IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 8 April 2023, accepted 20 April 2023, date of publication 27 April 2023, date of current version 4 May 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3270909

RESEARCH ARTICLE

Attracting Effect of Pinpoint Auditory Glimpse on Digital Signage

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This work was supported by Japan Society for the Promotion of Science (JSPS) KAKENHI under Grant JP21J20397 and Grant 22H03693.

This work involved human subjects or animals in its research. Approval of all ethical and experimental procedures and protocols was granted by the Faculty of Engineering, Information and Systems, University of Tsukuba, under Application No. 2020R434, and performed in line with the Declaration of Helsinki.

ABSTRACT Advertising signage installed in public spaces is intended to be seen by passersby to increase recognition. However, display blindness often occurs because people either assume that the displayed content is not relevant to them or the display blurs into their surroundings and they remain unaware of it. To improve advertisement recognition, it is necessary to solve display blindness. Although emitting a sound might be a solution to make passersby be aware of its presence, it would become noisy and make the space discomfort. We propose the use of a pinpoint auditory glimpse that stimulates a passerby to pay attention to signage by playing a pinpoint sound. Through acoustic measurements and participant experiments conducted in a pseudo-store, it was found that (1) the use of a pinpoint auditory glimpse can effectively trigger passersby to pay attention to signage and (2) the pinpoint auditory glimpse does not negatively impact purchasing behavior, despite emitting sound. This paper presents findings on a novel sound-based solution to the problem of display blindness.

INDEX TERMS Advertisement, display blindness, pinpoint auditory glimpse, public display, parametric loudspeaker, user-glimpse funnel.

I. INTRODUCTION

Digital signage is an electronic board that displays a wide range of information to the public. When installed in public spaces, these boards are more likely to catch the attention of a large number of people. Companies often use these boards to present advertisements to inform people about their services and products. As awareness of the advertisement spreads, passersby become more interested in the content, leading to more purchases and consumption [1]. In other words, as noted in Figure 1, recognition of advertisements is essential for selling services and products, and for this reason, it is necessary for people to see the signage.

The associate editor coordinating the review of this manuscript and approving it for publication was Orazio Gambino.

However, it has been found that this signage fades from view in public spaces [2], [3]. Müller et al. call this phenomenon "Display Blindness" [3]. In particular, it has been reported that when an advertisement is publicly displayed, it is often irrelevant to passersby, which can lead to a passive attitude towards the advertisement. Observational studies conducted in shopping malls have also shown that many digital signs are only seen from a distance and briefly [4]. In other words, the problem is that even when advertisements are presented on signage, they are rarely seen by passersby and do not spread awareness. Therefore, this display blindness problem must be solved to increase advertising effectiveness.

In previous Human-Computer Interaction (HCI) research, various solutions to display blindness have been attempted that rely on visual perception. These solutions have been

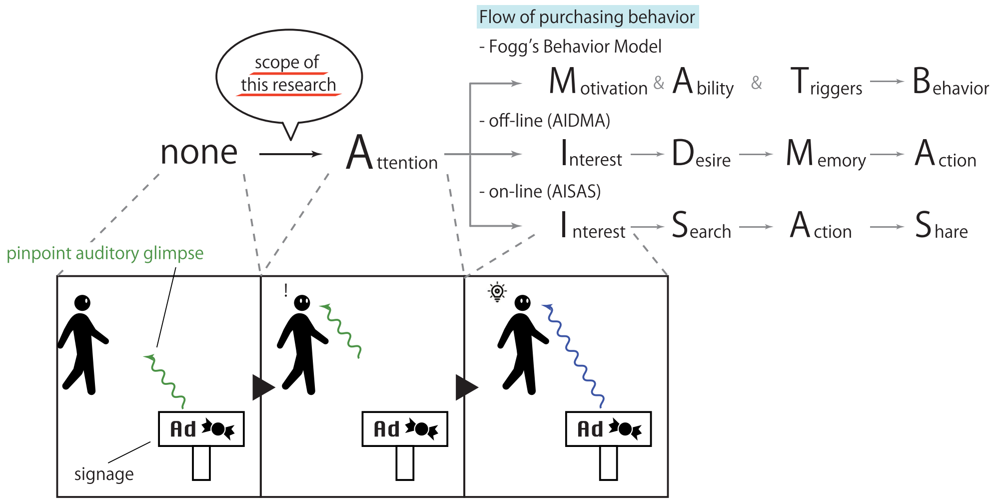

FIGURE 1. **The motivation of this paper and the flow position of purchasing behavior: For consumers to purchase services or products ("action" in AIDMA and AISAS model, "behavior" in Fogg's Behavior Model), it is essential for them to be aware of the advertisements (transition from none to attention). Therefore, it is necessary for advertisers' signage to be viewed. However, it has been shown that this signage is rarely seen in public spaces, which is called display blindness. This paper proposes an on-demand pinpoint sound signage presenting the pinpoint auditory glimpse, aiming at both recognition of the advertisement and comfort within the acoustic environment. This proposed system serves as a "trigger" to make passerby aware of the presence of the signage.**

proposed by studies that devise visual content meant to attract people's attention [2], [3], [5], [6], [7], [8] and by studies that physically place signs to lead people's visual focus to the signage [9], [10]. All of these have been reported to be effective in increasing the attention of passersby to signage. However, in urban areas, signage is often buried by many other visual things that compete for attention [4]. In addition, there are cases in which the display is small due to installation location constraints or in which the display is behind passersby. Thus, even if the display attempts to attract attention visually, passersby may not notice the presence of the display and not see it at all. Therefore, it is necessary to develop a method to attract attention to the display as an alternative to visual methods.

One potential solution to display blindness is to utilize sound in addition to vision. Even if a display is out of sight, its presence can be made known through sound. However, to our knowledge, there are few papers in HCI research that have considered sound-based solutions. In a limited study, Nordfält reported that sound can make passersby aware of the presence of a display even when it is behind them [11]. However, constantly emitting sound from a display can be considered noisy and may not be effective in attracting people's attention, especially if the sound is from an advertisement. Kuratomo et al. proposed a signage system that delivers sound only to those who are paying attention, using a camera to determine the level of attention of passersby and delivering pinpoint sound only to those people judged as attentive [12]. This can reduce noise, but if passersby do not look at the signage, the sound will not be played and the goal of informing the user of the display's presence will not be achieved. Therefore, further research is needed to develop sound-based solutions to display blindness that minimize noise and effectively inform users of the display's presence.

This study proposes a system called "pinpoint auditory glimpse," which uses sound to notify passersby of the presence of signage. The system presents pinpoint sounds to a passerby walking near the signage as a kind of "pump-priming," as shown in the Figure 1. In other words, there is no sound until a passerby approaches the signage, but the sound is initiated the moment they approach the signage, with the intention of making them aware of the presence of signage. Additionally, the pinpoint auditory glimpse is designed to be presented only for a short period of time to prevent noise pollution. However, it is necessary to verify whether the brief presentation of pinpoint auditory glimpses serves to increase recognition of the advertisement. Furthermore, the suddenness of the sound presentation and the addition of the pinpoint auditory glimpse in a noisy environment, such as a shopping mall, may increase discomfort among passersby. Therefore, this study poses research questions from two perspectives: advertisement recognition and the comfort level of passersby.

1) RQ #1. Does the presentation of the pinpoint auditory glimpse improve recognition even for a short time?
2) RQ #2. Does presenting the pinpoint auditory glimpse make the acoustic environment less comfortable?

In this study, research questions were tested by conducting a participant experiment in a pseudo-store that compares two conventional methods, silent signage and signage with a loudspeaker constantly emitting sound.

The contributions of this study are as follows: (1) The pinpoint auditory glimpse is capable of improving cognition without being perceived as noise. Thus, we will establish a new method for addressing display blindness caused by sound. (2) We will explain that the pinpoint auditory glimpse can be used not only for advertisements but also for making people aware of the existence of various types of information and interactive displays. It can also be used regardless of visual elements or context. We will discuss possible applications and report participants' behavior to provide insights for future design.

The paper is structured as follows: In Section II, we explain previous works related to this study from the viewpoint of the relationship between advertisement recognition and signage, resolving display blindness, and audience funnel. In Section III, we present the design of our proposal, the "Pinpoint Auditory Glimpse." In Section IV, we provide an explanation of the user experiment, including the experimental environment, advertisement selection, system performance test, experimental methods, and results with passerby observations. In Section V, we discuss the limitations and implications of our results, which provide answers to the research questions. Finally, in Section VI, we present our conclusion.

II. RELATED WORKS

This study aims to attract passersby to signage by using sound to enhance advertisement recognition. Therefore, this study is related to three areas: (1) the relationship between advertisement recognition and signage, (2) the solution to display blindness, (3) the passerby's behavior around the display, and (4) the role of the sound icon.

A. RELATIONSHIPS BETWEEN ADVERTISEMENT RECOGNITION AND SIGNAGE

In this section, we will first explain how signage is related to advertisement recognition. Advertising is a tool used to promote products and brands, which can lead to consumer purchasing behavior. Recognition of the advertisement is a crucial and fundamental step in the purchasing process. There are three main purchasing models: the AIDMA model [13] corresponding to off-line, the AISAS model [1] corresponding to online, and Fogg's behavior model [14] corresponding to offline and online commonly.

The flow of purchasing behavior can differ between offline and online environments. Offline purchasing behavior typically follows the stages of Attention (pay attention to an advertisement), Interest (interested in a product or service), Desire (desire to buy), Memory (memorize), and Action (buy in a physical store) [13]. The online flow is referred to as Attention, Interest, Search (search on the internet), Action (buy it online), and Share (spread the product or service on social networking sites or other sites) [1].

Attention, in particular, is defined as the behavior of "a consumer who notices a product, service, or advertisement" that leads to action, which is defined in this instance as "becomes a firm decision to make a purchase." There are cases where a purchase is made online after seeing an ad in digital signage. Attention, which is the scope of this study is to increase, and interest are common to both offline and online flows, as noted in Figure 1. However, not everyone who experiences attention moves on to action, but rather the percentage of those who do is decreasing rapidly. In other words, it is important to greatly increase attention to increase action.

The Fogg's Behavior Model consists of three elements necessary to elicit human behavior: "motivation," "barriers to action," and "triggers." Once these elements exceed a certain threshold, they lead to "behavior." In this case, the "behavior" refers to a purchasing behavior. The advertising aims to appeal to these three elements and to increase purchasing behavior beyond the threshold. In this sense, it is also important to increase Attention [14], [15].

Furthermore, the presence of in-store signage tends to make products seem like a bargain and increase customers' unplanned purchases [16], [17], [18]. This means that the signage can enlarge the actions in the purchase funnel. Consequently, it is both important and effective to stimulate people to actually see advertising signage. Hence, the objective of this study is to address display blindness to improve the recognition of advertising signage.

B. RESOLVING DISPLAY BLINDNESS

The previous section established that it is important for advertising signage to be seen. This includes not only advertising signage but also other information presentation displays and interactive displays and getting people to notice the presence of the display is the first step toward achieving effectiveness. Therefore, previous studies have contributed to the resolution of display blindness by devising various visual stimuli.

Huang et al. reported that the use of video content and signage at the eye level have made it easier to attract the attention of passersby [2]. Using animation in the content also improves the attention level [5], [6]. In addition, the vivid colors of the images make the display stand out and be seen easily [3], [7], [8]. Furthermore, visual stimuli such as changing luminance and the appearance of new objects also increase attention and contribute to increased interaction [19]. Studies which included a footprint positioned to guide the interaction [9] or physically waved a hand to call passersby [10] successfully notified people of the display's interactive elements and encouraged the passersby to initiate interactions. These studies addressed the first click problem [7], which refers to the difficulty of initiating interaction with signage. It has also been reported that placing mysterious objects in front of the display, completely unrelated to the display itself, can also attract attention to signage [20].

However, many passersby to whom the ads are presented have a negative attitude that the ads are of no interest to them. Field observations have reported that this has led many people to not look at ad signage in public spaces, even in prominent locations such as escalator signs, or to look at the signage only briefly as part of the scenery [4]. This means that there is a limit to the effectiveness of location devising, and it is obvious that people are even less likely to look at small signage installed among product shelves or similar locations. Therefore, in this study, we aim to overcome display blindness by using sound as an alternative to the traditional visual approach.

C. AUDIENCE FUNNEL

Our study uses audio as an alternate solution to display blindness than the visual modality. However, when the sound is heard by people who are not interested or who are not shopping, it will become noise and reduce the acoustic comfort level. Thus, it is necessary to present sound with the appropriate timing and at the appropriate sound level to notify a passerby of the signage's presence. Accordingly, it is necessary to consider the behavioral characteristics of the passersby who are exposed to the sound as a result of the display.

Prior studies have made various attempts to model the display and its effect on the audience's behavior. In studies of interactive displays, there are systems that divide the distance between the user and the display into zones and change the presented content accordingly. This improves information accessibility and personalization. Thus, it is easier to draw the user in and keep them interacting [21], [22]. There is a model that categorizes the concept and includes an interaction phase called the audience funnel [23]. This is meant to model the user's typical interaction-related behavior, which has allowed for a calculation of effectiveness based on the percentage of action phases, such as people passing by the display, initiating interaction, and continuing to the end. There is also research that creates a follow-up action at the end of the interaction based on the audience funnel to make people re-engage [24]. This is indeed a system that is based on the behavioral model of the audience, and its effectiveness has been verified.

Regardless of which model is used, they are all built on the idea that users have different degrees of interest in the display, and that it is important to present different information to each user. Based on this idea of the audience funnel, this study creates a model of passerby behavior when confronted with signage using a pinpoint auditory glimpse, which is called "User-Glimpse Funnel". We will also discuss the behavior of participants for each User-Glimpse Funnel through experimental observations.

D. SOUND ICON

Sound icons play a role in "drawing attention and prompting the next action." This is especially true in cases where something is not in the field of vision, and sound is often used to draw attention to it. The most familiar example is the notification sound on mobile phones. The purpose of this sound is to alert the user to the arrival of new information, such as new emails or incoming calls (unless the phone is in silent mode). It has been reported that even when not looking at the smartphone, users can react quickly to notifications by playing the ringtone [25]. Similarly, the jingles played at train stations serve to inform passengers that new information about the train is about to be announced and to prompt them to listen [26].

Not only new information but sounds also play a role in expressing traffic warnings. For example, railway crossings play a sound to stop vehicles to avoid collisions between trains and vehicles [27], [28]. Additionally, there is auditory feedback for potential dangers at intersections, especially for older drivers who may have difficulty noticing them [29]. This helps compensate for age-related cognitive decline and alerts to potential dangers.

Fire alarms sound warnings in locations within the same building where the flames are not visible [30], [31]. Similarly, emergency alerts widely inform about crises that are not visible [32], [33]. These sounds are designed to be uncomfortable, prompting people to evacuate as quickly as possible from life-threatening situations such as fires and tsunamis.

Sounds are also used as an alternative to perceptual information. There are many technologies that audible maps for navigation as assistive technologies. Capturing images and providing feedback allows for safe crossing at dangerous locations such as crosswalks, often presented in conjunction with tactile feedback [34], [35]. Additionally, technology that conveys which direction facilities are in [36] leads to intuitive actions by turning facilities into spatial sound icons.

As these examples show, there are many instances where sounds are used to "draw attention" to things that are not visible. This study also aims to draw attention to and focus on signage when it is not in the field of vision or when pedestrians are not consciously aware of it.

III. DESIGN OF THE PINPOINT AUDITORY GLIMPSE

A. SYSTEM OVERVIEW

In this study, we propose a system that presents a pinpoint auditory glimpse to passersby approaching the signage for a short time and changes the sound level depending on the degree of their attention in response. The system schematic is shown in Figure 2 a).

A parametric loudspeaker is used as the sound emitter. A parametric loudspeaker is a device that arrays ultrasonic waves while transmitting a signal that demodulates them into audible sound by using the nonlinearity of their propagation through the air, resulting in audible sound with a narrow directionality [37], [38]. Thus, the sound can only be heard in the area facing the parametric loudspeaker, and this is used in a variety of consumer applications [39], [40], [41].

The parametric loudspeakers are mounted on two motors for emitting sound to the left and right ears, as illustrated in Figure 2 c), the two motors move in the azimuth and elevation directions. A camera is used to track a passerby and keep track of the spatial coordinates of their heads and ears. The displacement angle of the motor is calculated based on the spatial coordinates of the ears, and when a passerby is within the range of the camera, the parametric loudspeaker continues to move so that the parametric loudspeaker is facing the ear.

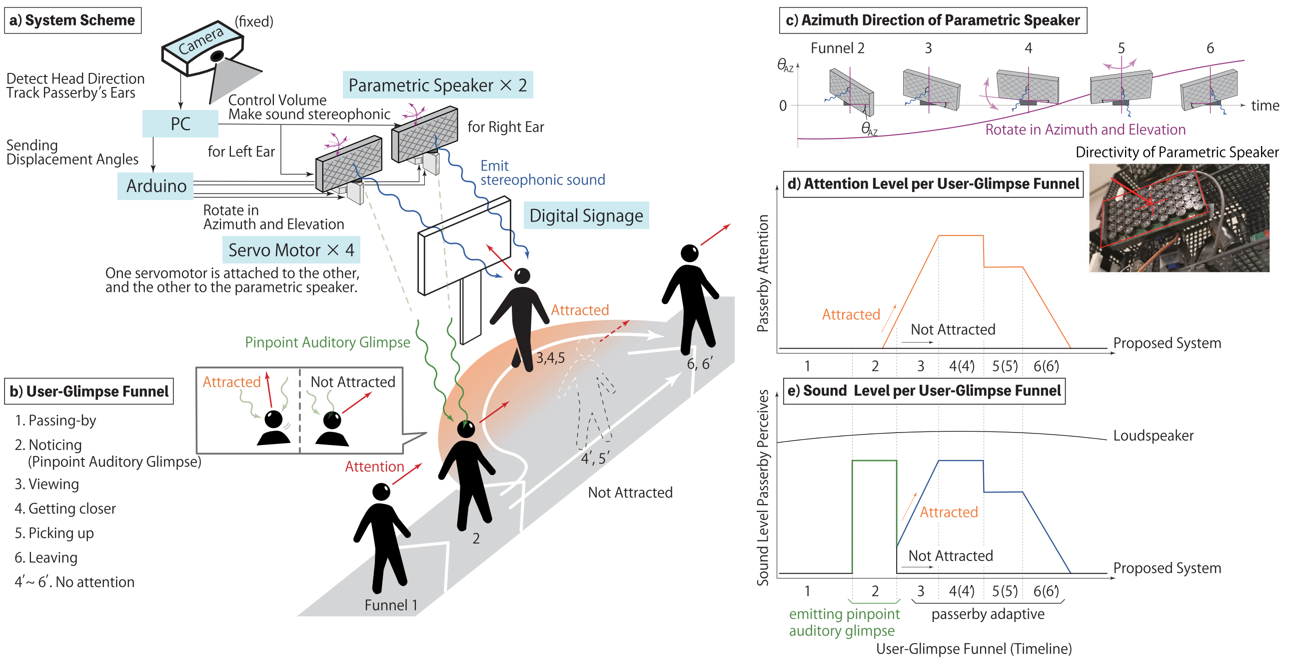

FIGURE 2. a) Architecture of the proposed system: Cameras are used to track the spatial coordinates of a passerby's head and ears. Parametric loudspeakers mounted on two motors rotate in azimuth and elevation to constantly follow the passerby. When the passerby approaches the signage, the pinpoint auditory glimpse is presented for a certain amount of time. The sound level varies depending on the direction of the head. b) User-Glimpse Funnel – Behavior flow of passerby when using digital signage with a pinpoint auditory glimpse. After emitting a pinpoint auditory glimpse, the flow is divided into two patterns: one for when the passerby pays attention to the signage, and another for when they do not. c) Orientation of the parametric loudspeaker in the proposed system, d) Attention level per User-Glimpse Funnel, e) Sound level fluctuation of the proposed system and loudspeaker: In Funnel 2, the pinpoint auditory glimpse is emitted regardless of the passerby's level of attention to attract their attention. After a particular time, it moves on to Funnel 3 and beyond, adjusting the sound level based on the passerby's level of engagement.

This ensures that only specific people can hear the sound and that it does not reach nontarget users.

The pinpoint auditory glimpse is presented when the user approaches the signage. The content of a pinpoint auditory glimpse is the corresponded audio as the video content playing on the signage. Then, if the user remains interested in the signage, the sound level changes as described above. If the user is not interested in the signage, the sound level is reduced so that it does not become noise. This is important because, while pinpoint sound serves to attract users to the signage, it should not be noisy, so it is only played for short time intervals, such as one second.

After the pinpoint auditory glimpse is emitted, the sound level is changed according to the passerby's attention level, as per previous research [12]. The sound level is changed according to the direction of the face as observed by the camera, which calculates whether the face is facing the direction of the digital signage and, if not, how far away it is. If the face is looking at the signage, then the sound level is set to a maximum, and if it is not, then the sound level decreases as the face moves away, as shown in Figure 2 (d) and (e). If the passerby is looking away and ignores visual content, then the system will automatically fade the sound so the passerby can ignore audio content. Therefore, the only noise that the user hears occurs during the pinpoint auditory glimpse, which is active for only a very short period of time. This scheme works with only one speaker. For the sake of providing a sense of localization, however, the sound is presented stereophonically so as to specify its source [42].

By controlling the exposure time and sound level as described above, the objective is to make it sound as if it has suddenly played while not creating noise in the surrounding area, thereby drawing attention to it. Additionally, the sound is not a special sound like an alert, but is the same as the content of the video, so that the passerby does not feel alerted.

The servo motor used in this study was an SG-90, which moves in 0.1-degree angle increments. The camera was an Azure Kinect, and the sensing during system runtime was approximately 30 fps. The parametric loudspeaker was a Tri-State K-02617 with as many as 50 transducers (AT40-10PB3) connected to it. Three Arduino UNO R3 microcomputer boards were used. The control application was developed in C++ and executed on Windows 10. The system latency, from the first detection of a person to the presentation of a pinpoint auditory glimpse, was up to 41 ms (average 40.07 ±0.68 ms). This is below perceivable time, and the system operates in real time with almost no subjective delay.

B. PINPOINT AUDITORY GLIMPSE AND USER-GLIMPSE FUNNEL

We applied the audience funnel [23] to the new behavior flow, which is specialized for using the proposed system.

The created funnel is called a User-Glimpse Funnel, which is shown in Figure 2 b). The level of attention and corresponding fluctuation in volume level compared to those of the loudspeaker signage are depicted in Figure 2 d) and e). The user-glimpse funnel is divided into six stages, which are explained in conjunction with the operation of this system as follows:

1. Passing-by: The passerby is walking toward the signage. The signage does not emit any sound.
2. Noticing (Pinpoint Auditory Glimpse): The passerby approaches the signage. The signage emits a pinpoint auditory glimpse for a certain period of time.
3. Viewing: The passerby reacts to the pinpoint auditory glimpse and pays attention to the signage. The signage stops the pinpoint auditory glimpse after a certain time.
4. Getting closer: The passerby pays attention to the signage and, in some cases, approaches it. The signage increases the volume depending on the direction of passerby attention.
5. Picking up: The passerby is attracted to the product displayed by the signage and puts it in a shopping cart. The signage output is turned down slightly.
6. Leaving: The passerby walks away. The signage decreases in volume and eventually reaches a minimum.

4' . No attention: The passerby is not attracted to the signage and does not pay attention to it. The signage stops the pinpoint auditory glimpse after a certain time.

5', 6'. No attention: The passerby walks away without paying attention to the signage. The signage keeps the sound level to a minimum.

User-Glimpse Funnel has two features. The first is the transition between stages 2 and 3 of the Funnel. The pinpoint auditory glimpse is presented at the time of approaching the signage to draw the attention of the passerby to the signage.

The second feature, Funnel 4 and beyond, adjusts the sound level based on the passerby's continued attention to the signage. If the passerby continues to pay attention, the sound level increases. However, if they pass by without paying attention, the sound level decreases. This allows for control of the amount of information received and the creation of an appropriate sound environment.

Traditional silent signages do not provide an opportunity for passersby to pay attention, resulting in display blindness. Additionally, systems that use loudspeakers do not take into account the passerby's position or attention, leading to an uncomfortable sound environment. The proposed system aims to address these issues.

In terms of sound, the sound level required by listeners differs between loudspeakers and parametric loudspeakers. A previous study reported that the speech recognition threshold is lower when parametric loudspeakers are used than when loudspeakers are used [43]. Therefore, comparing the maximum sound level, this system is operated at a slightly lower level than the loudspeaker, as shown in Figure 2 e).

TABLE 1. Sound level setup in the experiment, unit:[dBA].

Background Music	49.72
Proposed System (Funnel 4)	53.44
Environmental Noise	53.46
Proposed System (Funnel 5)	51.84
Loudspeaker System	67.26

TABLE 2. Equipments List used in the experiment except for proposed system.

Digital Signage	GREEN HOUSE GH-EP4RW
Recording Camera	GoPro HERO5
Background Music Loudspeaker	SONY SRS-X1
Product Shelf	HPC-TOMOYA-30854XXX
Environmental Noise Loudspeaker	TEAC S-300NEO

IV. USER EXPERIMENT

A. MATERIALS

1) EXPERIMENTAL ENVIRONMENT

To answer the research questionns, a pseudo-store was setup in a laboratory room as the experimental environment. The setup is shown in Figure 3. The use of a pseudo-store is an experimental method often used in the field of service engineering, and its effectiveness has been measured [44].

In the pseudo-store, posters of the display shelves were placed on the wall. The sound level was set after conducting pilot study, as shown in the table in Table 1. The average sound levels were measured by a sound level monitor (RION NL-31) set up where the star mark appears in Figure 3. The calibration of the system sound level was performed using the signage located in front of the star mark. To replicate a real store, the environmental sounds of a shopping mall and some instrumental background music were played. The equipment used is shown in the Table 2.

There were eight kinds of products in total, arranged in two rows across the aisle. Among the products in the store, daily necessities were displayed on the shelves without signage ads, while alcohol-based disinfection products were displayed on the shelves with signage ads. This system was adopted because daily necessities and alcohol-based disinfection products, which are essential items during pandemics, do not fluctuate in demand based on preferences. Each product was displayed on a three-tiered platform, with the actual product in the middle of the front row and paper product pieces arranged around it. There were three digital signage units installed behind the products. Each signage unit was equipped with no loudspeaker, a loudspeaker, or the proposed sound system. The pinpoint auditory glimpse was emitted when the user walked past a neighboring product shelf. A camera was installed on top of the signage to record and measure the viewing time. These experimental environments are shown in Figure 3.

2) ADVERTISEMENT SELECTION

The advertisements for the products on the shelves were played on the signage in a loop, with each advertisement

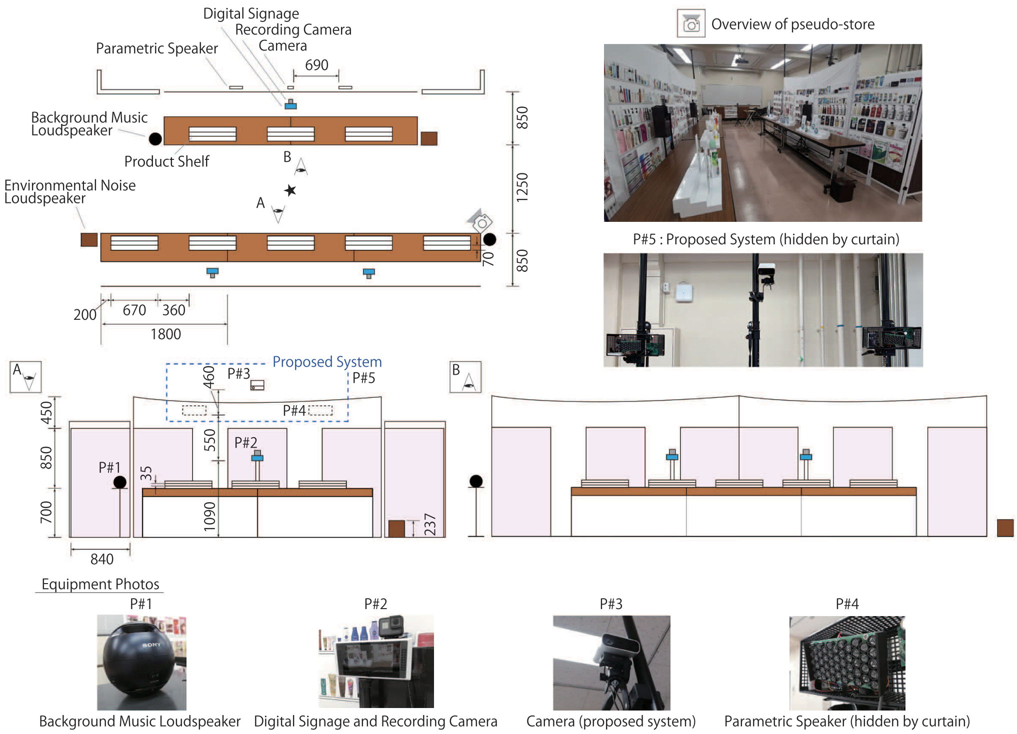

FIGURE 3. Setup of the user experimental environment.

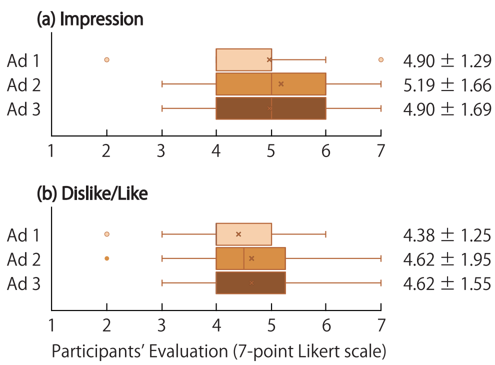

FIGURE 4. Results of the preliminary advertisement questionnaire. It was confirmed that there were no differences in recallability and likes/dislikes among the advertisements used in this experiment.

lasting 15 seconds, the typical length of a TV commercial. The advertisements focused on the benefits of using the particular product, which is suitable for unplanned purchases [45].

However, advertising preferences can affect product preferences and evaluations [46]. To avoid this, we conducted a preliminary questionnaire to ensure user preferences for the advertisements used in the pseudo-store experiment. The list of the questionnaire can be found in Appendix I.

The number of participants in the preliminary advertisement questionnaire was 21 (13 males and 8 females aged 22 to 34 with an average of 26.19) and consisted of people who did not participate in our main experiment (i.e., the pseudo-store experiment). They were recruited by snowball sampling. Not all participants were university staff or students. The results showed no significant differences among advertisement preferences and are illustrated in a Figure 4. To ensure randomness in the pseudo-store experiment, three signage systems and three advertisements were used at random.

B. SYSTEM PERFORMANCE TEST

With sound level measurement, we confirmed the change in acoustic comfort when using the proposed system compared to using a loudspeaker. The sound level was measured in the same location as the user experiment. The author wore binaural microphones in both ears and recorded while walking in front of the signage. The loudspeaker and proposed system were used to compare the sound level changes between when the participant was paying attention to the signage and when they were not. The ambient noise was set to only include ground noise, and the sound source was white noise. Subsequently, bandpass filters were applied to the range of 1 k to 3 k Hz and a 5-point moving average was used to remove other noise.

The measurement environment for sound level was the same as the user experimental environment, as shown in Figure 5. The results of the measurement are also shown in Figure 5. It can be observed that the sound level changes in each stage, even though the time on the horizontal axis is not perfectly aligned in both systems. The proposed

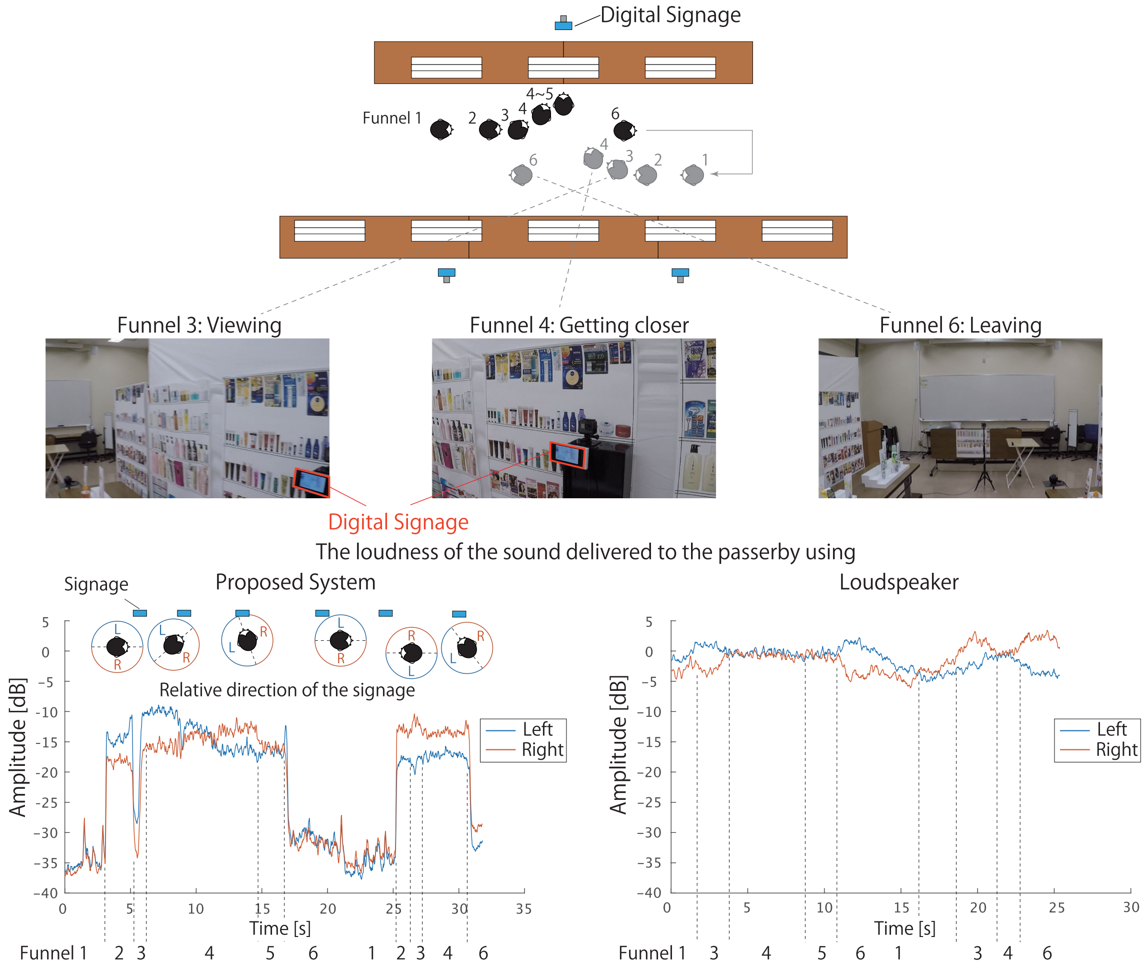

FIGURE 5. First person view of the User-Glimpse Funnel, the relative direction of the signage position as seen by a passerby, and the results of the system performance test of proposed and the system with a loudspeaker: For the proposed system (left bottom side), it can be confirmed that the pinpoint auditory glimpse played and the sound level fluctuated depending on the degree of attention to the signage.

system played the pinpoint auditory glimpse in Funnel 2, and the sound level fluctuated depending on the degree of attention to the signage. On the other hand, the loudspeaker system had a constant sound level, regardless of the degree of attention to the signage. As a result, it was confirmed that the proposed system created a more comfortable acoustic environment as the sound level was lowered when the user was not paying attention to the signage.

C. METHODS

Participants were asked to shop at a pseudo-store. There were 33 participants recruited by snowball sampling in the pseudostore experiment (27 males and 6 females aged 16 to 36 with an average age of 23.36), who were students and working adults. Not all of them were university staff or students. They had no visual or auditory problems by self-report. Besides, they didn't practice listening to the stereophonic sound before the study. The scenario for the experiment was as follows: Participants were given a shopping list and a basket of products in advance. Two products on the list were randomly chosen from five options, which are no signage ads, and participants were required to purchase them. They were free to choose from the remaining six products (three with and three without signage ads) as unplanned purchases. The items outside of the list were chosen based on the participants' preferences and did not affect the results of the experiment. It is important to note that only one of each item could be placed in the basket and participants were allowed to purchase products without consideration of the price. This setup aimed to simulate unplanned purchases and increase awareness of the products through watching the signage.

Participants can roam the aisles of the pseudo-store during the experiment. They completed their shopping, including the items on the provided shopping list, and then filled out questionnaires afterwards. There was no set time limit for shopping and participants were able to signal when they were finished. The questionnaire content was based on the characteristics of the advertisements [47], similar previous experiments [12], and the research questions being addressed. The questionnaires included the following two questions:

(a) How recallable is the advertising for this product?
(b) During shopping, how loud was the sound of this advertisement?

These corresponded to RQ #1 regarding the evaluation of advertisement recognition and RQ #2 regarding acoustic comfort. The detail of the questionnaire is listed in Appendix II. These questions were answered for each of the three advertisements. Each questionnaire was based on a seven-point Likert scale, with 4 considered to be the midpoint.

Additionally, viewing time was used as the objective evaluation of recognition. Cameras (GoPro) were placed directly above each sign and recorded constantly during the experiment. The recorded video was reviewed by the author frame by frame to calculate the participant's signage viewing time. The recordings were made at 60 fps and converted to seconds. By analyzing the viewing times thus obtained, we measured the level of attention to each sign and evaluated the perception of RQ #1. By analyzing the participants' self-reports and viewing time, we evaluated the transition into the first phase of the AIDMA purchasing behavior, attention, as indicated in Figure 1.

D. RESULTS

1) ANALYSIS OVERVIEW

Through a participant experiment, viewing time was analyzed on the basis of three factors: the system type, the response to the pinpoint auditory glimpse and the purchase stage. Subsequently, the results regarding recallability and perceived loudness were analyzed on the basis of participant questionnaires. Analyzing the level of attention, viewing time and advertisement recallability from questionnaire responses reveals the attracting effect of the pinpoint auditory glimpse, which is a factor in the purchasing cycle (see Figure 1). Furthermore, since previous studies have already shown that the degree of attention to signage changes depending on the purchasing stage [45], the purchasing stage was included in the analysis. The following is a summary of each section.

- Effect on Funnels 2–5: 2) Viewing Time for Each System; The analysis of viewing time using the system type as a factor.
- Effect on Funnel 2: 3) Viewing Time with a Response to the Pinpoint Auditory Glimpse: The analysis of viewing time with the response to the pinpoint auditory glimpse as a factor.
- Effect on Funnels 3–5: 4) Viewing Time Based on the Stage of the Purchasing Process: The analysis of viewing time using the system type and the purchasing process as factors.
- 5) Participant Questionnaire: An evaluation of the recallability and perceived loudness as obtained from participant questionnaires.

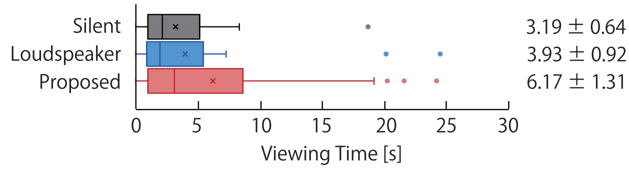

FIGURE 6. Results of the average participant viewing time for each system: there was no significant difference in the mean viewing time.

2) VIEWING TIME FOR EACH SYSTEM

Figure 6 shows the results of the average participant viewing time for each system. This provides an evaluation of the change in recognition level of the signage based on the systems used. The silent signage, signage with a loudspeaker, and that using the proposed systems had average participant viewing times of 3.186 s, 3.929 s, and 6.179 s, respectively. A one-way independent-measure ANOVA (system type: three levels, silent signage, signage with a loudspeaker and the proposed system) was performed on these data. There was no significant difference ($F(2,98)=2.451$, $p=0.092$).

The lack of a significant difference in the results is thought to be due to the large within-group variance. The silent signage, signage with a loudspeaker, and the proposed system have variances of 13.390, 28.062, and 56.489, respectively. This suggests that the variance is particularly high when using the proposed method. Therefore, a comparison was made between those who responded to the pinpoint auditory glimpse and those who did not respond to it among the proposed system group.

3) VIEWING TIME WITH A RESPONSE TO THE PINPOINT AUDITORY GLIMPSE

The proposed signage system presented a pinpoint auditory glimpse, and the experiment monitored the participants' responses to it. Participants were considered to have responded to the pinpoint auditory glimpse if they paid attention to the signage when the pinpoint auditory glimpse was played, but not if they were already paying attention to the signage before the pinpoint auditory glimpse was played. When the number of required products in the basket was 0, no one responded to the pinpoint auditory glimpse. However, when the number of required products in the basket was 1 or 2, five participants responded to the pinpoint auditory glimpse each time. These responses were made by different participants, and a total of 10 out of the 33 participants responded. To evaluate the effect of the pinpoint auditory glimpse on viewing time, the amount of time that the participants paid attention to the signage during and after the sound was played was measured.

The results of viewing times with and without a response to the pinpoint auditory glimpse are shown in Figure 7. The average viewing time for participants who responded to the pinpoint auditory glimpse was 5.588 seconds, while the average viewing time for those who did not respond was 1.571 seconds. We conducted an independent-means

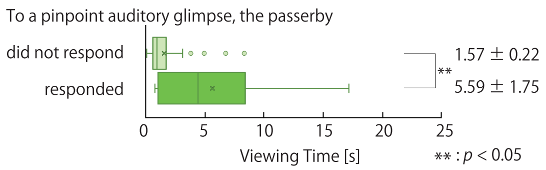

FIGURE 7. The results of viewing time with and without response to the pinpoint auditory glimpse when the number of items in the basket was 1 or 2: a significant difference was confirmed at the 5% level.

t-test, in which the factor was the mean viewing time in the presence or absence of a response to the pinpoint auditory glimpse. This showed a significant difference at the 5% level ($t(9)=2.277$, $p=0.049$). This suggests that the use of a pinpoint auditory glimpse in digital signage can increase the amount of time that passersby spend viewing the signage.

4) VIEWING TIME BASED ON THE STAGE OF THE PURCHASING PROCESS

The viewing time for the signage was calculated based on the number of items on the shopping list that had already been added to the basket. This method allows for the evaluation of not only the proposed system, but also the change in signage recognition due to the stage of purchase. In a real store, having 0 items in the basket indicates that the customer has just entered the store and is in the process of making a planned purchase. When the number of items in the basket is 2, the person has completed their planned purchases and may be in the process of making an unplanned purchase or about to finish shopping. The number of items in the basket can also be 1, and in this experiment, it was observed that some participants intermingled their unplanned purchases.

Figure 8 displays the results for the viewing time by the number of required products in the basket and the type of system. A two-way independent-measures ANOVA (system type: three levels, silent signage, signage with a loudspeaker and the proposed system; purchasing stage: 0, 1 and 2) was performed on these data. The results showed that there were no significant differences in the system type factor ($F(2,237)=1.010$, $p=0.366$), in the type of stage factor ($F(2,237)=1.857$, $p=0.158$) or in both types ($F(4,237)=0.559$, $p=0.692$).

Moreover, when the average viewing time was independently calculated for the cases where the number of required items placed in the basket was [0,1] and 2 independent of the system, the results were 1.787 s for [0,1] and 1.779 s for 2 items. According to the independent-means *t*-test, when the purchasing stage was used as a factor, the two-tailed test showed no significant difference ($t(244)=0.023$, $p=0.981$).

The average times per viewing when the number of required items in the basket was 0 and [1] and [2] were 1.244 s and 1.949 s, respectively. According to the independent-means *t*-test when the purchasing stage was used as a factor, the two-tailed test showed that a significant difference was confirmed at the 5% level ($t(173)=2.312$, $p=0.022$). These results are shown in Figure 9.

5) PARTICIPANT QUESTIONNAIRE

After the purchase, the participants answered the questionnaire. All answers were self-reported by the participants, and the results are shown in Figure 10.

The recallability ratings of the advertisement were 2.15, 3.33, and 2.84 in condition silent signage, signage with a loudspeaker, and utilizing the proposed system, respectively. A one-way independent-measure ANOVA of whether the advertisement was strongly recallable was conducted, and the results showed no significant difference ($F(2,96)=3.091$, $p=0.073$).

The recallability levels of those who noticed the pinpoint auditory glimpse and those who did not in the proposed system were 2.80 ($n=10$) and 2.87 ($n=23$), respectively. A two-tailed *t*-test was performed and resulted in no significant difference ($t(23)=0.091$, $p=0.93$).

Subsequently, the loudness of the loudspeaker and proposed systems were rated as 4.70 and 3.84, respectively. A two-tailed independent-means *t*-test using loudness as a factor showed no significant difference ($t(23)=1.839$, $p=0.073$)

E. PASSERBY OBSERVATIONS

Here, observations related to the proxemics of purchasing behavior other than that of viewing time and questionnaires are described. The following description is arranged on the basis of the user-glimpse funnel proposed in Section III-B.

1) **Passing-by, Noticing (Funnels 1 and 2)**: Many participants who received the shopping list tried to put the two products specified on the list in their baskets rather than looking carefully at the other products. Many people's behavior consisted of walking around comparing the list with the products displayed on the shelves. During this time, the signage was treated as reference information, and received little attention from the participants (refer to Figure 8, 9). When the basket contained one or two items from the list, more participants were observed viewing the signage for unplanned purchases. In some cases, as they approached to view a shelf across the aisle, the pinpoint auditory glimpse caused them to suddenly look back at the signage.
2) **Viewing, Getting Closer (Funnels 3 and 4)**: Some participants who were exposed to the pinpoint auditory glimpse paid attention to the signage, glancing around to determine the source of the sudden sound. Their walking pace slowed down, and some individuals briefly looked at the signage before continuing on their path, while others approached and stopped in front of the signage to observe it. Participants who did not respond to the pinpoint auditory glimpse were also observed to pass by the signage without paying attention to it, skipping the Funnel 3 of reacting to the pinpoint auditory glimpse.
3) **Picking up, Leaving (Funnels 5 and 6)**: Many participants who were observed to pass close by the signage or

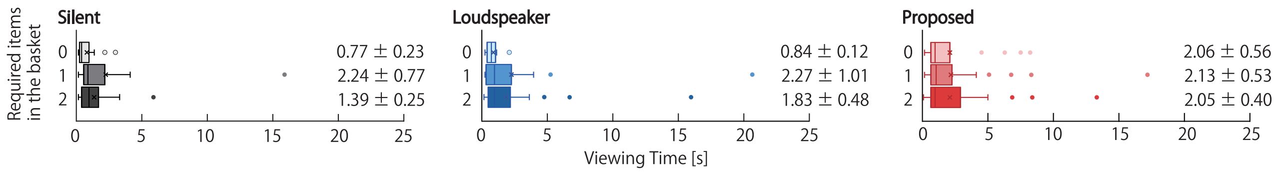

FIGURE 8. Results of the viewing time by the number of required products in the basket and the type of system: there were no significant differences in the mean viewing time among all groups.

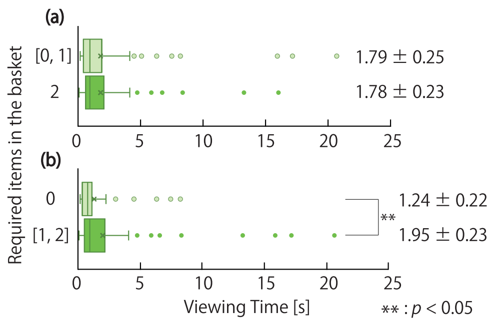

FIGURE 9. (a) Independent results for the average viewing time where the number of required items placed in the basket was [0,1] and 2 independent of the system: no significant difference was confirmed. (b) Independent results for the average viewing time where the number of required items placed in the basket was 0 and [1] and [2] independent of the system: a significant difference was confirmed at the 5% level.

spend a significant amount of time viewing the advertisements, considered whether to include the advertised product in their shopping basket while they were viewing the advertisements and products. Some participants also examined the back label of the product, which lists its active ingredients, and compared it with those of other products to make a purchase decision. After making a decision, they walked away from the shelf with their back turned. When they passed by the signage again, they almost completely avoided looking at it.

4) **No Attention (Funnels 4' – 6')**: There were some cases in which participants passed by without paying attention to the signage even when a the pinpoint audio glimpse was presented. These included those who focused on buying the products on the shopping lists and those who had already decided whether or not to buy the suggested products. This also included some participants who did not make unplanned purchases but bought only the listed products. In this case, their walking speeds did not decrease. Among them, one participant made purchases without paying attention to any digital signage.

As previously mentioned, the behaviors of participants were varied. However, most behaviors were consistent with the User-Glimpse Funnel, and we were able to observe interesting connections between the pinpoint auditory glimpse and purchasing behavior. These will be discussed in later sections.

V. DISCUSSION AND LIMITATIONS

A. SUMMARY OF EXPERIMENTS

1) ATTRACTING EFFECT – RESULTS OF RQ #1

Considering the results of IV D 2), 3) and Figure 7, it can be said that the time spent viewing the signage of the proposed system in response to the pinpoint auditory glimpse was significantly longer than that in no response to the pinpoint auditory glimpse. This implies that once a person responds to the sound, they are more likely to continue paying attention to the source of the sound, i.e., the signage. This is also observed in passerby observations. In several cases, passersby who were looking in another direction (Funnel 2) turned toward the signage (Funnel 3) when the pinpoint sound was presented. After this, some passersby continued to observe the signage and approached the product (Funnel 4).

We then calculated the percentage of passersby who responded to the pinpoint auditory glimpse. Pinpoint auditory glimpses were triggered in all 33 trials for a cumulative total of 71 instances. In ten of those instances, different participants responded to each pinpoint auditory glimpse. Thus, the percentage was 30.3 % when calculated based on the number of individuals and 14.1 % when calculated based on the number of instances. Here, the effect is discussed based on a comparison of our ratio with that of a previous study. The existing research that prompts passersby to interact with public displays aims to measure participant interaction with and viewing of advertisements [48]. Among all passersby, the ratios of persons who interacted with and watched traditional advertisements were approximately 10% and 0.1%, respectively. However, the proposed system could trigger 14.1% of participants to watch advertisements without interacting with displays. Since this experiment was not conducted in a public space and the advertisements were different from those used in existing research, the two results cannot be directly compared. Nonetheless, our results suggest that using a pinpoint auditory glimpse can be an effective way to encourage people to watch display advertisements without the need for interaction.

From these results, we obtain the answer to RQ #1, "Does the presentation of the pinpoint auditory glimpse improve recognition even for a short time," as follows: even a very short sound presentation increases the ratio of passersby who look at the advertisement. Additionally, those who respond to the pinpoint auditory glimpse continue to look at it for a longer period than those who do not. These factors lead to improved advertisement recognition.

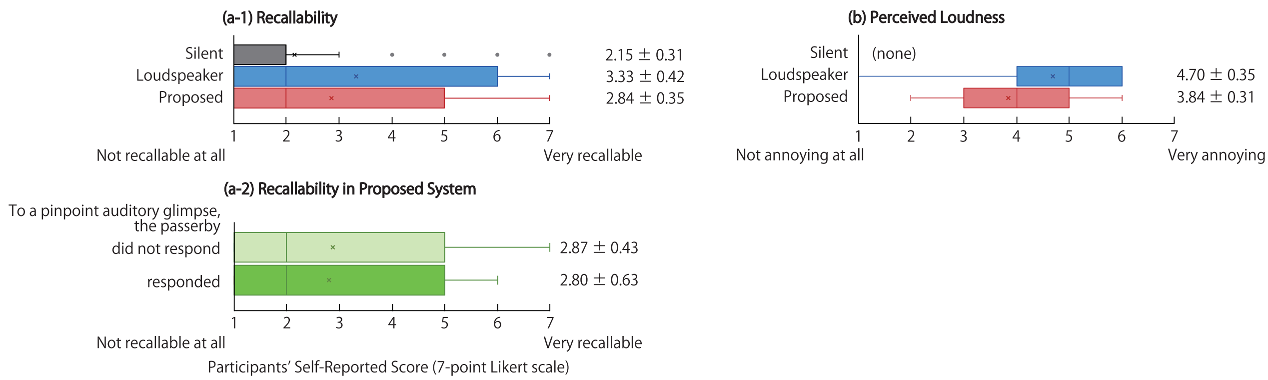

FIGURE 10. Results of the self-report questionnaire completed by participants. (a-1) The recallability ratings of the advertisement showed no significant difference. (a-2) The strength of recallability between those who noticed the pinpoint auditory glimpse and those who did not in the proposed system: no significant difference was confirmed. (b) The loudness of the loudspeakers and that of the proposed systems showed no significant difference.

2) ACOUSTIC COMFORT – RESULTS OF RQ #2

In terms of the acoustic comfort, the questionnaire results, as shown in Figure 10 (b), indicate that there was no significant difference in loudness between the proposed system and the system using a loudspeaker. One participant commented "*The sudden sound was slightly distracting, but then the sound was lowered, so I didn't pay attention to it.*" This means that a sudden presentation of sound used a pinpoint auditory glimpse that momentarily disturbed the participant, but it was quickly muted in accordance with their choice not to see it, so it did not interfere with their activities. This comment suggests that the proposed system was able to provide acoustic comfort.

However, since there was no significant difference between the proposed system and the system using a loudspeaker, and since only one proposed system was used in the experiment, it is necessary to further consider the possibility of the noise problems when multiple proposed systems are being used. Therefore, the answer to RQ #2, "Does presenting the pinpoint auditory glimpse make the acoustic environment less comfortable," is that when a single pinpoint auditory glimpse is used, it does not negatively impact the acoustic comfort of those nearby.

B. SOUND LEVEL

Traditionally, emitting a loud sound was an effective way to draw users' attention to digital signage [11]. However, the results of using the proposed system indicated that users can turn towards signage that emits sound for a brief period without necessarily requiring a loud sound. We assume this to be because the person who was presented with the pinpoint auditory glimpse became interested in the sound, which drew attention to the signage. In general, sound is heard gradually as one gets closer to the sound source, and the phenomenon of sudden hearing does not exist in nature. Therefore, the phenomenon of suddenly hearing the sound of an advertisement is considered to be mysterious and curious. This phenomenon is similar to a previous study in which a mysterious object was placed in front of the signage [20]. This previous study showed that passersby were interested in the mysterious object, which made them more likely to notice the presence of the signage nearby. Our results can be described as a sound version of this previous study. This can be explained by the fact that people are more interested in the pinpoint auditory glimpse and are more likely to pay attention to the source of the sound, the signage.

Passersby might be offended by the output of a sudden loud sound. Sound output is often restricted in public spaces [49], and there may be concerns that the output sound may be drowned out in places where other sounds are emitted loudly. However, prior research has shown that parametric loudspeakers require less sound level than traditional loudspeakers, even in noisy environments [43]. Additionally, the narrow directive sound of parametric loudspeakers means that they are barely audible to non-target listeners nearby. This allows for the use of the pinpoint auditory glimpse in a wide range of environments, from places where noise should be minimized to louder environments such as shopping malls. Overall, the proposed system is a useful solution to the limitations of sound level that hinder the improvement of public awareness, and it increases the flexibility of sound design in public spaces.

C. STAGE OF PURCHASING PROCESS – DESIGN IMPLICATION FOR IN-STORE SIGNAGE

Further analysis in IV D 4) and Figure 8 revealed that there was no significant relationship between the viewing time and the number of products using the proposed system. Additionally, it was found that the average viewing time for the signage was significantly longer when the number of required items in the basket was 1 or 2, regardless of the system being used.

Previous research, such as a study conducted in a real store [45], has shown that advertising placed near the cash register is more likely to lead to purchases. This is because customers' movements towards the cash register indicate the end of their purchasing behavior. The results of this current experiment reinforce these findings by showing that the use of the pinpoint auditory glimpse increases recognition even during the middle of the purchasing process.

Future studies should take into account various parameters within the store. As customers go through different products during the purchasing process, it is important to investigate the optimal timing for presenting pinpoint auditory glimpse to draw attention to specific products. Additionally, the duration and sound level of these cues should be adjusted based on factors such as the size of the product shelves and the layout of the store. For example, in smaller stores with limited space, auditory cues may need to be presented earlier or for a longer duration in order to be effective. By examining the relationship between store layout and these parameters, a system can be designed that improves product recognition while maintaining acoustic comfort.

D. APPLICATION FOR THE PINPOINT AUDITORY GLIMPSE – DESIGN IMPLICATION FOR PUBLIC DISPLAY

This study explores the use of pinpoint auditory glimpses in advertising signage. The use of this technique does not interfere visual information, haptic design, or context. Additionally, audio can be applied to a variety of displays beyond just advertising signage, such as interactive signage with playful elements. This solution has possibility for addessing the "first click problem" [7], [50], [51] where passersby may not understand that a display is interactive and thus do not engage with it. The use of a pinpoint auditory glimpse, such as a sudden callout (e.g., "Come talk with me!"), can increase the likelihood that they will turn to look.

The study can be also applying for strategies for maintaining audience engagement after initial interaction, such as predicting when people will leave and using new forms of interaction to retain their interest [24], or using auditory cues to surprise and deter them from leaving. The study suggests that future research should investigate the degree of attraction that different types of sound used in a pinpoint auditory glimpse may have. Overall, the study suggests that the use of a pinpoint auditory glimpse has the potential to change the business model of displays without disrupting conventional systems.

E. LIMITATIONS AND FUTURE WORKS

1) SOUND REFLECTION

When using a parametric loudspeaker, the reflection can be considered as the parametric loudspeaker emitting super directive sound. For this point, whereas the sound of a loudspeaker may reflect from many different directions, the super directive sound of parametric loudspeakers limits reflections. In addition, by producing sound from a high point in a slightly downward direction, we adjusted the sound to not reach that person's ears after reflection on a wall. If the reflected sound were audible, the sound would be heard from a different direction than the intended direction, and the sound pressure difference between the left and right sides would be incorrect in the sound measurement. In contrast, when we look at the Proposed Systems Funnels 3 and 4 in Figure 5, the sound is delivered in such a way that the sound pressure in the intended direction becomes higher. For example, in Funnels 2–4 on the return route in Figure 5, since the signage is on the right side, the sound pressure presentation should be louder to the right ear. The measurement results show that it is indeed louder to the right ear. Therefore, we think that the participants in the experiment did not misunderstand the direction of the sound source due to reflections and that the reception of reflected sound was a rare case. From the above, we consider that the priming effect of the pinpoint auditory glimpse was maintained. In fact, there were no comments from participants that they heard sounds coming from different directions or that they felt uncomfortable. However, when parametric loudspeakers are used in a smaller space or when there are several people present at the same time and the number of speakers increases, the effect of reflected sound may be unavoidable. Countermeasures against these include the use of phased arrays and the use of sound-absorbing materials in reflective walls.

2) DIFFERENCES BETWEEN ENVIRONMENTS

In this experiment, we used a pseudo-store to evaluate the proposed system on the basis of viewing time. Although the pseudo-store was constructed to be as close to an actual store as possible, it has not fully reproduced an actual store. To further validate the effectiveness of the system, future researchers should conduct experiments in real-world public settings to gather a larger sample size and measure the attention of participants towards the signage over a specific period of time.

When using a pinpoint auditory glimpse, it is important to consider the transportation context. In outdoor settings, it is important to ensure that the auditory cues are only presented to pedestrians to avoid distracting bicyclists or drivers while they are operating vehicles. This can be achieved by limiting the use of the system to environments where only pedestrians are present, such as indoors, or by using cameras to detect the speed of movement and only playing the cues for pedestrians. When implementing the system in public places, it is essential to prioritize safety and take measures to minimize any potential risks to the public.

A possible approach for providing simultaneous coverage for multiple people is to increase the number of parametric loudspeakers or cameras in proportion to the number of people that the camera can detect. However, using many parametric loudspeakers at the same time may result in an excessive amount of directional sound in a given location, which could be as disruptive as using a traditional loudspeaker. Therefore, future research should investigate whether the "Honey Pot Effect" [52] can be observed. The honey pot effect is a phenomenon where one person or a small group's interaction with signage can stimulate others in the vicinity to also interact with the signage. This study did not involve direct interaction with the system, so it is unlikely that the honey pot effect would be observed in this experiment. However, when multiple passerby are present, it is possible that the behavior of passerby may change, and similar phenomena such as the honey pot effect could be observed. For example, a scenario could be created where one person in a group notices a pinpoint auditory glimpse and then tells the others, ''Did you just hear something,'' which causes the whole group to pay attention to the signage. Although this is a hypothetical situation, such multi-person-specific phenomena are conceivable. Future research should investigate if other similar phenomena exist by conducting further experiments.

VI. CONCLUSION

In this study, we proposed the use of a pinpoint auditory glimpse as a sound-based solution to address display blindness. Our findings indicate that a pinpoint auditory glimpse can effectively draw people's attention to signage, and that once a person responds to the sound, they are more likely to continue paying attention to the signage. Additionally, our results suggest that the presence of a pinpoint auditory glimpse does not negatively impact participants' purchasing behavior.

Furthermore, this system offers benefits not only for advertisers, but also for the general public by reducing the overall sound level and minimizing any potential harm to passersby. These results demonstrate the potential of the pinpoint auditory glimpse as a novel, sound-based method for solving display blindness, and highlight the potential for it to lead to changes in advertising display business models and increased flexibility in sound design in public spaces.

APPENDIX I. PRELIMINARY QUESTIONNAIRE LISTS

The questions in the preliminary questionnaire are as follows:

- Q (a) How recallable is the advertising for this product? (1: Not recallable at all. 7: Very recallable.)
- Q (b) Please rate your preference for this ad. (1: Very dislikeable, 7: Very likeable)

The results of these questionnaires are presented in Figure 4.

APPENDIX II. MAIN QUESTIONNAIRE LISTS

The questionnaires used in our main experiment use the following questions:

- Q (a) During shopping, how loud was the sound of this advertisement? (1: Not annoying at all. 7: Very annoying.)
- Q (b) How recallable is the advertising for this product? (1: Not recallable at all. 7: Very recallable.)

Participants evaluated the advertisements that were played on each piece of signage. This list corresponds to the Figure 10.

REFERENCES

[1] K. Sugiyama and T. Andree, *The Dentsu Way: 9 Lessons for Innovation in Marketing from the World's Leading Advertising Agency*. New York, NY, USA: McGraw-Hill, 2011.

[2] E. M. Huang, A. Koster, and J. Borchers, ''Overcoming assumptions and uncovering practices: When does the public really look at public displays?'' in *Proc. Int. Conf. Pervasive Comput.* Cham, Switzerland: Springer, 2008, pp. 228–243.

[3] J. Müller, D. Wilmsmann, J. Exeler, M. Buzeck, A. Schmidt, T. Jay, and A. Krüger, ''Display blindness: The effect of expectations on attention towards digital signage,'' in *Proc. Int. Conf. Pervasive Comput.* Cham, Switzerland: Springer, 2009, pp. 1–8.

[4] N. S. Dalton, E. Collins, and P. Marshall, ''Display blindness?: Looking again at the visibility of situated displays using eye-tracking,'' in *Proc. 33rd Annu. ACM Conf. Hum. Factors Comput. Syst.*, Apr. 2015, pp. 3889–3898.

[5] G. Du, L. Lohoff, J. Krukar, and S. Mukhametov, ''Comparing two methods to overcome interaction blindness on public displays,'' in *Proc. 5th ACM Int. Symp. Pervasive Displays*, Jun. 2016, pp. 243–244.

[6] M. Ghare, M. Pafla, C. Wong, J. R. Wallace, and S. D. Scott, ''Increasing passersby engagement with public large interactive displays: A study of proxemics and conation,'' in *Proc. ACM Int. Conf. Interact. Surf. Spaces*, Nov. 2018, pp. 19–32.

[7] H. Kukka, H. Oja, V. Kostakos, J. Gonçalves, and T. Ojala, ''What makes you click: Exploring visual signals to entice interaction on public displays,'' in *Proc. SIGCHI Conf. Hum. Factors Comput. Syst.*, Apr. 2013, pp. 1699–1708.

[8] J. Müller and A. Krüger, ''Mobidic: Context adaptive digital signage with coupons,'' in *Proc. Eur. Conf. Ambient Intell.* Cham, Switzerland: Springer, 2009, pp. 24–33.

[9] H. Limerick, ''Call to interact: Communicating interactivity and affordances for contactless gesture controlled public displays,'' in *Proc. 9TH ACM Int. Symp. Pervasive Displays*, Jun. 2020, pp. 63–70.

[10] W. Ju and D. Sirkin, ''Animate objects: How physical motion encourages public interaction,'' in *Proc. Int. Conf. Persuasive Technol.* Cham, Switzerland: Springer, 2010, pp. 40–51.

[11] J. Nordfält, ''Improving the attention-capturing ability of special displays with the combination effect and the design effect,'' *J. Retailing Consum. Service*, vol. 18, no. 3, pp. 169–173, May 2011.

[12] N. Kuratomo, H. Miyakawa, S. Masuko, T. Yamanaka, and K. Zempo, ''Effects of acoustic comfort and advertisement recallability on digital signage with on-demand pinpoint audio system,'' *Appl. Acoust.*, vol. 184, Dec. 2021, Art. no. 108359.

[13] S. R. Hall, *Retail Advertising and Selling: Advertising, Merchandise Display, Sales-planning, Salesmanship, Turnover and Profit-figuring in Modern Retailing, Including, Principles of Typography as Applied to Retail Advertising*. New York, NY, USA: McGraw-Hill, 1924.

[14] B. Fogg, ''A behavior model for persuasive design,'' in *Proc. 4th Int. Conf. Persuasive Technol.*, Apr. 2009, pp. 1–7.

[15] E. Yom-Tov, J. Shembekar, S. Barclay, and P. Muennig, ''The effectiveness of public health advertisements to promote health: A randomized-controlled trial on 794,000 participants,'' *NPJ Digit. Med.*, vol. 1, no. 1, p. 24, Jun. 2018.

[16] M. Chevalier, ''Increase in sales due to in-store display,'' *J. Marketing Res.*, vol. 12, no. 4, pp. 426–431, Nov. 1975.

[17] G. F. McKinnon, J. P. Kelly, and E. D. Robison, ''Sales effects of point-of-purchase in-store signing,'' *J. Retailing*, vol. 57, no. 2, pp. 49–63, 1981.

[18] A. G. Woodside and G. L. Waddle, ''Sales effects of in-store advertising,'' *J. Advertising Res.*, vol. 15, no. 3, pp. 29–33, 1975.

[19] J. Müller, F. Alt, D. Michelis, and A. Schmidt, ''Requirements and design space for interactive public displays,'' in *Proc. 18th ACM Int. Conf. Multimedia*, Oct. 2010, pp. 1285–1294.

[20] S. Houben and C. Weichel, ''Overcoming interaction blindness through curiosity objects,'' in *CHI Extended Abstr. Hum. Factors Comput. Syst.*, vol. 6, pp. 1539–1544. 2013.

[21] T. Prante, ''Hello. wall–beyond ambient displays,'' in *Adjunct Proceedings of Ubicomp*. Cham, Switzerland: Springer, 2003, pp. 277–278.

[22] D. Vogel and R. Balakrishnan, ''Interactive public ambient displays: Transitioning from implicit to explicit, public to personal, interaction with multiple users,'' in *Proc. 17th Annu. ACM Symp. User Interface Softw. Technol.*, Oct. 2004, pp. 137–146.

[23] D. Michelis and J. Müller, ''The audience funnel: Observations of gesture based interaction with multiple large displays in a city center,'' *Int. J. Hum.-Comput. Interact.*, vol. 27, no. 6, pp. 562–579, Jun. 2011.

[24] F. Alt, D. Buschek, D. Heuss, and J. Müller, ''Orbuculum–predicting when users intend to leave large public displays,'' *Proc. ACM Interact., Mobile, Wearable Ubiquitous Technol.*, vol. 5, no. 1, pp. 1–16, Mar. 2021.

[25] A. Mashhadi, A. Mathur, and F. Kawsar, "The myth of subtle notifications," in *Proc. ACM Int. Joint Conf. Pervasive Ubiquitous Comput., Adjunct Publication*, Sep. 2014, pp. 111–114.

[26] J. Tardieu, P. Susini, F. Poisson, and S. McAdams, "Soundscape design in train stations," in *Proc. Journées du Design Sonore (Sound Design Symp.)*, 2004, pp. 1–10.

[27] C. Nadri, S. C. Lee, S. Kekal, Y. Li, X. Li, P. Lautala, D. Nelson, and M. Jeon, "Investigating the effect of earcon and speech variables on hybrid auditory alerts at rail crossings," Georgia Inst. Technol., Atlanta, GA, USA, Tech. Rep. 24, 2021.

[28] X. Yan, Y. Zhang, and L. Ma, "The influence of in-vehicle speech warning timing on drivers' collision avoidance performance at signalized intersections," *Transp. Res. C, Emerg. Technol.*, vol. 51, pp. 231–242, Feb. 2015.

[29] S. Bakhtiari, T. Zhang, T. Zafian, S. Samuel, M. Knodler, C. Fitzpatrick, and D. L. Fisher, "Effect of visual and auditory alerts on older drivers' glances toward latent hazards while turning left at intersections," *Transp. Res. Record, J. Transp. Res. Board*, vol. 2673, no. 9, pp. 117–126, Sep. 2019.

[30] A. Lee, "The audibility smoke alarms residential homes," Consum. Product Safety Commission, Bethesda, MD, USA, Tech. Rep. CPSC-ES-0503, 2005.

[31] P. Havey, M. Munoz, M. S. Klassen, M. M. Holton, and S. Molenick, "Variability and error rates in fire alarm audibility measurements and calculations," *Fire Technol.*, vol. 54, pp. 1725–1744, Dec. 2018.

[32] D. S. Mileti and J. H. Sorensen, "Communication of emergency public warnings: A social science perspective and state-of-the-art assessment," Oak Ridge National Lab., Oak Ridge, TN, USA, Tech. Rep. ORNL-6609, 1990.

[33] J. Sutton, S. C. Vos, M. M. Wood, and M. Turner, "Designing effective tsunami messages: Examining the role of short messages and fear in warning response," *Weather, Climate, Soc.*, vol. 10, no. 1, pp. 75–87, Jan. 2018.

[34] G. Balakrishnan, G. Sainarayanan, R. Nagarajan, and S. Yaacob, "Wearable real-time stereo vision for the visually impaired," *Eng. Lett.*, vol. 14, no. 2, pp. 1–15, 2007.

[35] S. Yu, H. Lee, and J. Kim, "Street crossing aid using light-weight CNNs for the visually impaired," in *Proc. IEEE/CVF Int. Conf. Comput. Vis. Workshop (ICCVW)*, Oct. 2019, pp. 1–10.

[36] K. Zempo, Y. Mashiba, T. Kawamura, N. Kuratomo, and H. E. B. Salih, "Phonoscape: Auralization of photographs using stereophonic auditory icons," in *Proc. Adjunct 31st Annu. ACM Symp. User Interface Softw. Technol.*, Oct. 2018, pp. 117–119.

[37] K. Aoki, T. Kamakura, and Y. Kumamoto, "Parametric loudspeaker—Characteristics of acoustic field and suitable modulation of carrier ultrasound," *Electron. Commun. Jpn.*, vol. 74, no. 9, pp. 76–82, 1991.

[38] M. Yoneyama, J. Fujimoto, Y. Kawamo, and S. Sasabe, "The audio spotlight: An application of nonlinear interaction of sound waves to a new type of loudspeaker design," *J. Acoust. Soc. Amer.*, vol. 73, no. 5, pp. 1532–1536, May 1983.

[39] H. Uchida, T. Ebihara, N. Wakatsuki, and K. Zempo, "Alise: Through the mirrored space, and what user interacts with avatars naturally," *Interact. Surf. Spaces*, vol. 3, pp. 29–32, Dec. 2021.

[40] R. Iwaoka, M. Moriga, H. B. S. Elser, K. Zempo, K. Mizutani, and N. Wakatsuki, "Ultrasound from cyber map: Intuitive guidance method using binaural parametric loudspeaker," in *Proc. ACM Int. Conf. Interact. Surf. Spaces*, Nov. 2018, pp. 469–472.

[41] A. Burka, A. Qin, and D. D. Lee, "An application of parametric speaker technology to bus-pedestrian collision warning," in *Proc. 17th Int. IEEE Conf. Intell. Transp. Syst. (ITSC)*, Oct. 2014, pp. 948–953.

[42] S. Aoki, M. Toba, and N. Tsujita, "Sound localization of stereo reproduction with parametric loudspeakers," *Appl. Acoust.*, vol. 73, no. 12, pp. 1289–1295, Dec. 2012.

[43] N. Kuratomo and T. Ebihara, "How much is the noise level be reduced?—Speech recognition threshold in noise environments using a parametric speaker," in *Proc. IFIP Conf. Hum.-Comput. Interact.* Cham, Switzerland: Springer, 2021, pp. 542–550.

[44] Y. E. Lee and I. Benbasat, "Interaction design for mobile product recommendation agents: Supporting users' decisions in retail stores," *ACM Trans. Comput.-Hum. Interact.*, vol. 17, no. 4, pp. 1–32, Dec. 2010.

[45] S. van de Sanden, K. Willems, and M. Brengman, "How do consumers process digital display ADS in-store? The effect of location, content, and goal relevance," *J. Retailing Consum. Services*, vol. 56, Sep. 2020, Art. no. 102177.

[46] S.-J. Yoon and Y.-G. Choi, "Determinants of successful sports advertisements: The effects of advertisement type, product type and sports model," *J. Brand Manag.*, vol. 12, no. 3, pp. 191–205, Feb. 2005.

[47] S.-C. Chuang, C.-C. Tsai, Y.-H. Cheng, and Y.-C. Sun, "The effect of terminologies on attitudes toward advertisements and brands: Consumer product knowledge as a moderator," *J. Bus. Psychol.*, vol. 24, no. 4, pp. 485–491, Dec. 2009.

[48] G. Parra, J. Klerkx, and E. Duval, "Understanding engagement with interactive public displays: An awareness campaign in the wild," in *Proc. Int. Symp. Pervasive Displays*, Jun. 2014, pp. 180–185.

[49] W. H. Organization, "Environmental noise guidelines for the European region," World Health Org., Geneva, Switzerland, Tech. Rep., 2018.

[50] J. Müller, R. Walter, G. Bailly, M. Nischt, and F. Alt, "Looking glass: A field study on noticing interactivity of a shop window," in *Proc. CHI Extended Abstr. Hum. Factors Comput. Syst.*, May 2012, pp. 297–306.

[51] R. Walter, G. Bailly, and J. Müller, "StrikeAPose: Revealing mid-air gestures on public displays," in *Proc. SIGCHI Conf. Hum. Factors Comput. Syst.*, Apr. 2013, pp. 841–850.

[52] H. Brignull and Y. Rogers, "Enticing people to interact with large public displays in public spaces," *Interact*, vol. 3, pp. 17–24, Dec. 2003.

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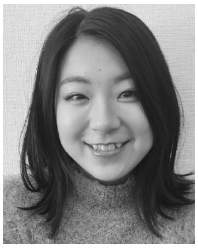

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