that authors also used several synonyms for IB, such as "looking but not seeing effect" or "perceptual blindness", which were not included in our original keyword search. Furthermore, we decided to exclude publications in non-peer-reviewed formats such as workshop papers. Thus, we contribute a broad set of literature but can not claim that our review on mitigating and exploitation strategies of IB is exhaustive.

3.5 Discussion

Our literature search could identify several key points that can motivate the design of unobtrusive interfaces in public spaces. We found that many publications mentioned IB but did not evaluate its occurrence or effects. It was often mentioned on the sideline, mostly in the related work section creating awareness of the phenomenon itself without it being a central topic. In other publications, it was used to justify results, e.g., a post-hoc explanation when participants had failed to see a particular object or change in the UI.

For the sake of our work, we were particularly interested in those publications where IB was explicitly created and exploited. We found several publications describing strategies for this effect (cf. Table 2); however, the majority of those evaluated IB in a controlled laboratory scenario. As those publications concern animations, 3D graphics, and VR, the strategies deployed are not necessarily transferable to the context of public urban interfaces. Similarly, various publications mentioned strategies to overcome IB (cf. Table 1), while only a few deployed strategies that would be applicable in a real-world context. Especially the frequently used techniques of visual attention and gaze re-direction are somewhat challenging to implement in a public setting due to the complexity and unpredictability of the surrounding environment. Nevertheless, some strategies, e.g., using subtle light cues for non-interrupting task switches [36], show great potential for building unobtrusive interfaces in public spaces.

We emphasize two key findings that influence our further study development. First, IB is already exploited to hide different aspects in digital contexts unobtrusively but has rarely been explored for public physical interfaces in a real-world scenario. Second, for designing an unobtrusive interface that would be noted by direct users but missed by indirect users, we need to apply a balance of both overcoming and benefiting strategies.

4 PROTOTYPING AND STUDY PREPARATION

This section presents how our findings from the literature study and prior work motivated the field study design. We introduce the control objects and discuss them as well as their design and placement considerations.

4.1 Methodology

We could identify only one prior work reference [10] reporting on testing IB in an outdoor environment at the time of the literature review. Researchers provided participants with photographs from an environment and asked them to find the spot from which the picture was taken. As they were looking for obvious cues that participants used for orientation in particular, they related less obvious cues to IB. As we are aiming to test whether we can exploit IB, we looked into psychology research projects' methodologies. I.e., Moore et al. [84] applied a self-directed photography method to track attention capturing objects in a real-world context. The method lets participants decide independently which aspects they rate as task-relevant. It was followed by interviews with the participants about the pictures taken. Moore et al. [84] were able to identify differences in attention guidance and capturing aspects compared to lab study results. The method additionally provides an easy and accessible way of tracking participants' perception of task-relevant features and points of interest [33]. We decided to use the self-directed photography method for our study and reverse-engineer aspects that people failed to notice.

4.2 Control Objects

As study preparation, we selected three objects that were already part of the testing environment (a screen, a historical information sign, and a flagstone) and added two additional ones, a QR code made from concrete and a translucent concrete information box as our control objects (cf. Figure 1). The objects are referred to as "place objects" and "add-on objects" respectively below. In the selection as well as in the design process, we considered previous research about unobtrusive, implicit, and obtrusive interfaces [12, 62, 69, 121], peripheral awareness [4, 5], and calm technology [19, 97] to derive interface characteristics which might be easier to ignore and which hence, might be more unobtrusive. We selected a variety of objects differing in size, material, positioning, familiarity, and perceivable information. However, we ranked each as presented in Figure 3 using Leifer's framework to assure a certain range according to our expectations.

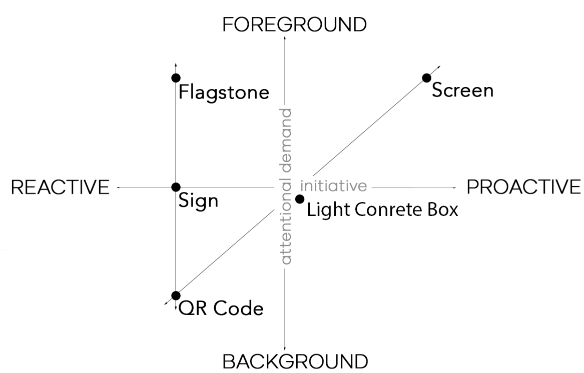

Fig. 3. Mapping our control objects to Leifer's scale for implicit interaction [69].

Table 3. IB Design Considerations: We based the choices of our study control objects on the literature study results and prior work. We used overcoming strategies to select more obtrusive objects and benefiting strategies for more unobtrusive objects.

Picture	Object	IB Related Consideration	Spatial Integration & Materials
	Screen	Overcoming: salient visual cues, movement, familiar cue. Benefiting: - Prior work: -	Position: in a 90° angle to an entrance at eye-height. Size: ~120x90cm². Material: modern HD display. Activity: proactive; moving and colorful images.
	Sign	Overcoming: pattern interruption, familiar cue. Benefiting: still, soft colors, small size. Prior work: peripheral position.	Position: eye-height. Size: ~80x100cm². Material: assurrounding, pattern interruption. Activity : non-reactive
	Light concrete box	Overcoming: bright illumination, closely positioned to focal point Benefiting: soft colors. Prior work: peripheral position.	Position: on bench, parallel to main road. Size: 23x12x12cm³. Material: translucent concrete, LED strips, powerbank. Activity: illuminated by default.
	QR Code	Overcoming: Gestaltlaw, pattern interruption. Benefiting: still, soft colors. Prior work: peripheral position, using existing objects.	Position: on stairs, parallel to main road. Size:10x10x2cm³. Material: concrete and black paint. Activity: non-reactive.
	Flagstone	Overcoming: 3D continuity interruption, size. Benefiting: still, no colors difference. Prior work: using existing objects.	Position: protruding into the road. Size: ~80x200x15cm³. Material: as surrounding. Activity: non-reactive.

The most obtrusive object was the screen, as it was placed at eye-height, positioned vertically to an entrance, and displaying dynamic content. It was followed by the flagstone and the box. The flagstone is over 2m high and sticks out into the pedestrian way. However, it was solely made from engraved stone without any additional highlighting indicators. In comparison, we camouflaged the box by selecting a material that was reoccurring in the environment: concrete. It was mixed with fiberglass so that light could shine through. We attached LED strips in the back and controlled their color and brightness via an Arduino, powered by a power bank. The box displayed through an additional mask the word "info". It was much smaller than the flagstone but positioned on a bench at one of the square's main passages. As the most unobtrusive interfaces, we ranked the historical information sign and the QR code. We assumed the sign to be perceived easier as it is placed at eye-height and interrupting the wall's pattern to which it is attached. In contrast, the QR code was also made of concrete. We molded its patterns into a 3D shape, used black paint to emphasize the depth difference, and linked it to a website with information about the place. At the location, we placed it on a doorstep (cf. Figure 1), which is opposite the flagstone. The doorstep also slightly sticks out into the way, which is frequently used by passers-by. While the QR code was the smallest object, it is a familiar and a modern information medium for the historical testing environment. We summarized our design and placement considerations in Table 3, connecting our related work section with the results from our literature study.

5 FIELD STUDY

Our initial hypothesis guided the study design: Indirect users involved in interface-independent tasks will not notice the objects, whereas users engaged in interface-dependent tasks will.

We conducted a field study with 40 participants and randomly assigned each to one of four user profiles. Two profiles represented the indirect user group, and two defined the control group as the direct user groups. The main goal was to identify task-relevant as well as task-irrelevant objects and interface characteristics for both groups. An additional goal was to identify the groups' perception differences concerning the objects' perceived unobtrusiveness. We decided to conduct a field study with less controllable conditions, including realistic, external influences on (indirect) users' perception. As eye-tracking in the wild is still a rather unreliable and challenging task, we used the method of self-directed photography as described above. Similar to Moore et al. [84], we asked our study participants to document their personal opinions, liking, and perception of all task-relevant scenes and objects by taking photos and rating them afterward. We finalized the study by interviewing each participant in a semi-structured interview.

5.1 Location and Context

The chosen location was the first royal residency in Munich from eight centuries ago. The place is located in the city center and is currently used for multiple purposes and by diverse user groups. It includes a museum about the town's history and development, a bar, office spaces, and rental apartments. In the center of the residency's square, a fountain is frequently visited for taking a break or having lunch, while a road runs close by it. As can be seen from this description, the location attracts a dynamic audience with entirely different intentions for visiting it. According to the museum's director, results from a previously unpublished internal study revealed conflicting interests between inhabitants and other user groups about newly added objects, such as the illumination by an information screen at night. This mix of partly contradicting interests and the historic value of the location that should stay accessible to visitors made this location a good choice for our study.

5.2 Study Design and Preparation

As IB is often task-dependent (e.g., [89]), we developed four user profiles that provided different tasks for our participants (P). Ten participants enacted each profile. Table 4 shows the details of the tasks and each profile. We created profiles A and B, expecting they would report and note our control objects (the direct user group). In comparison, we expected the profiles C and D to ignore our control objects (the indirect user group). Each profile was created by considering the location's current user profiles, including a tourist, a lunch breaker, an apartment-hunter, and an a profile of an event organizer. We decided on two profiles per group to counteract potential limitations or biases caused by our task descriptions. The study was conducted over six weeks, and participants were recruited online.

At the beginning of the study, we introduced participants to the task and the location, informed them about hygiene measures[3] and data collection, which we processed and stored according to the GDPR. After signing a consent form also corresponding to GDPR, we asked participants to pick up a tablet and take pictures according to their task description. After this, participants were asked to fill out a questionnaire with demographic and rating questions using a 7-point Likert-scale from 1 = "very low" to 7 = "very high" for tracking their workload according to NASA-TLX [49] and from 1 = "very little" to 7 = "very well" for rating their pictures (A and B profile) or the control elements (C and D profile). We asked about six attributes related to the design of unobtrusive interfaces in the object rating:

(1) Level of embeddedness,
(2) Suitability,
(3) Perceptibility of the object as a potential interface,
(4) Perceptibility of the object in the environment,
(5) Recognizability,
(6) Easiness-to-ignore.

Finally, we concluded each session with a semi-structured interview to receive additional qualitative data about the ratings. Overall, the study took between 20-45min, depending on the task and the participant's thoroughness. We reimbursed each participant either monetarily (5€/30min) or by giving study credit points to students from our university, depending on their preference. Students' participation in user studies is a prerequisite by the department. However, because we left it to each participant to decide, we did not see any difference in motivation or performance.

Table 4. The four user profiles we designed for the study. A and B profile had the same task.

	Abbreviation	**Description**	**Task**
Control Group	A	Tourist	Take pictures of everything where you could get further information about the location or of information carriers as a one time visitor intentionally exploring the site.
	B	Lunch break taker	Take pictures of everything where you could get further information about the location or of information carriers as a frequent visitor who's main intention is to relax and take your mind of work.
Test Group	C	Apartment-hunter	Take pictures of objects or spots that could influence your decision to move to the place.
	D	Event manager	Take pictures of everything that could help you to decide on the place as event location.

[3]As the study took place during the COVID-19 pandemic, all participants and examiners followed the local hygiene and social distancing rules required. We additionally disinfected every device and pen after each participant. Since the study was conducted outdoors, we do not expect these requirements to have influenced our results.

5.3 Participants

We recruited participants via the university student mailing list, social media groups, the museum's social media group, and two neighborhood apps. In total, we had 22 male and 18 female participants ranging in age from 20 to 45 years with an average age of 27.5 years ($SD = 4.8$). The majority (27) were students (bachelor, master, and Ph.D.). The remaining participants represented four researchers, two architects, and various individual backgrounds. 20 participants had been at the study location before. The others were either not sure, had never been, or had forgotten. Overall, participants were interested in historical places, such as our testing environment ($M = 5,175$ with a $SD = 1,662$ on a 7-point Likert-scale from 1 = "very low" to 7 = "very high").

5.4 Evaluation

Our evaluation included three steps to clarify whether and how we can take advantage of IB in the design for public, urban interfaces. First, we compared which objects participants perceived as relevant for completing their tasks. Second, we reviewed how the different profile groups scored the aforementioned attributes per reported object and significant differences in the ratings. Third, we deducted the characteristics and potential interaction concepts from qualitative feedback. Additionally, we compared the profile groups' results.

Table 5. Recognition frequency of the control objects per subgroup (each $N = 10$), including the mean in % and the standard deviation. Not reported objects, such as the screen or the box by our test group (C/D), are labeled with "none".

	Screen	**Sign**	**Box**	**QR Code**	**Flagstone**	***M* in %**	*SD*
A	5	10	8	9	8	90%	0.035
B	5	9	2	4	8	56%	0.083
C	none	3	none	3	2	16%	0,023
D	none	1	none	none	1	4%	0,003

6 FIELD STUDY RESULTS

Our results support the hypothesis that direct users' and indirect users' perception differs regarding the ignoring of public interfaces (cf. Figure 4) depending on their task-relevance. The results differ greatly within our control group, as presented in Table 5. Control group B only documented 56% of the objects, whereas A recorded up to 90%. While the received task-relevance for the rated place objects are almost identical, they are much lower for our add-on objects. In comparison, we only see little differences in the indirect group results, which has a reporting rate of overall 10%. We could not identify any differences in results when participants had been at the location before or not. Hence, we ignore it for our result's presentation and discussion. Below, we present the statistical results as well as the qualitative feedback of the semi-structured interview. Quotes were translated from the participants' mother-tongue into English.

6.1 Task Load and Self-Reported Photography

When consolidating all group ratings (in the following reported on a 7-point Likert-scale from 1 = "very low" to 7 = "very high"), participants reported executing their tasks with low mental effort ($M = 2.05$, $SD = 1.04$) and minimal feeling of stress, annoyance, or irritation ($M = 1.6$, $SD = 1.17$). On the contrary, they felt rather successful in accomplishing their task ($M = 5.175$, $SD = 1.24$).

The reasons for noticing and documenting the control object differed per object and subgroup. Here, we present a summary of mentioned arguments per object that are relevant for the following discussion. Beginning with the screen, subjects reported that it was partly hard to see because of its darkened display. "I saw there was something there but didn't realize it was [a] screen" (P D6). Even participants from the direct group reported that

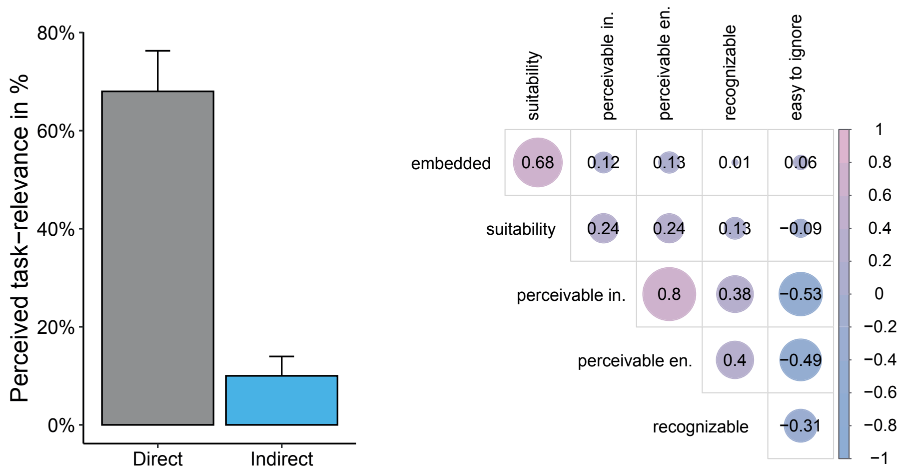

Fig. 4. Left: The overall rate of reported control objects in percent by groups, direct(A/B), and indirect (C/D). Right: The correlation between the attributes over all objects. We abbreviated the attribute “perceivable as an interface” to perceivable in. and the attribute “perceivable in this environment” to perceivable en.

something was moving but that it was hard to recognize what was displayed. While the sign’s content was also mentioned to be hard to read, participants expected these interfaces as typical artifacts for such environments and were hence, more attentive toward it. From the indirect user group, 4 participants also reported it because it would show interesting historical information about the place.

As one of our add-on objects, the light concrete box was not primarily recognized as an information interface but instead interpreted as a lost or forgotten loudspeaker and hence, mainly ignored. In comparison, as participants were familiar with QR codes, they captured it more often. “[...] I specifically looked for something interesting”, stated P C10, mentioning that the location’s history would be relevant information for her decision-making. Lastly, the flagstone seemed clearly task-related to the direct group but was mainly ignored by the indirect group. Participants from the indirect subgroup C partly included the flagstone as it appeared as an interesting feature of the environment that they could further share with their visitors. I.e., “I look[ed] for things to show people” stated P C2. Reasons against noticing it was that it would have looked neither interesting nor task-relevant.

6.2 Correlations of Interface Attributes

The Likert-scale ratings were not normally distributed. Hence, we evaluated the data using Kendall’s rank correlation coefficient and adjusted the data with the Benjamini and Hochberg method [7] in R version 1.2.5033, including the packages “corrplot” and “psych”.

Figure 4 shows the dependency between embedded interfaces and their perceived suitability. The results further indicate that the recognizability of interfaces is completely unrelated to their level of embeddedness. In comparison, the perceived suitability is slightly negatively correlated with the ease of ignoring an interface. The perceptibility ratings further strengthen this finding. Suitable interfaces also show a weak correlation to being perceivable as an interface and a certain environment.

Stronger correlations can be found in the comparison of both perceptibility ratings and each perceptibility rate to the recognizability values. The negative correlation of these three values to the easiness of ignoring interfaces is consistent with the aforementioned correlations.

6.3 Results per Control Object

Inspecting the attributes on an object level, we present the most diverse results below, including the screen, the QR code, and the flagstone profile in Figure 5.

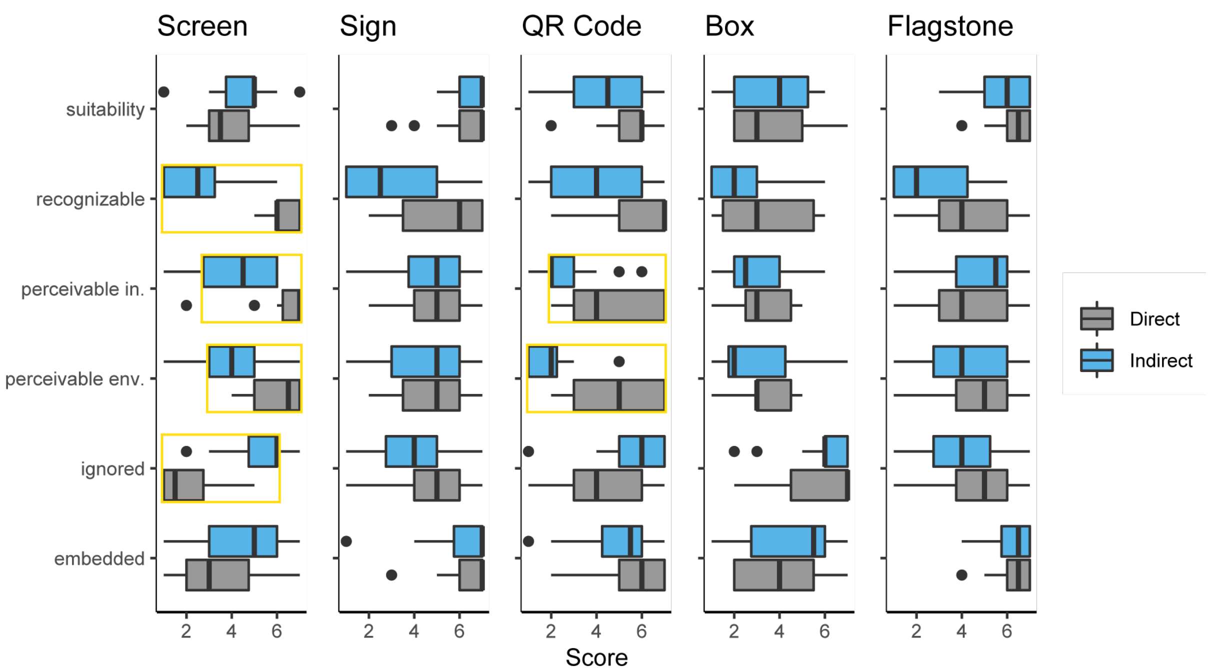

Fig. 5. The evaluated object profiles on a scale from 1 = "very low" to 7 = "very high". We highlighted ratings where there is no overlap between the direct and the indirect group's ratings, indicating a clear perception difference at group level.

The largest differences in rating between the direct and indirect user groups appeared in the screen profile. As an example, the indirect user group rated its recognizability low but easy to ignore. The direct user group rated the exact opposite. This mirrors the results from the self-directed photography method and reveals the screen as one type of interface, where we can benefit from IB in indirect users. However, the direct user group gave only low to medium ratings concerning the device as embedded and suitable for the environment.

The QR code showed the largest diversion in its perceptibility ratings. On the one hand, the indirect user group rated it consistently below three for both perceptibility attributes. On the other hand, the direct user group chose higher average scores with more variability. Similar to the flagstone, the QR code can be considered easy to ignore yet recognizable and perceivable as an interface. In contrast, ratings by the direct user group show overall high scores for each of the attributes. Considering the perception rate per subgroup, a QR code seems to be another example where IB can be exploited according to our hypothesis. However, the QR code design is challenged by being almost too unobtrusive if we further look at the results by subgroup B (Table 5), in which only four of ten participants reported on it.

The flagstone shows overall, equally distributed ratings between groups. Together with the sign, participants rated it as deeply embedded and suitable for the environment while also rating it as particularly perceivable and easy to ignore. Additionally, the direct group equally scored its recognizability, whereas the indirect group ratings show the biggest rating differences.

6.4 General Qualitative Feedback

In the interviews, participants gave feedback to interfaces at historical places such as our testing environment, including remarks on our control objects' design. Overall, they emphasized the importance of interfaces to support the location's atmosphere and value instead of interrupting it. "[Interfaces should be] very unobtrusive, you don't want to take away anything from the history of the place. I think the screen is a bit too technologically advanced for this place [...]" stated P D6. Besides embedding technology into existing objects and turning those into interactive interfaces, about a third of the participants preferred either the interaction via phone or no interactivity. Especially concerning the historic objects, the sign and the flagstone, participants differed greatly in their opinion. One would appreciate a "Harry Potter interaction" (P D8) in which the letters of the sign would change and move around. Others would rather keep it as it is and add information on an interface beside it.

7 DISCUSSION

In our work, we address the current research gap concerning the role of IB in the design of unobtrusive interfaces for public real-world contexts. The topic is especially relevant for shared, public places where interfaces ideally are unobtrusive for indirect users but will be easily perceived by direct users. In the process, our literature review showed that IB is almost exclusively discussed in the context of lab studies (e.g., [20, 21, 24]) and the perception of digital content (e.g., [43, 70, 76]). Nonetheless, we found several strategies to overcome (cf. Table 1) or exploit (cf. Table 2) IB in HCI research. This includes design considerations for the information positioning in space, applied color-coding, or patterns. The survey results influenced our prototyping process and the selection of control objects for our field study (cf. Table 3). Our field study's main results revealed that IB varies for direct and indirect user groups, and so does its influence on how obtrusive or unobtrusive interfaces are perceived. This supports our initial hypothesis that indirect users are less likely to notice public interfaces.

Below, we discuss our study results, emphasizing the role of IB in HCI domain, focusing on unobtrusive interface design for real-life context, and shared public places. We start by stating our study's limitations to frame the scope of our results.

7.1 Limitations

In our literature study, we excluded references using synonyms, closely related terms, or findings from other research fields by including the keyword "inattentional blindness" from the ACM Digital Library only. Our field study results revealed weaknesses in the B and C profiles. Participants were either less (B profile) or more interested (C profile) than we anticipated. However, profiles A and D counterbalanced the results (cf. Figure 5).

Our method's explanatory power is limited by the qualitative measurements and the subjective feedback that does not necessarily have to concur with more objective data such as physiological proxies of visual attention, e.g., eye-tracking, as utilized in lab-based studies. However, our newly introduced photography-oriented method allowed for economically measuring the effect of IB in a real-world context. Note that we also ignored any cross-modal influences, such as surrounding noise, sounds, smells, etc., that have been shown to influence IB in laboratory studies [82, 93]. However, while conducting our study over various weeks and thus varying conditions, no significant difference occurred on a day-by-day basis that we can report on.

7.2 IB for Urban Interface Design in Shared Public Places

The field study results support the literature study findings that IB is overall a *task-dependent phenomenon*. This means that IB differs between direct and indirect user groups, independently of how the visual information is processed (bottom-up or top-down).

Salient, but ignored. We saw this particularly confirmed in the screen, which we ranked as the most obtrusive of our control objects considering Leifer's framework (cf. Figure 3). It already includes salient cues in moving and colorful pictures, which would appeal to task-independent bottom-up perception [41, 68]. Yet, it was only reported by the direct user group. The indirect user group did not report on it once but instead rated it also high on the attribute "easy to ignore". Therefore, we suspect that the interface's high salience has only triggered bottom-up attentional processing in the direct group and not in the indirect group. Hence, we suspect that the application of cues triggering bottom-up processing is similarly effective for direct users as in laboratory studies [65, 88]. However, the indirect user group's results indicate that even salient features can be ignored if not task-relevant. This is also in line with laboratory studies of Simons and Chabri's and others' [14, 94, 104].

Top-down perception before bottom-up. A participant from subgroup C, i.e., ignored the screen but photographed the QR code and the flagstone because he wanted to share "interesting information" with friends. This particular example strengthens the hypothesis that top-down processing has a stronger influence on the perception in public environments than bottom-up cues. From this, we can further specify that a person's semantic interest [54, 96], their intention of visiting a place, as well as the task-dependent prior knowledge [37, 53] are key in the perception of public interfaces. We also relate these aspects to explain the differences within our control subgroups A and B. Participants of subgroup A were supposed to have a touristic, one-time experience with the intention to visit the place and reported on our control objects up to 90%. In comparison, subgroup B's participants perceived less interesting objects to report on (M = 56%). While lacking the data to have a more in-depth explanation, the main difference between the two subgroups was the profile descriptions, including the intention to visit the place.

User group depending attention-guidance. With our findings, we can show that with a careful design that draws upon IB's concept, we can manage varying stakeholder interests and intentions in shared, public places [27]. We suggest to include it already at the beginning of a design phase when user profiles and requirements are generated and instead create user group profiles and requirements. Our approach aims at a user group-centered design, including the design for the indirect user group. In this way, indirect users could turn into non-users because they would ideally neither notice the interface nor interact with it in future iterations. Considering IB in the design process supports to design for semantically interested and non-interested or task-relevant and task-irrelevant groups. Therefore, our results can inform the design of unobtrusive interfaces for indirect user groups and obtrusive interfaces for direct user groups.

7.3 IB for Unobtrusive Interfaces

Our results of the subjective Likert-scale ratings combined with participants' qualitative feedback confirmed the need for unobtrusive interfaces for our testing environment. This aligns to findings by Häkkilä and Colley [47] as well as by Häkkilä et al. [48] who emphasized the need for unobtrusive interfaces at sensitive, historical places. However, our results further show a conflict between an interface's embeddedness and perceptibility. Increased embeddedness was rated as more suitable for the target environment but also as little perceivable or recognizable (see Figure 4). Interfaces should still be perceivable and accessible when needed [3, 119]. The emerging question is whether IB can support to balance both the perceptibility and unobtrusiveness of the same interface by adapting its perceptibility on a user group level by design.

Balancing IB. In our prototyping, we used similar materials, placement strategies, and color schemes from the environment to exploit IB. We based this approach on suggestions by Wiethoff and Hußmann [120] and Huang et al. [57], who noted that it is viable to use every-day objects or the every-day environment as readily available interfaces. In line with this idea, we applied *soft pop-out effects* and small representations of known and familiar interactivity indicators to overcome a potential IB of the direct user group. Hence, we used bottom-up and top-down processing cues to guide the users' attention and to find a balance for IB per user group [26, 39, 68, 81]. To increase the interfaces' obtrusiveness and potentially achieve 100% recognition by the control group, we suggest to apply stronger visual, attention-grabbing cues as presented in Marcos et al. and others [11, 29, 32, 65, 76, 80, 88, 94, 117]. This could include using stronger contrasting colors for the interfaces or by creating a framing effect that emphasizes the interfaces more to stand out from their surrounding. We further see potential in exploring multi-modal approaches, such as the spatial audio-guide in Albrecht et al. [1]. However, these points can be considered hypothetical because they are limited to this study's scope and context and thus need to be explicitly addressed in future studies.

Balancing (un-)obtrusiveness. Considering Figure 5, there are clear differences between the direct and the indirect user group's ratings on the object-level. The QR code, i.e., was much appreciated because it blended in with the environment but still provided accessible information on the spot. It is a good example of an object that was rarely perceived by the indirect user group but overall often perceived by the direct user group. We positioned the QR code on Leifer's framework [69] as the least perceivable (cf. Figure 3) due to its non-reactivity and being placed rather in the periphery of passers-by. However, participants recognized it as an information source. They reported it more often than, i.e., the screen, which was often not perceived due to, i.e., being in dark mode (cf. Table 5). The QR core was further rated as highly embedded, recognizable, and easy to ignore. Hence, it is a good example of an object perceived as task-relevant by the direct user group, yet unobtrusive and mostly ignored by the indirect user group. We can conclude that the consideration of IB in both the design and in the placement of an interface supports the balance between an interface's perceptibility and unobtrusiveness.

7.4 IB in HCI: Research Gaps and Opportunities

Based on the discussion points above, we see great potential in including IB in the perception of public interfaces at an individual and user group level, in general. This also hints at other related issues, such as light pollution [40] and information overload [31] caused by current public interfaces. It reveals a gap between the design considerations for calm and unobtrusive technology [19, 97, 118] and the actual design of interfaces at shared, public places for multiple users. Perceptual psychology could act as a connecting factor here. Our findings can further be transferred to any kind of user group-centered designs (targeted for public context or not). Hence, we see additional research gaps and opportunities deriving from this.

Opportunity for pervasive displays. I.e., pervasive displays struggle with guiding and capturing users' attention [12, 17, 116]. Our findings contribute to this challenge by considering IB in the design process and the placement strategy of the interface in context. We provide a solution for interfaces to move between the focal point and peripheral attention easily. I.e., designing pervasive displays to appear task-relevant could make them more explicit and recognizable to their targeted user groups, contributing to the challenge mentioned by Davies et al. [28]. However, the question is outstanding about how applicable the design for IB is for rich media content.

Adapting to attention. Our findings further relate to the application of attention-aware systems. Those systems are an alternative solution with similar ideal considering to offer information only when the user's attentive behavior has been recognized [2, 17]. However, they ignore the users' intentions and display information regardless of the user's goal. Such systems are also still challenged by the complexity and dynamic conditions of public contexts. Hence, we see the potential in shifting this responsibility of perceiving information back to users and designing for what they perceive as task-relevant and irrelevant instead of for their attentional behavior.

IB outside the lab. Lastly, another research gap we identified is the lack of established methods to track and measure IB in real-life contexts. Hence, we introduced the self-directed photography method by Moore et al. [84], slightly adapted to our study context. Bessa et al. [10] used a similar methodology using photographs to report on attention-capturing cues. Combining both examples and our study experience, image capturing seems a valid and appropriate methodological approach to track IB in real-world scenarios. However, future work is needed to determine the scope of it.

8 SUMMARY AND CONCLUSION

Our work focused on whether inattentional blindness (IB) can be used to design interfaces for shared, public places that stay unobtrusive for indirect users but are noticeable by direct users. We began by researching the role of IB in HCI by conducting an extensive literature study based on a keyword search in the ACM Guide to Computing Literature. Our results reveal that IB is mainly exploited for image rendering in laboratory studies to hide changes or unnatural conditions from the user. However, it is little discussed in the design of public interfaces in a real-world context.

Hence, we selected five objects, of which three were already embedded in our target environment, and two were prototyped by us. With these objects, we conducted a field study using self-directed photography as a method. We introduced four profiles, two for the direct user group for which the objects were task-relevant and two for the indirect user group for which they were not. We evaluated the perception rates per group and object and found that direct users noticed the objects much more frequently, thus supporting our hypothesis.

We also revealed a gap in HCI research about exploiting and preventing IB in the design of public interfaces as an alternative for attention-aware systems, which opens up design space for further research projects.

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