Physiological and psychological influence of multi-media in urban business districts

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Abstract: Understanding the complex interaction between human needs and physical facilities in public spaces remains a challenge given the knowledge gap in sustainable cities design and research. This study selected six typical urban business walkways to compare the physiological and psychological effects of a visual-audio environment dominated by visual media on visitors. A total of 180 visitors were randomly selected on 6 walkways to collect physiological and psychological data, and visual-audio environment data were collected in the matching location. Results show that visual media are the most attractive content type in the multi-media system of business walkways, and their attractiveness is evenly distributed among all visitors. This type of media also continuously extends the engagement of visitors during their visiting time. Specifically, visitors spend 71% of their time gazing at visual media that occupy only 31.4% of the walkway facade area. Visitors also stare at videos for a longer time compared with text and images. The different visual-audio interactions in the walkway have different effects on visitors' eye movements. These visitors also have different evaluations between indoor and outdoor walkways. Specifically, visitors feel 64.4% more comfortable with the visual-audio environment in indoor walkways than in outdoor walkways. Visual-audio interaction has varying effects on visitors' comfort. Combining images with sound elements generates positive feedback, and visitors feel comfortable when the video content matches the music. The types of music played in indoor and outdoor walkways lead to differences in the temporal variability of acoustic environments. The results of this work contribute to an optimized design of multi-media installed on different functional business district walkways, which in turn can enhance the attractiveness of urban business district areas and bring a comfortable experience to visitors.

Keywords: Business district; Multi-media; Eye-tracking; Visual-audio interaction;

Comfort level evaluation

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1. Introduction

The 17 Sustainable Development Goals (SDGs) set by the United Nations provide a blueprint for a better and sustainable future for people around the world. Goal 11 clearly states that developing sustainable cities and communities requires more inclusive, engaged, integrated, and sustainable planning and management. Providing safe, healthy, inclusive, accessible, and green public spaces for all is a priority to achieve the 2030 SDGs in cities (Maffei, Masullo, Pascale, Ruggiero & Romero, 2016).

Business districts serve as a window that shows the social, economic, and environmental development of a sustainable city. They serve multiple functions in an urban environment, such as strengthening community activities (Hassen & Kaufman, 2016), promoting the urban economy (Rice, 2020), and creating a vibrant urban environment (Llc, 2013). The fundamental function of a sustainable city is to provide a convenient, comfortable, and safe place for human activity. Public spaces are closely related to human daily activities. The quality of a public space greatly affects the physiological and psychological responses of visitors. A good street design not only benefits visitors by enhancing their comfort, health, and well-being but also contributes to the promotion of environmentally sustainable and socially resilient cities (El-Shimy & Ragheb, 2017, Ge & Han, 2020).

As an important human sense, vision directly affects the information received by a visitor (Yue, 2008). An urban landscape is closely related to the human living environment. Optimizing urban landscapes can promote urban vitality and quality, which is the latest goal of modern urban sustainable development (Calleri, Astolfi, Armando & Shtrepi, 2016; Kang, Fukahori & Kubota, 2018; Zhang et al., 2019). Compared with rural or pastoral natural landscapes, urban residents receive massive amounts of fast-changing media information in cities (Chen, 2016; Tang, 2020). Moreover, visitors of cities are influenced by the information, thoughts, and inspiration disseminated through various media. Visual media comprise information presented as text, images, videos, brands, advertisements, signs, and art and have become one of the most influential visual elements for modern urban residents (Meng, 2020). Previous studies on visual media collect them by using digital image technologies that present visual information on screens (Li & Fan, 2015). However, only a few studies have attempted to collect data by performing in-situ experiments in real scenarios.

The acoustic environmental quality in urban business districts has become a critical factor for improving urban sustainability (Tong & Kang, 2020). A good acoustic environment can reduce crimes and promote investments (Kang & Fortkamp, 2015; Kang, Schulte-Fortkamp, Fiebig & Botteldooren, 2015). The sound environment of urban business areas is a key environmental factor linked to visitor experience (Hong and Jeon, 2013, Sanchez, Van Renterghem, Sun, De Coensel, & Botteldooren, 2017; Meng & Kang, 2015; Meng, Sun & Kang, 2017). A sound environment includes complex sound sources, such as human voices with high sound pressure levels (SPL) (Fernandes, Tomas, Acuto, Pascale & Coelho, 2020; Wang, Cai & Luo, 2017). The acoustic characteristics of this environment, including loudness, sharpness, frequency, and reverberation time, greatly affects the emotions, health, well-being, and other physiological and psychological factors of visitors (Aumond et al., 2017; Axelsson, Nilsson & Berglund, 2010). Environmental factors and visitors' social characteristics also have different impacts on the latter's physiological or psychological responses to the same soundscape. Specifically, if visitors are familiar with the soundscape, then their sensitivity to this soundscape also increases (Basner et al., 2014).

Furthermore, the interaction between Visual and audio also can significantly affect a visitor's experience of the onsite environment. When the visual and auditory perceptions of humans are coupled, their attention to visual aspects changes according to their perception of sound, and vice versa (Hong & Jeon, 2013; Hong, Lam, Zhen, Ooi & Tan, 2020). After the soundscape concept was introduced by Schafer (Grueneisen, 2003), researchers have begun to focus on how the different interactions of hearing and vision can be used to improve the human perceptual experience (Deng et al., 2020; Park, Lee, Jung & Swenson, 2020). Some behavioural and neuropsychological studies have established a correlation between visual information (e.g., location, color, and layout) and auditory affective perception (Benfield, Bell, Troup & Soderstrom, 2010; Iachini et al., 2012). Studies on the interaction between sound and vision (Li & Lau, 2020; Ye, Luo, Kang & Wu, 2020) highlight the importance of acoustic-image consistency (Tatlikazan et al., 2017, Van Renterghem and Botteldooren, 2016). The complex interaction between sound and vision also affects one's evaluation of the soundscape. A visual-audio mismatch (Benfield et al., 2010) produces physiological and psychological effects (Schormans et al., 2017) and subsequently change the human mood (Liu & Kang, 2018).

As the main part of the visual system of urban business districts, visual media serve as an important communication platform between merchants and visitors (Wang, 2014; Zheng, 2009). The visual media in urban business districts has various visual features (e.g., rich visual color, wonder, and shape contour) and forms (e.g., paper media, LED screens, and laser projectors). In this case, urban business districts present an ideal scenario for conducting in-situ experiments on visual media. A visual engagement experimental test provides objective and measurable indicators of cognitive process and perception, and the introduction of eye movement tracking technologies has enabled accurate and convenient measurement of visual engagement (Aletta & Xiao, 2018). However, eye movement visual experiments mostly focus on landscapes (e.g., roads, greening landscapes, and their users) in cities. Several studies have focused on security, planning, mapping, participation, and visitor experience (Burian, Popelka & Beitlova, 2018; Li et al., 2020; Lisińska & Krupa, 2020; Maurage, Masson, Bollen & D'Hondt, 2019; Mele & Federici, 2011), whereas others have examined the role of natural landscape elements (e.g., green vegetation, buildings, and human performance activities) in improving visitor's emotions (Kang et al., 2016; Ren, Kang, Zhu & Wang, 2018; Van, 2018). However, only a few have examined the use of visual media in promoting visual engagement. Moreover, urban business districts have limited natural landscape elements, and the visual media in these areas usually take the form of humanistic signs, natural symbols, or digital visual elements used for advertising. Psychology, neuroscience, and medical studies have highlighted the huge impact of visual media on visitors' emotions. Therefore, extending this research to urban business districts is valuable.

While visual media interact with audio in digital devices such as mobile phones, computers, and televisions, such interaction is limited by the size of screens and the capability of devices to produce sound. However, the visual media in business districts are spatially and temporally integrated into surrounding landscapes as the large background (Li & Lau, 2020). The sound sources in these areas are also distributed across various locations, with accidental sound sources being commonplace. Normally, visitors often stay in a fixed posture when using their devices, but the interaction between visitor experience and the business district environment is highly dynamic and complex. Previous studies on visual-audio interaction have mostly focused on the use of assessment indices and performing experiments in a natural landscape (Aletta, Kang & Axelsson, 2016, 2018; Axelsson et al., 2010; Brown, 2012). Meanwhile, laboratory experiments have examined how the natural landscape of visual-audio elements can be optimized to improve the health of visitors. However, only a few studies have examined the visual-audio interaction experience of users when looking at visual media in urban business districts.

To address the aforementioned gap, this study explores the physiological and psychological effects of multi-media in urban business districts. More specifically, the complex design of multi-media presents a challenge in providing an attractive and comfortable environment that can enhance the visitor experience in business districts. In this emerging research area, collecting both subjective and objective data from visitors is crucial to understand their interaction with multi-media systems. The objectives of this research are (1) to objectively analyze visitors' visual engagement with visual systems in urban business districts by using quantitative data on their gazing time at different visual systems, (2) to investigate the impact of visual systems in urban business districts on the visitors' physiology, and (3) to analyze the psychological impact of multi-media on visitors in urban business districts through a subjective evaluation of their comfort in a visual-audio environment. The in-situ field survey experiment methods were performed to fulfill the above objectives. An eye-tracking device was used to collect data for understanding the physiological impact of multi-media, and a comfort level evaluation was performed for understanding its psychological impact. The in-situ experiment investigated the impact of the multi-media environment on the visitors' physiology through three aspects, namely, overall visual engagement time, visual engagement with different visual types, and visual-audio interactions on different walkways. The impact of visual-audio elements on visitors' psychology was also investigated through three aspects, namely, the comfort level of the multi-media environment, the comfort level of visual-audio interaction, and the perceived sound sources. The outcomes of this study can guide the optimized design of visual and audio elements and their interactions with visitors on walkways, improve the comfort of visual and sound environments, enhance visitors' shopping experience, and provide economic benefits for urban business districts.

The paper is organized as follows. Section 2 explains the methods used for collecting and analysing the data. Section 3 analysed the interrelationship among visitors' visual engagement, the subjective evaluation results, and the psychological impact of multi-media. Section 4 discusses the physiological and psychological effects of multi-media on visitors, the implications of these effects to theory, practice, and policymaking, the limitations of this paper, and some recommendations for future research. Section 5 summarizes the key findings and scientific contributions of this study.

2. Data collection and methods

2.1. Site selection and field survey

The experimental sites were selected with visual media, as the most important influencing factor in this study, as the main consideration. As shown in Fig. 1, modern business district walkways in Wuhan (provincial capital city), China were selected for the field study. All these walkways were in a central business district with many visual media. All walkways had different proportions of visual media types (text, images, and video) and were divided into three indoor walkways and three outdoor walkways.

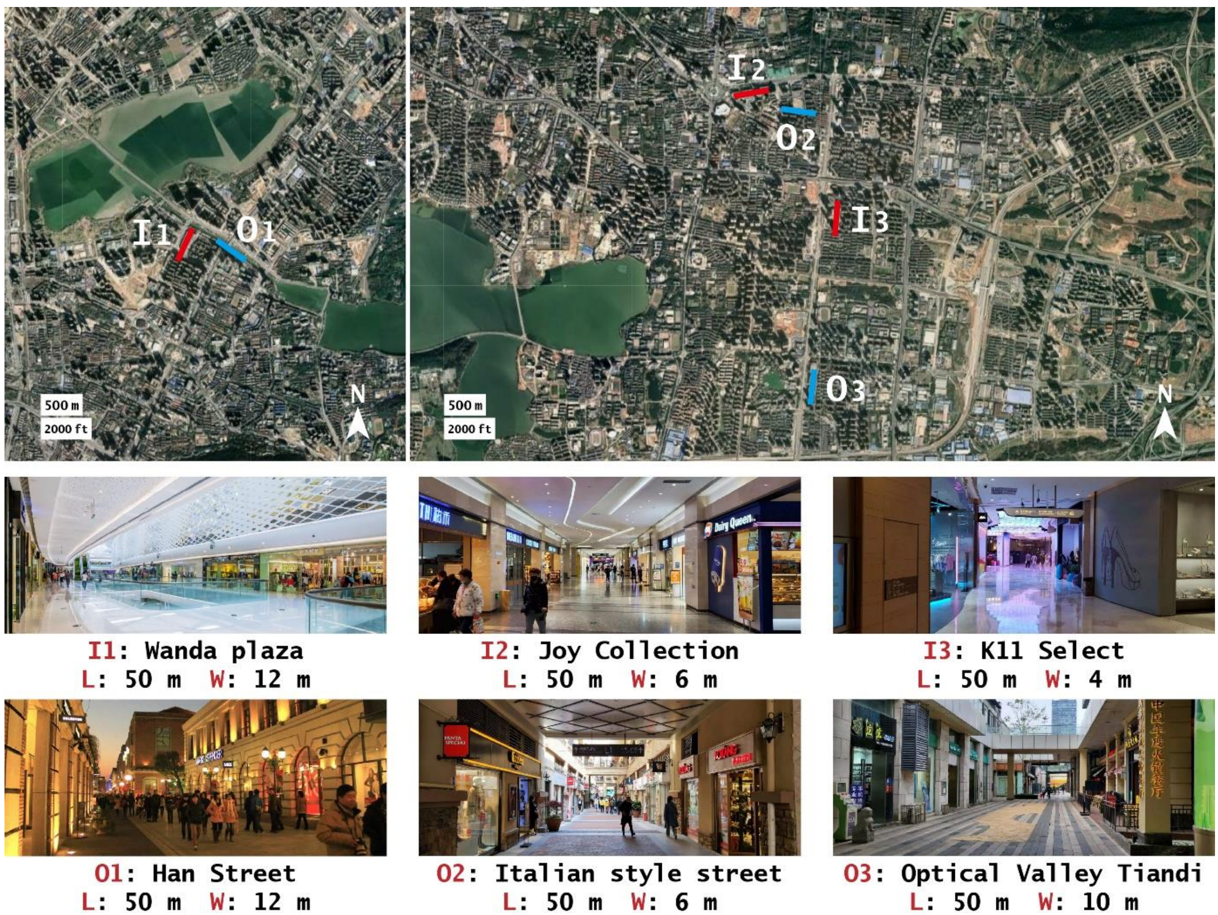

Fig. 1. Study sites: Six selected walkways in Wuhan, China,. Three indoor walkways (I1 - I3) and three outdoor walkways (O1 - O3), with "L" and "W" representing their experimental length and width (Map source: https://www.earthol.com/, The street view was taken by the author.)

The three outdoor walkways, marked as O1 to O3, are in the Wuhan Business District. O1 is in the central downtown of Wuchang District. A famous business walkway in Wuhan, O1 is located near the river and has a unique underwater soundscape. O2 is in the Hongshan University business park, where shops are relatively dense, and the visitors are mainly students. O3 is in an industrial park near a busy driveway, where the majority of the visitors are employees working in nearby offices. Meanwhile, the three indoor walkways were marked as I1 to I3. I1 and O1 are in the same business district and are mainly populated with clothing merchants. I2 and O2 are in the same university campus area and are mainly populated with entertainment and snack shops. I3 is populated with chain merchants of famous posh brands.

Each selected walkway has a uniform length of 50 m. The outdoor business walkways are 6 m to 12 m wide, whereas the indoor business walkways are 4 m to 12 m wide. I1 and O1 are the widest 12 walkways, whereas I3 is the narrowest 4 m walkway. All these walkways are occupied with merchants on both sides with various visual media.

2.2. Visual media data collection

According to Simpson, Freeth, Simpson and Thwaites (2018), almost all visual media and visual attention areas are mainly distributed on the facades of walkways in business areas. Therefore, to investigate the visual media distribution of the six selected walkways, a mobile HD video recorder was used to record high-quality videos of their facades. A hand-held portable camera was also used to capture high-definition 4 K quality photos. Consistent screenshots were taken from the videos to generate a coherent photo of each walkway's facade.

The process of editing the captured walkway photos is shown in Fig. 2, where 2(a) presents a video screenshot (with the upper and lower boundaries cropped out) of the entire facade of the store, 2(b) presents the location of different types of visual information (denoted by the green boxes) as identified using Adobe Illustrator, and 2(c) presents the same green boxes without the background. The distribution position and ratio of the visual media areas on the walkway facade were obtained after processing the image.

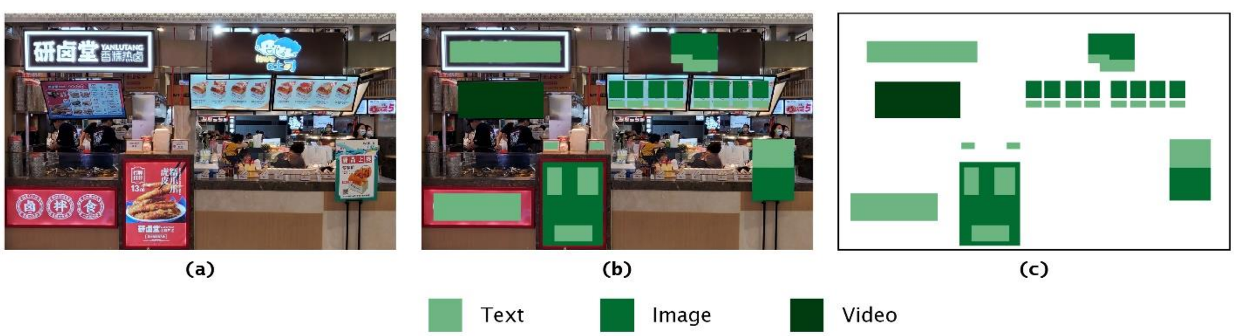

Fig. 2. Extraction of visual information for a walkway facade (image taken by the author.).

After repeating the above process, the positions, and areas of visual media on the facades of all six walkways were obtained as shown in Fig. 3. Visual media were evenly distributed across all walkways. Fig. 4 presents the area proportion of different types of visual media on the walkways (denoted by green boxes). The total visual media proportions for these six walkways ranged from 25.6% to 39.7%, with I3 having the highest proportion of 39.7% and O1 having the lowest proportion of 25.6%. Among the three forms of visual media, images accounted for the highest proportion (about 16.5%), whereas text and video accounted for about 7.9% and 6%, respectively.

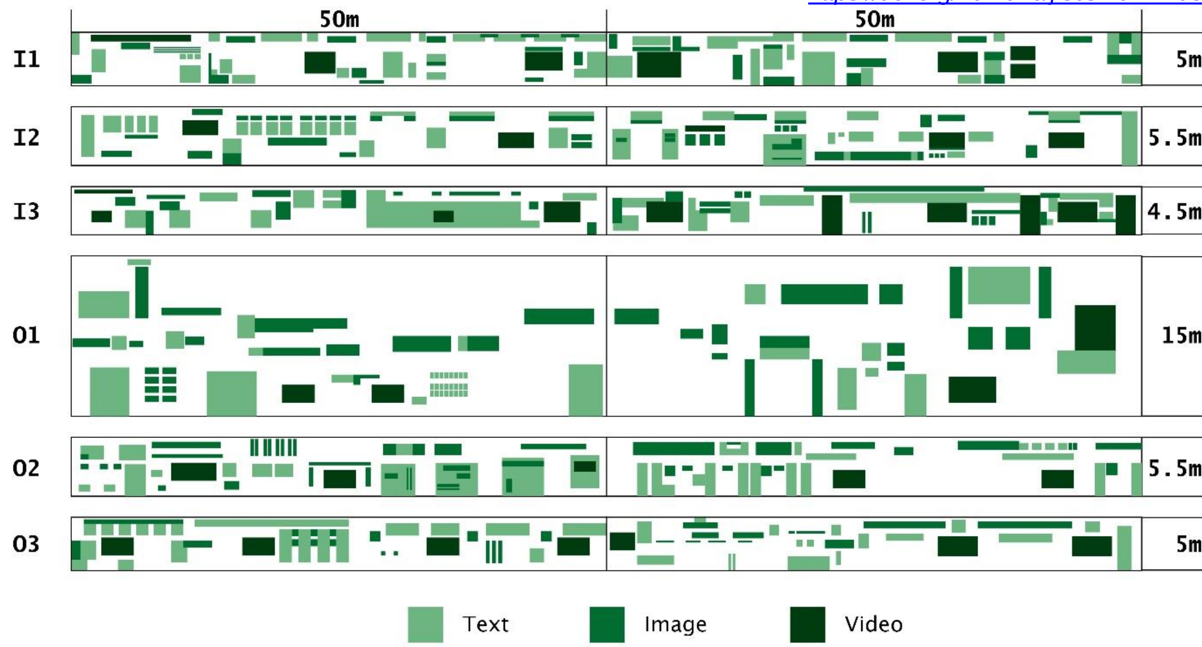

Fig. 3. Distribution of the position and areas of visual media on the six selected walkways.

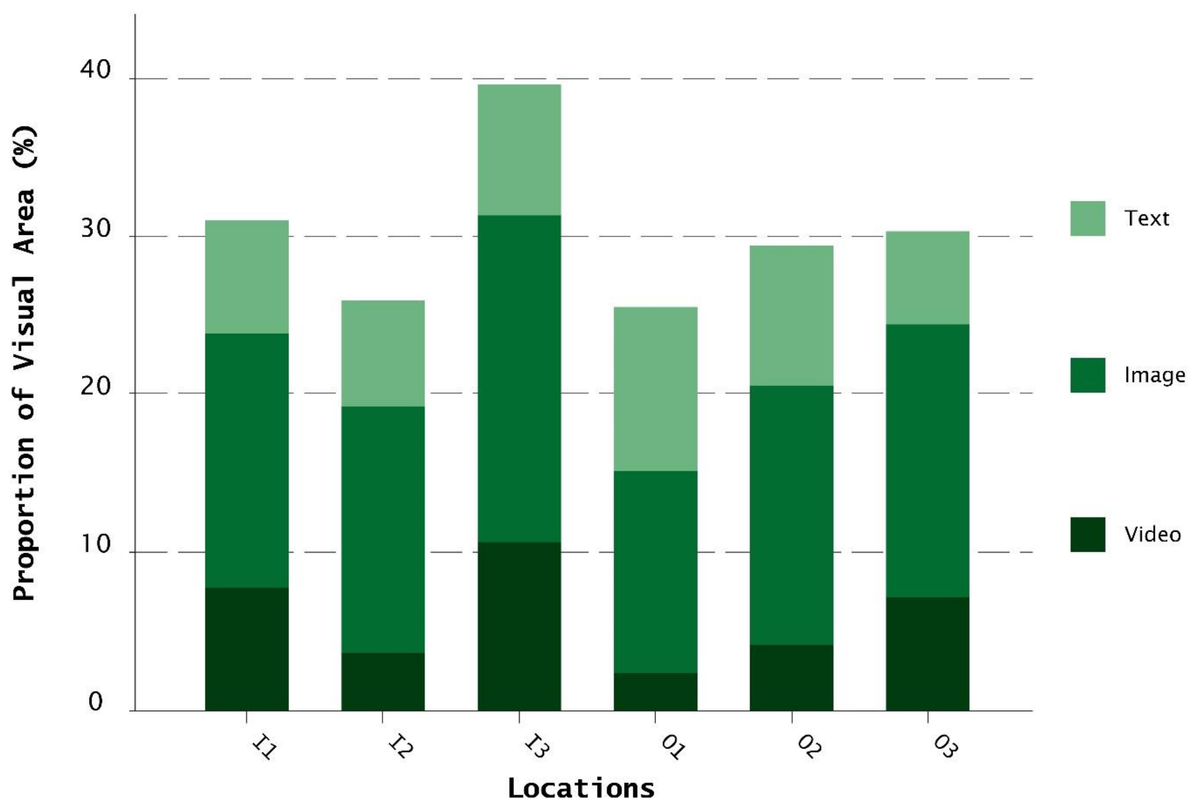

Fig. 4. Area proportion of each type of visual media on the walkway facades.

2.3 Acoustic parameters collection

The acoustic parameters of the selected walkways were measured using a sound level meter (model: AWA6228+, IEC60651 Class1). The 5-minute A-weighted equivalent sound pressure level ($L_{Aeq, 5\text{-}min}$) was also collected to describe the overall sound level during the on-site perceived sound source assessment. The difference between the 10th and 90th percentile levels (L_{A10}–L_{A90}) was used to describe the temporal variability of the sound environment. The standard deviations (SD) of both L_{Aeq} and (L_{A10}–L_{A90}) were calculated.

The acoustic parameters collected from the 6 business walkways are shown in Table 1. The average L_{Aeq} of the indoor business walkway ranged from 48.12 dB to 66.77 dB during the acoustic parameters' measurement. Meanwhile, the average L_{Aeq} of the 3 indoor business walkways was approximately 61.27 dB (SD = 4.32 dB) in 5 min. The L_{Aeq} in I1 was much lower than that in I2 and I3 in 5 min. The L_{Aeq} of outdoor business walkways, which ranged from 71.83 dB to 84.7 dB, was much higher than that of indoor business walkways, and the average L_{Aeq} of the three outdoor walkways was about 76.52 dB (SD = 3.02 dB) in 5 min. These outdoor walkways also reported a similar L_{Aeq} (78.26, 76.65, and 74.66 dB) in 5 min, and their average L_{Aeq} was 15.2 dB higher than that of indoor business walkways in 5 min. The average L_{A10}–L_{A90} of all walkways demonstrated a small temporal variation of 8.9 dB (SD = 1.6 dB), thereby indicating a high temporal difference between the indoor and outdoor walkways.

Table 1
The acoustical parameters calculated from the sound-level meter. The numbers in parentheses represent the numbers of measurements conducted at each location.

Locations	$L_{Aeq, 5\text{-}min}$ [dB]				L_{A10}-L_{A90} [dB]			
	Mean	SD	Min	Max	Mean	SD	Min	Max
I1 (n=30)	56.96	4.23	48.12	60.6	7.37	1.78	3.67	9.25
I2 (n=30)	62.24	2.04	59.38	65.53	8.89	1.01	7.59	10.46
I3 (n=30)	64.61	1.83	62.31	66.77	9.54	0.77	8.55	10.46
I1-I3 (n=90)	61.27	4.32	48.12	66.77	8.6	1.56	3.67	10.46
O1 (n=30)	78.26	1.4	76.18	80.09	8.76	0.9	7.65	10.14
O2 (n=30)	76.65	3.65	74.31	84.7	10.07	2.13	7.78	14.18
O3 (n=30)	74.66	2.36	71.83	77.44	8.76	1.2	7.2	10.48
O1-O3 (n=90)	76.52	3.02	71.83	84.7	9.2	1.63	7.2	14.18
Total (n=180)	68.9	8.49	48.12	84.7	8.9	1.62	3.67	14.18

SD: Standard deviation

2.4. Walkway's visual-audio interactions data

Table 2 categorizes the visual-audio interactions of the 6 walkways based on the ranking of their visual-audio and sound information:

- I1: Quiet and low temporal variability walkway with a high ratio of video content.
- I2: Quiet walkway with a low ratio of visual media content.
- I3: Moderate noise walkway with a high ratio of visual media content.
- O1: Traffic-noise-dominated outdoor walkway with a high ratio of visual text.
- O2: High temporal variability outdoor walkway with moderate visual media content.
- O3: Moderate noise walkway with a moderate ratio of images.

Table 2
Ranking of the proportion of visual media area and sound index parameters of all walkways.

Location	Walkways	Rank				
		The proportion of media visual area			$L_{Aeq,\ 5\text{-min}}$	L_{A10}-L_{A90}
		Text	Image	Video		
I1-I3	I1	4	4	2	6	6
	I2	5	5	5	5	3
	I3	3	1	1	4	2
O1-O3	O1	1	6	6	1	4
	O2	2	3	4	2	1
	O3	6	2	3	3	5

(Nos. 1 to 6 denote highest to lowest)

2.5. Participants experimental data collection

2.5.1. Participants selection and test procedure

A total of 30 participants were invited from each walkway for the experiment. All experiments were completed during the weekend between 14:00 and 17:00, which is a busy time when most visitors are walking around the business district. The experiment was not conducted on overcast or rainy days, early mornings, or nighttime to reduce the impact of weather and environmental parameters (e.g., temperature, humidity, illumination, and daylight).

Random visitors were invited to participate in the experiment through active enquiry. Before the experiment, these participants were informed about the purpose of the experiment and provided instructions on how to operate the experimental equipment. However, they were not informed about the aim of the experiment to minimize subjective bias. All participants signed an ethical consent form.

After the participants were equipped with the mobile eye-tracking device, the positions of three points were calibrated. This calibration procedure was repeated before each test. At the beginning of the experiment, the Rapid Eye Movement (REM) instrument started collecting data, and the integrated eye movement apparatus-recording devices started recording data in sync with the position of the participants as they moved around the walkways. Each selected walkway is a straight line and does not intersect with any other walkway. The participants were forbidden to enter shops during the experiment to ensure their comfort. Each participant held physical buttons on their left and right hands to send real-time feedback, and all evaluations corresponded to the eye movement data captured in real-time. After the participants reached the endpoint of the walkways, the data collection was immediately terminated, and the participants were requested to fill in a questionnaire asking for information about their perceptions toward their acoustic environment. Two researchers supported the participants throughout the entire experiment (i.e., from the starting point to the end-point of the walkways) to minimize interference from other visitors.

2.5.2. Eye-tracking data collection

The participants were asked to wear the Eye Tracking Core+ mobile eye-tracker device following the recommendations of a real-world eye-tracking study (Jeon & Hong, 2015). This lightweight device has a front-facing camera inside to record videos of the environment in front of the wearer and two rear cameras (one for each eye) to capture his/her eye movements. The information collected from these videos was processed using the Core Studio software to provide a single video output with a frontal video superimposed on the top gaze position.

2.5.3. Comfort level evaluation

To evaluate the visitors' comfort level of the visual-audio environment, two subjective evaluation indexes ("comfortable" and "annoyed") were adopted. The participants were given two physical buttons that were clipped to a touch induction clamp and were linked to virtual buttons on a mobile phone. The participants controlled these buttons on each hand to report their comfort level.

2.5.4. Questionnaire for sound evaluation

A questionnaire was used to measure the participants' perception of their acoustic environment. Each item was rated on a 5-point Likert scale (0: not heard at all; 1: heard a little; 2: heard moderately; 3: heard a lot; 4: completely dominant) to indicate the dominance of different sound sources. The sound sources were categorized into traffic noise (e.g., cars, buses, and motorcycles), human voices (e.g., talking, footsteps, and laughter), natural sounds (e.g., water flowing, birds singing, and wind blowing), music (e.g., from shops and the walkway), and other sounds. Only those sound sources with a ranking of 2 (heard moderately) or above were considered dominant data. The valid data for each sound source were used to calculate the overall dominant sound source of a selected walkway.

2.5.5. Data coding and statistical analysis

After the experiment, the eye-tracking data of the participants were exported to a video, with each frame indicating the area they were looking at for 0.1 s or longer. As shown in Fig. 5, the participants' visual gaze time on a predefined Area of Interest (AOI; the text, image, and video areas) was encoded using Core Studio. No overlap was allowed among these AOIs to ensure that all visual gaze and visual engagement time were assigned only to a single AOI on a selected walkway. Instead of automatically categorizing the eye movements as either gaze or glimpse, they were exported to a video to overcome the difficulty in capturing eye movement orientation data in outdoor environments (Evans, Jacobs, Tarduno & Pelz., 2012; Tomasi, Pundik, Bowers, Peli & Luo., 2016; Vansteenkiste, Cardon, D'Hondt, Philippaerts & Lenoir., 2015). After coding, the log with the continuous gaze duration on a predefined AOI was exported. The amount of time spent by each participant in visually interacting with each AOI on different walkways was then calculated to determine which AOI received the most attention from the participants during their movement.

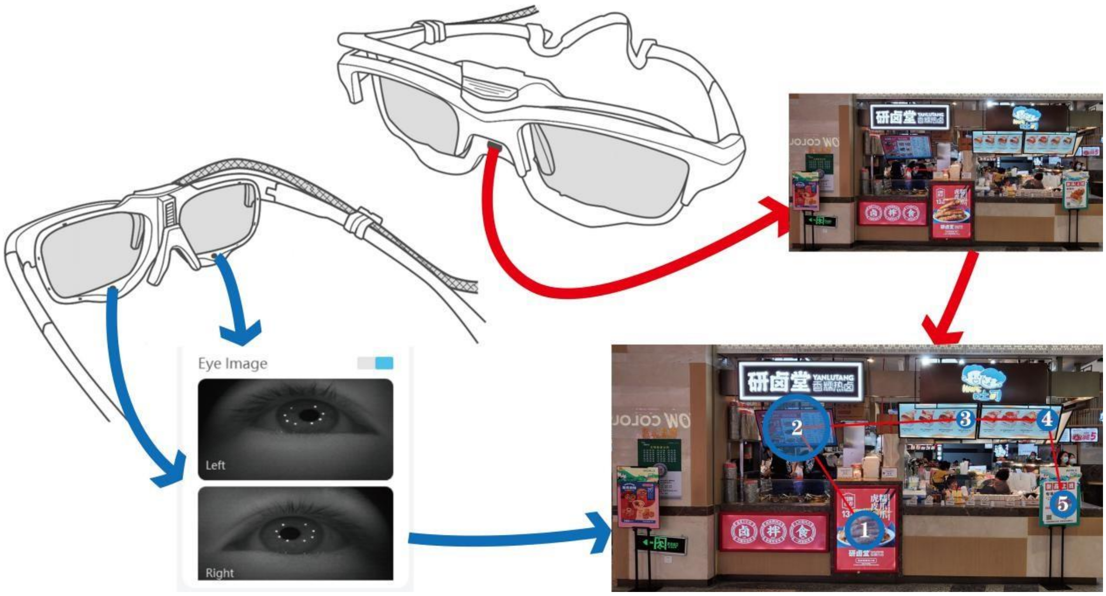

Fig. 5. Data collection concept of the portable eyeglass for the eye tracker (the eye tracker image was provided by the supplier, and the street view was taken by the author.).

Spearman's rank correlation coefficient (rs) was used to evaluate (1) the perceived sound environment and sound index of the field and (2) the visual-audio elements and comfort level. The SPSS software (version 23.0, IBM, USA) was used for the statistical analysis.

3. Results

3.1 Eye-tracking data analysis

3.1.1. Overall engagement time with visual media

Fig. 6 shows the gaze time of each participant on all types of visual information along the selected walkways. The browsing time varied from 49 s to 167 s, and the average visiting time was 107.3 s (SD=33.8 s). The results for engagement time were mainly ascribed to each participant's walkway preferences. These participants were interested in the walkway facades and often stopped and observed the visual information present in their environment. The average visiting time for indoor walkways (mean=108.1 s, SD=36.7 s) was similar to that for outdoor walkways (mean=106.4 s, SD=30.6 s), thereby indicating that the difference between indoor and outdoor environments does not affect the visiting time for walkways. The visiting times for I3 (mean=117.4 s, SD=38.8 s) and O2 (mean=114.3 s, SD=30.4 s) were significantly longer than those for the other walkways mainly because the videos taken on I3 largely focused on facades, whereas the videos taken on O2 contained much noise coming from shop assistants shouting at customers, which slowed down the walking pace of the participants.

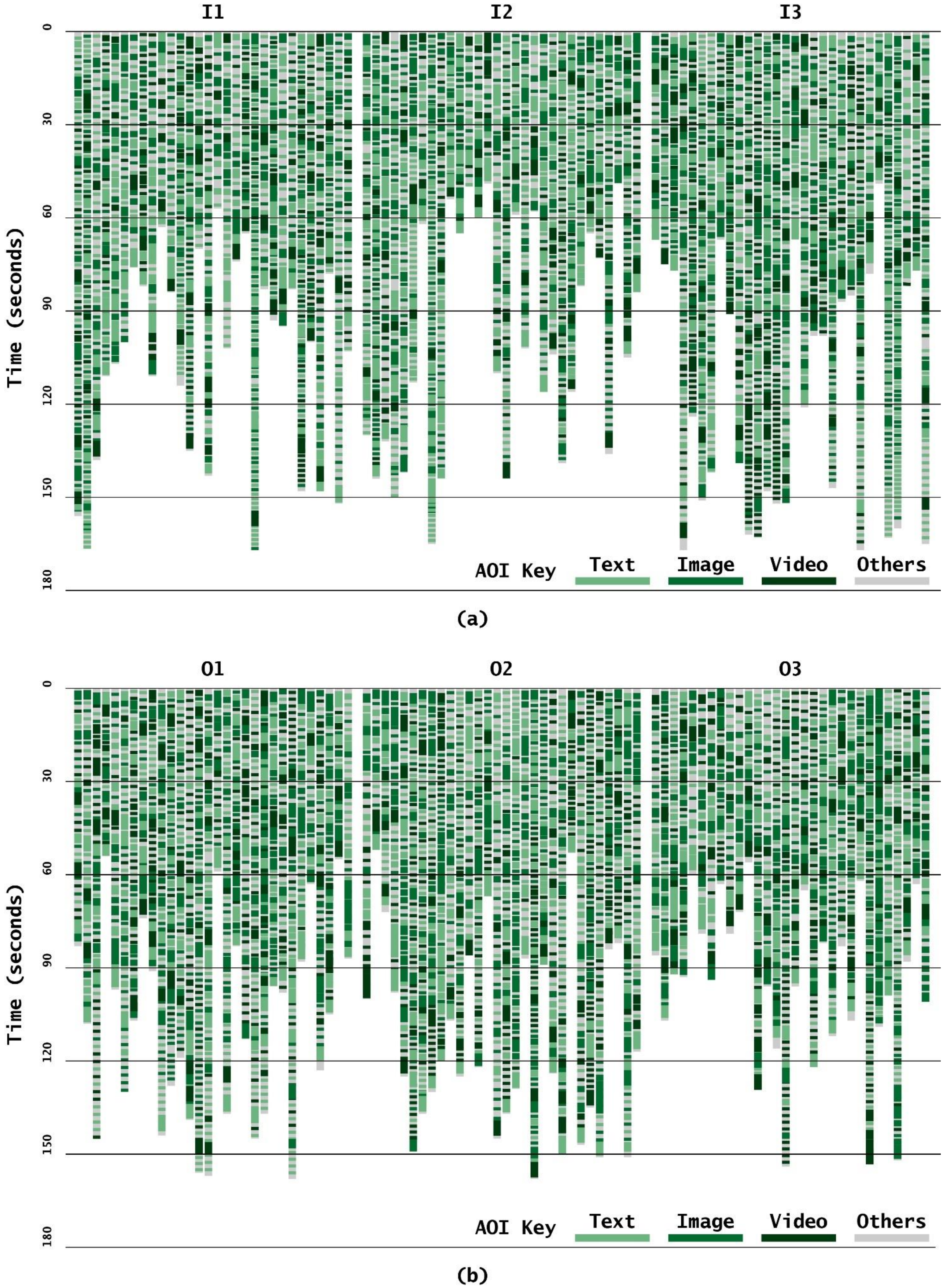

Fig. 6. Visitors' visual engagement on all walkways. Each longitudinal column represents the gaze time of each

participant. (a): Three indoor walkways, and (b): three outdoor walkways. Each color represents different key AOI information, and the length of each box represents the length of gaze time at each AOI.

3.1.2. Visual engagement with different types of visual media

Figure 7 shows that 71.5% of the participants focused on visual media, thereby highlighting the dominant role of visual media in the visual system of the selected business walkways. Visual media present a large amount of readable information and can attract the attention of visitors for a long period. Among these media, images (27.7%) and text (27.3%) captured the visual attention of more than half of the participants. Both text and images have important roles in visual attention. Although videos only attracted the visual attention of 16.7% of the participants, they only accounted for 6% of the entire walkway facade. Given the relatively high video attraction to area ratio, videos should be considered a key element in the visual system.

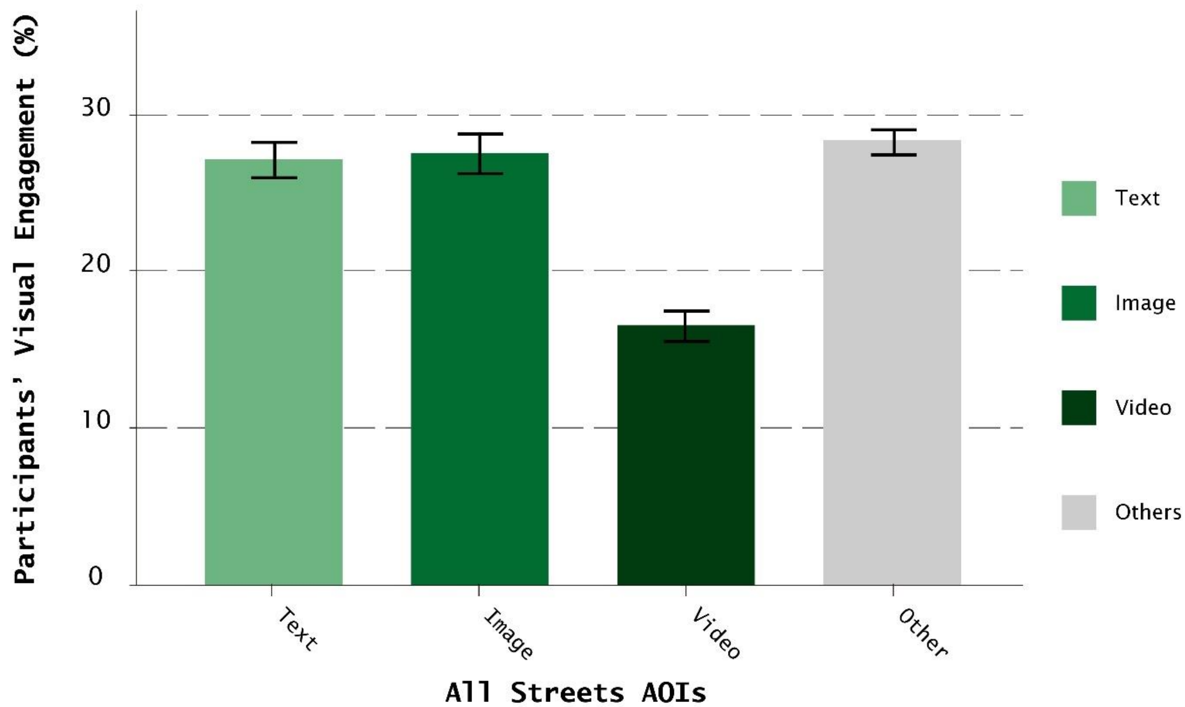

Fig. 7. Percentage of participants' visual engagement with AOIs on the walkways. The error bar represents the standard error.

Figure 8 shows the differences in the participants' visual engagement as reflected in the duration of their gaze at each visual media. A shorter gaze time corresponds to a higher percentage of visual engagement. The visual engagement with a duration "0 s–1 s" had the highest proportion (40.2%), whereas the visual engagement with a duration of "> 4 S" had the lowest proportion (11.3%).

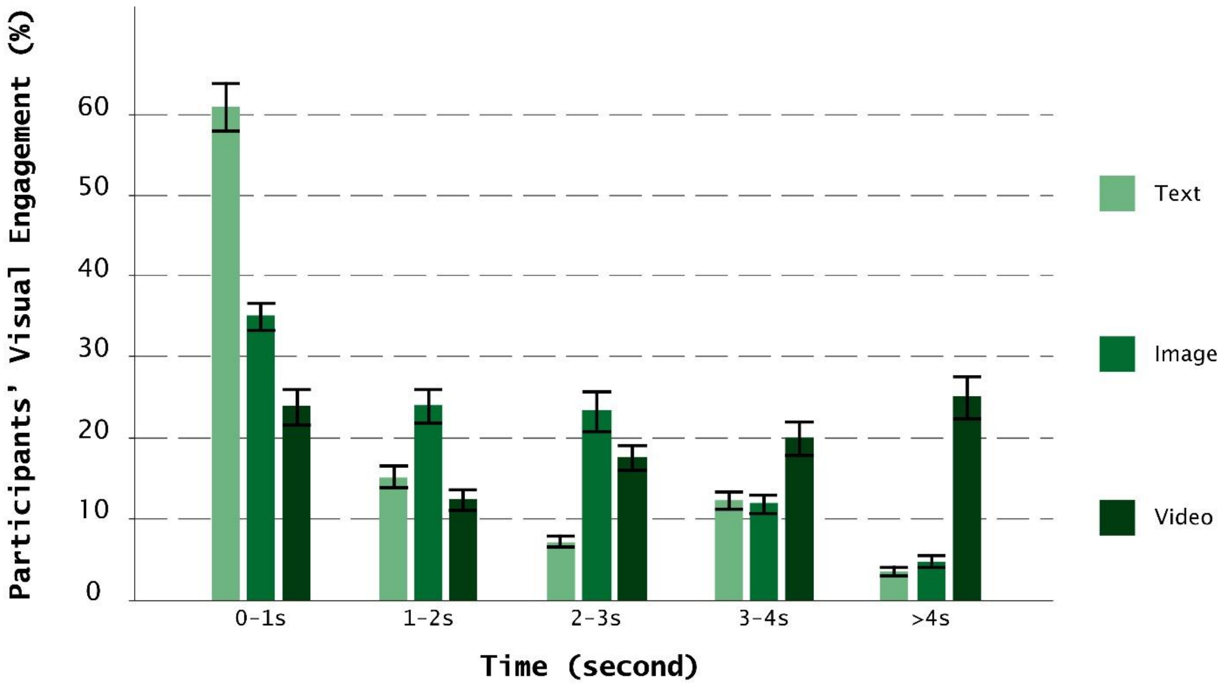

Fig. 8. Percentage of visual engagement with different visual media as measured by gaze duration. The error bar represents the standard error.

Most of the textual information on the 6 walkways only had around 10 Chinese characters. Around 61.2% of the visual engagement with a “0 s–1 s” duration focused on simple and short texts. A playback of the video captured by the eye-tracking devices reveals that the participants only focused on textual information with two to three Chinese characters.

Around 35.2% of the visual engagement with images had a duration of "0 s–1 s." Given that images usually include richer amounts of information compared with texts, visitors tend to pay more attention to images for extended periods.

The visual engagements with videos lasting for ">4 s" and "0 s–1 s" accounted for the majority (25.3% and 24.1%, respectively), thereby indicating that the high visual engagement of visitors with videos is polarized in shortest and longest gaze durations.

3.1.3. Engagement with visual media on different walkways

Figure 9 shows the visual engagement of the participants with the visual media on the 6 selected walkways. O3 had the highest visual engagement (low-value consumption walkway with a moderate amount of images) with an engagement rate of 82.5% (SD=0.21), whereas I1 had the lowest engagement (quiet and low temporal variability walkway with a large amount of videos) with an engagement rate of 62.8% (SD=0.17). While the visual media areas of O3 and I1 were similar, the visual gaze durations of visitors on these walkways differed, thereby indicating that the size of the visual media area is not closely correlated with the visual engagement of visitors. A comparison of I1-I3 and O1-O3 reveals that the gaze time of visitors on outdoor walkways is 10% longer than that on indoor walkways. Interestingly, O2 reported the highest sound temporal variability and the lowest visual media attention among the three outdoor walkways, whereas I1 reported the lowest temporal variability and visual media attention among the three indoor walkways.

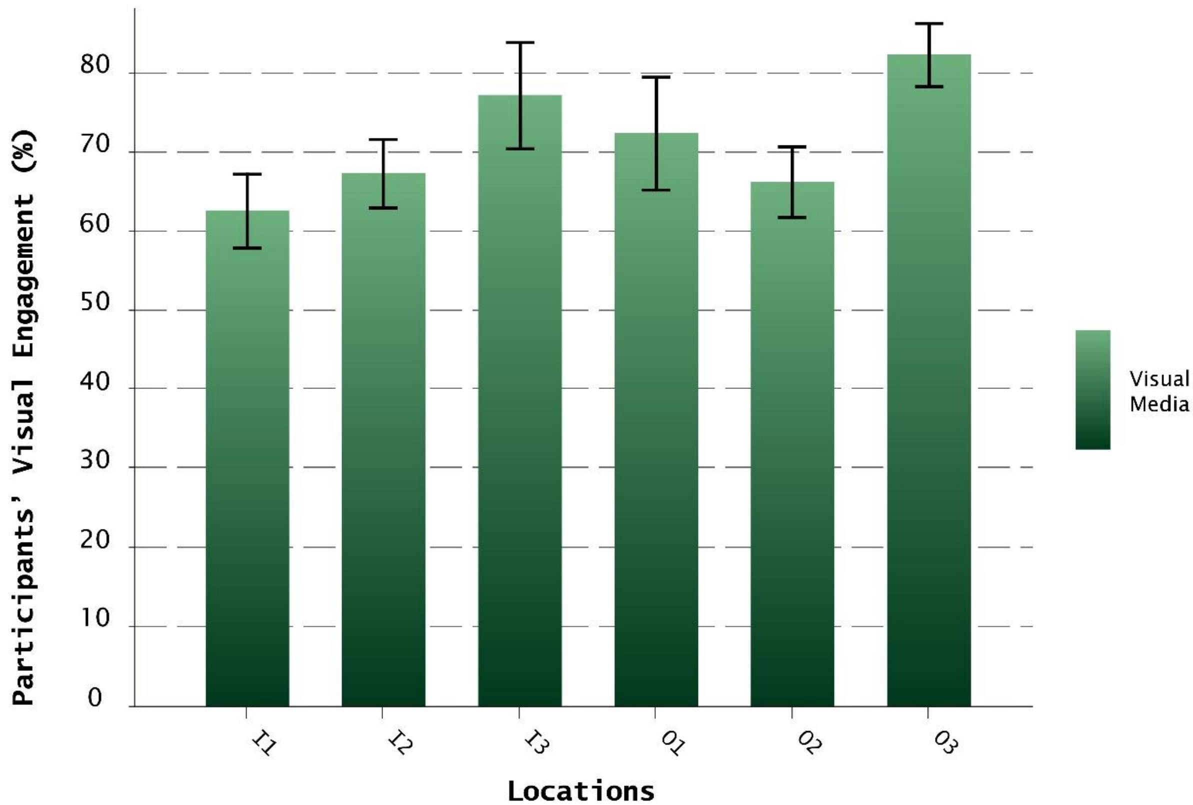

Fig. 9. Percentage of visual engagement with visual media. The error bar represents the standard error.

3.2 Subjective evaluation analysis

3.2.1. Comfort level evaluation of the overall multi-media environment

As shown in Figure 10, a total of 661 comfort level evaluations were collected, among which 423 (64%) rated the environment as "comfortable" and 238 (36%) rated the environment as "annoying." The positive evaluations for the six walkways significantly outnumbered the negative ones. Figure 10 shows that I3 has the most positive evaluation (29.1%) and the least negative evaluation (6.3%), O2 has the least positive evaluation (5.7%), and O3 has the most negative evaluation (29%). Interestingly, the positive evaluation was positively correlated with more spending in shops, whereas the negative evaluation was negatively correlated with spending.

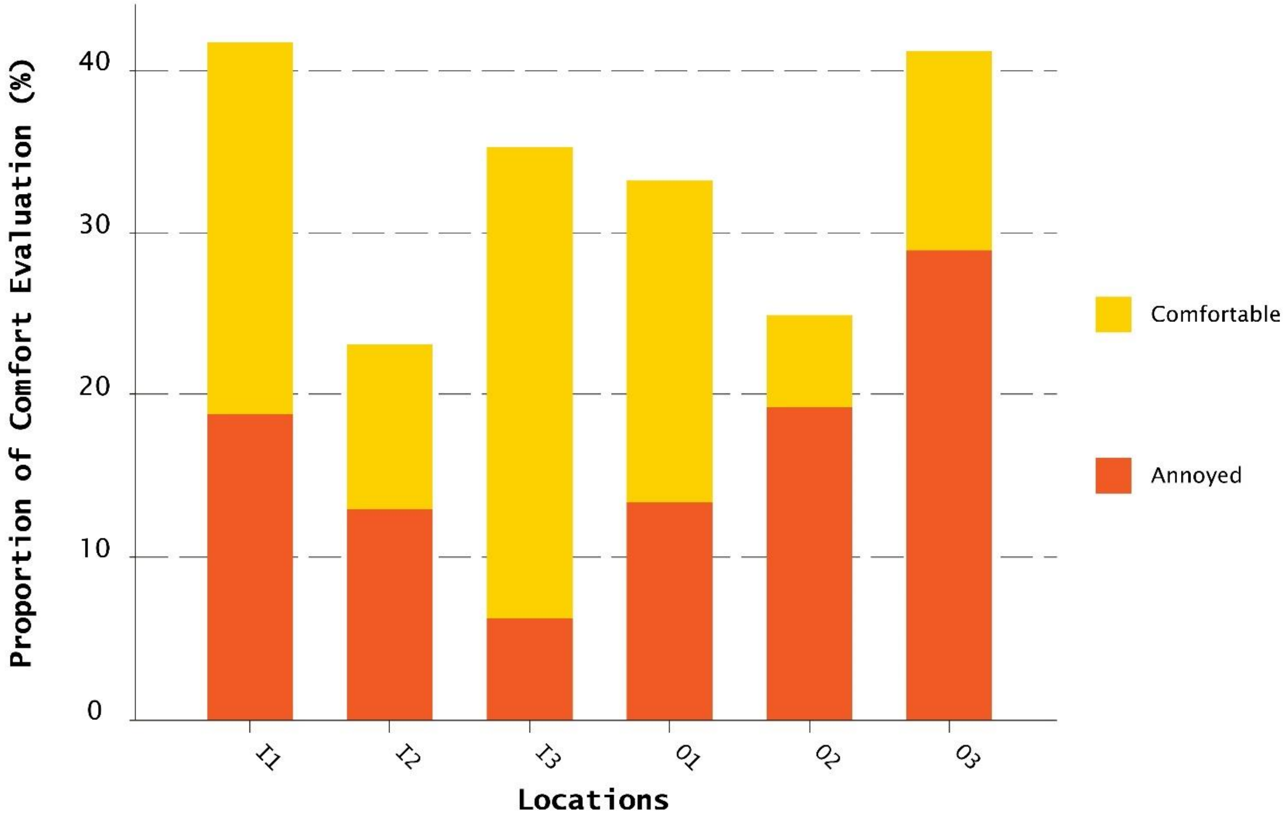

Fig. 10. Ratio of participants' comfort level evaluation

Table 3 shows the correlation between comfort level evaluation and visual-audio elements on the 6 walkways. On I1 to I3, the images reported the highest correlation with "comfortable" evaluations ($r_s = 0.78$, $p < 0.01$), followed by videos ($r_s = 0.63$, $p < 0.01$). In other words, having a large area of images and videos improves the visitors' comfort level on indoor walkways. Video ($r_s = -0.57$, $p < 0.01$) and human voice ($r_s = 0.47$, $p < 0.01$) were highly correlated with "annoyed," thereby indicating that excessive human voices negatively affect the visitors' comfort level in indoor shopping areas. On O1 to O3, traffic noise reported the highest correlation with "comfortable" evaluations ($r_s = -0.68$, $p < 0.01$), followed by nature sound ($r_s = 0.48$, $p < 0.01$) and video ($r_s = 0.47$, $p < 0.05$), thereby suggesting that traffic noise negatively affects the comfort level on walkways in outdoor shopping areas. However, both natural sound and video showed opposite effects on the visitors' comfort level. Traffic noise, which increases the temporal variance of the acoustic environment of outdoor walkways, reported the highest correlation with "annoyed" ($r_s = 0.49$, $p < 0.01$), followed by image ($r_s = -0.48$, $p < 0.05$).

Table 3
Spearman's rank correlation coefficients between visual-audio elements and comfort evaluation.

Location	Visual-audio elements		Evaluation	
			Comfortable	Annoyed
I1-I3	Visual media	Text	0.14	0.05*
		Image	0.78**	-0.29*
		Video	0.63**	-0.57**
		others	0.21*	-0.12
	Sound	Traffic	0.01	0.04

		Human	-0.36*	0.47**
		Nature	0.08	-0.2
		Music	0.35**	-0.41**
		Others	0.19*	0.08
O1-O3	Visual media	Text	0.25*	-0.18*
		Image	-0.26*	-0.48*
		Video	0.47*	-0.26
		others	0.17	0.06
	Sound	Traffic	-0.68**	0.49**
		Human	0.16	0.37**
		Nature	0.48**	-0.14
		Music	-0.37*	0.18
		Others	0.19*	0.03

(*p < 0.05, **p < 0.01)

3.2.2. Visual-audio comfort level evaluation of visual-audio interaction

The 6 walkways contained 4 visual elements and 5 sound sources producing 20 visual-audio interaction scenarios. Figure 11 shows the proportion of each scenario, with 11(a) showing the "feel comfortable" evaluation, and 11(b) showing the "feel annoyed" evaluation. The 4 interaction scenarios with the "music" element were ranked 1, 3, 4, and 8, respectively, and altogether accounted for 42.5% of all scenarios, which was significantly higher than the proportions reported for the other scenarios. In other words, playing background music can greatly improve the comfort of visitors on all walkways. Among the interactions of the top five comfort scenarios, three interactions included "image," thereby suggesting that the presence of images improves the comfort level of visitors on walkways.

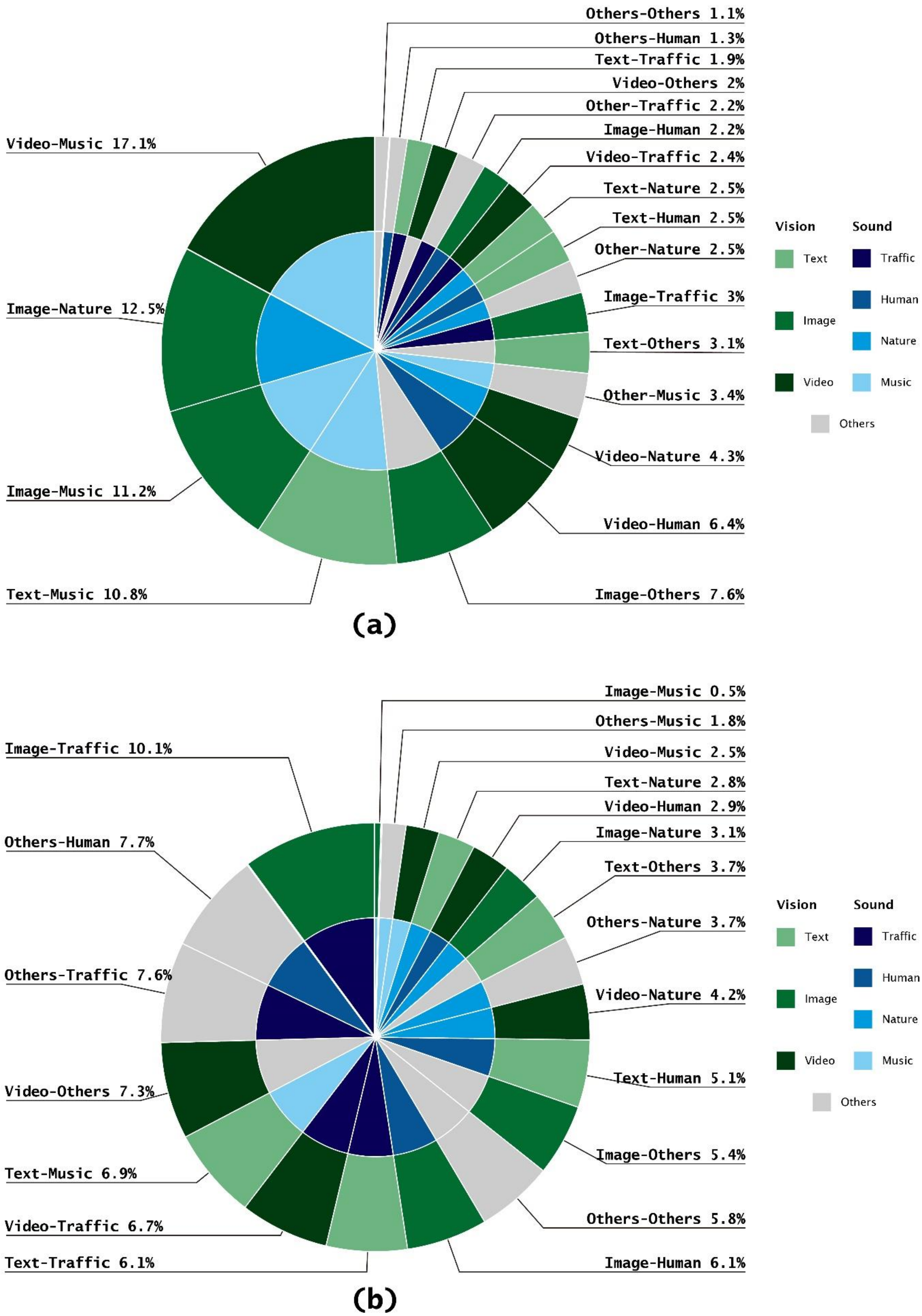

Fig. 11. Proportion of participants' comfort level evaluation in different visual-audio interactions: (a) comfortable, and (b) annoyed

In terms of negative evaluation, the 4 interaction scenarios involving "traffic noise" were ranked 1, 3, 6, and 7, respectively, and altogether accounted for 30.5% of all scenarios, which was significantly higher than the proportions reported for the other sound sources. Therefore, traffic noise significantly reduces the comfort level of visitors while moving along the walkway. Seven out of nine scenarios with few negative evaluations combined "natural sound" and "music," thereby suggesting that music and natural sound can significantly reduce the annoyance of visitors.

3.2.3. Evaluation of perceived sound sources

Figure 12 highlights human activities (32.1%) and music (28%) as the most common sound sources on business walkways given the high mobility of visitors and the background music playing on most walkways. A relatively high level of traffic noise (42.8%) influenced the visitors on the O3 walkway. Only a low proportion (5%) of natural sound was reported on outdoor walkways given that outdoor business areas are located in the city centre and far away from parks and other natural places. I3 reported the highest proportion of natural sound (8.7%) given the artificial wind sound and singing birds coming from a public art exhibition area nearby. O1 and O2 had the highest proportion of sound coming from human activities (51.8% and 38.2%, respectively), thereby suggesting that these two walkways have the highest visitor mobility. These findings indicate that the composition of sound sources depends on the function and location of walkways.

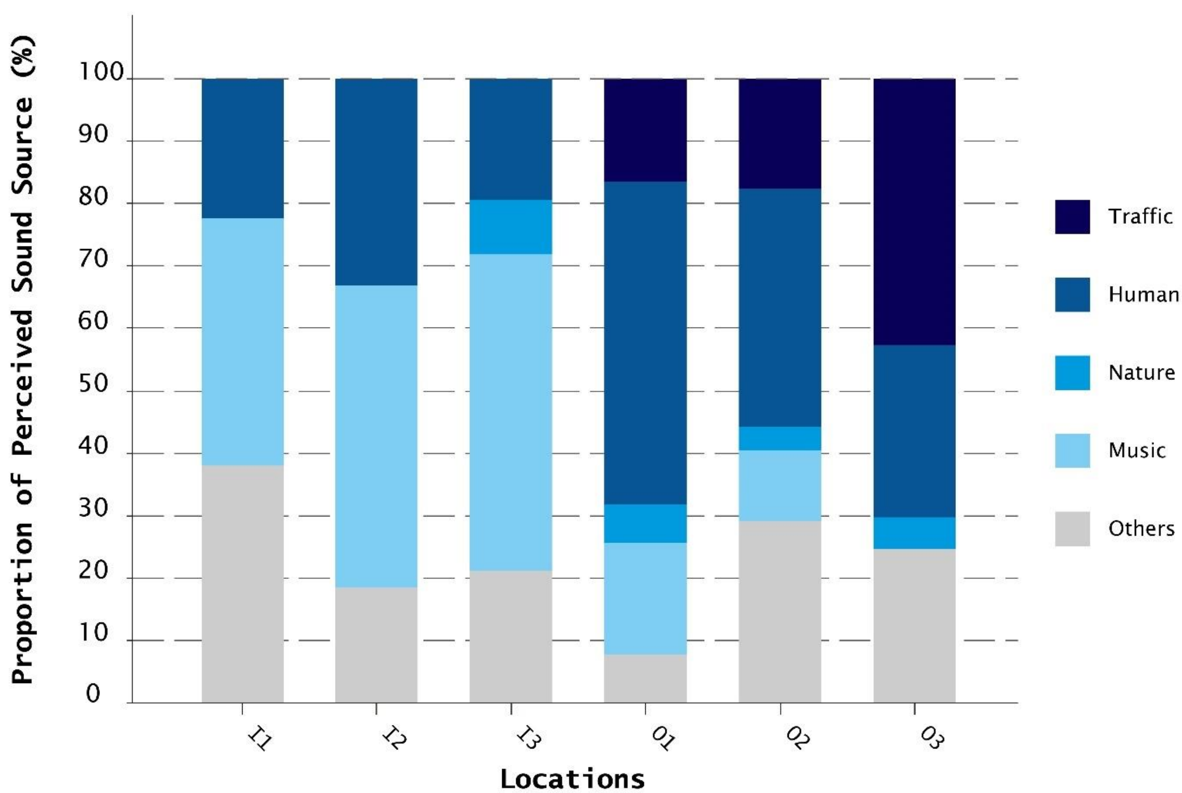

Fig. 12. Proportion of each perceived sound source on each walkway

Table 4 shows the correlation between the acoustic parameters and perceived sound sources on all walkways. For the indoor walkways, human voice reported the highest correlation with $L_{Aeq, 5\text{-}min}$ (r_s = 0.67, p < 0.01), followed by music (r_s = 0.57, p < 0.01), thereby suggesting that human voice and music increase the overall SPL of the acoustic environment of indoor walkways. Meanwhile, music reported the highest correlation with L_{A10}-L_{A90} (rs = -0.48, p < 0.01), thereby suggesting that music decreases the temporal variance of the acoustic environment of indoor walkways. For outdoor walkways, traffic noise reported the highest correlation with $L_{Aeq, 5\text{-}min}$ (r_s = 0.77, p < 0.01), followed by nature sound (r_s = -0.59, p < 0.01) and other sounds (r_s = -0.52, p < 0.01), thereby suggesting that traffic noise increases the overall SPL of the acoustic environment of outdoor walkways. Natural sounds and traffic noise had opposite effects. Meanwhile, music was highly correlated with L_{A10}-L_{A90} (r_s = 0.57, p < 0.01), thereby suggesting that music increases the temporal variance of the acoustic environment of outdoor walkways.

Table 4
Spearman's rank correlation coefficients between the identified sound sources and acoustic parameters.

Walkway	Sound	$L_{Aeq, 5\text{-}min}$	L_{A10}-L_{A90}
I1-I3 (n=90)	Traffic	-0.12	0.28*
	Human	0.67**	0.25*
	Nature	-0.18*	0.32*
	Music	0.57**	-0.48**
	Others	0.35	-0.1*
O1-O3 (n=90)	Traffic	0.77**	0.23
	Human	0.46**	0.43**
	Nature	-0.59**	-0.13
	Music	0.28*	0.57**
	Others	-0.52**	-0.12

(*p < 0.05, **p < 0.01)

4. Discussion

4.1. Physiological influence of visual media

The overall visual engagement time shows that visitors continuously pay much attention to visual media, thereby highlighting the critical role of visual media in attracting customers. Visual media contain numerous readable information that can easily inspire visitors. Similar findings have also been reported in the network media literature (Shao & Yang, 2009). Furthermore, the average walking pace was calculated in this study based on the average walking time of the 180 participants along the entire length of the 6 selected walkways. The average walking pace of the participants was 0.47 m/s (SD = 1.48 m/s), which is nearly 70% lower than the normal walking pace (Lordall, Bruno & Ryan, 2020). The above analysis proves that visual media can increase the visitor's visual engagement and redirect their attention, thereby greatly decelerating their walking pace and motivating them to go shopping.

Based on their visual engagement with different visual elements, a relationship was established between the visitors' eye movement and the overall composition of visual media on walkway facades. While visual media attracted the attention of 71% of the participants, they only covered 30.4% of the visual area on the walkway facades. Similar results have been reported in a canteen setting (Ye et al., 2020). Different combinations of visual elements in visual media also affect visitor experience on walkways. Having a high proportion of video areas on walkway facades increases the chances for visitors to go shopping (Zhang, 2013). Commercial advertisements broadcast via high dynamic range (HDR) videos tend to attract more visual attention. The high-density distribution of videos may also stop visitors on their tracks to watch visual media for a while. Visitors are attracted by HDR videos in business areas whether they are standing or sitting (Ye et al., 2020). These findings are consistent with those described in the previous paragraph regarding the visitors' walking pace being slower than normal under the influence of visual media. Noteworthy, while text and image areas accounted for 7.9% and 16.5% of the walkways, respectively, their visual gaze times were nearly similar at 27.3% and 27.7%, respectively. This result indicates that even though the texts are short, simple, and have a limited visual area, their expression is intuitive, thereby effectively attracting the attention of visitors (Gu & Li, 2021).

In summary, increasing the quantity and quality of visual media on walkway facades can drive more customers to shop.

Each visual-audio environment induces a different response from the visitors. Given that the SPL of outdoor environments is higher than that of indoor environments, visitors on outdoor walkways spend more time looking at visual media and watching videos. Notably, their gaze time at single visual information is short because the contents of visual media frequently switch and are difficult to read. Human voices and traffic noise are the main sound sources on outdoor walkways. In such an acoustic environment, the human voice becomes annoying to the visitors, thereby preventing them from receiving information, which is consistent with the findings of Liu, Kang and Xie (2020). I1 and I2 had a large area of images yet lacked natural sounds. Compared with other walkways, visitors paid less attention to visual media present on I1 and I2, thereby suggesting that the combination of image and natural sound can improve visitors' visual engagement, which is consistent with the findings of Jeon and Jo (2019). O3 was the only walkway to have no background music. Song lyrics may also come in conflict with the text presented on visual media, and some people may not enjoy receiving both visual and auditory messages simultaneously (Einhäuser, Methfessel & Bendixen, 2017).

4.2. Psychological influence of multi-media

In the results of the visual-audio environment comfort level evaluation, 64% of the evaluations were positive, among which the positive evaluation for indoor walkways was 64.4% greater than that for outdoor walkways. In terms of the perceived sound source, most walkways had background music, whereas indoor walkways had no interference from traffic noise. Many studies (Bo & Kang, 2011; Jiang et al., 2017; Tong et al., 2021) have proven that traffic noise reduces visitors' comfort. However, background music can significantly increase visitors' satisfaction, promote their positive behavior, and increase the time they spend browsing and exploring shops. Foreground music can also arouse emotions (Chen et al., 2017; Mu, Kang & Wu, 2021; Yi & Kang, 2019). Visual media greatly affect the comfort evaluation of visitors, and both images ($rs = 0.78$, $p < 0.01$) and videos ($rs = 0.63$, $p < 0.01$) showed a strong and positive correlation with visitors' comfort. This finding is supported by Ye et al. (2020), who found that visual media can improve visitors' comfort experience in a gathering space.

The comfort evaluation for visual-audio interaction reveals that the combination of different visual-audio elements significantly affects visitors' comfort. All forms of visual media create a relatively comfortable experience for visitors when combined with background music. Combining videos with natural sound and background music also elicits more positive feedback from visitors. As a common sound source for outdoor walkways, traffic noise negatively affects visitors' comfort, whereas natural sound and background music can mitigate such negative impacts. I2 and O2 reported the highest number of evaluations, whereas I1 and O3 obtained the lowest number of evaluations, thereby suggesting that visitors tend to share feedback when a large amount of video content is available. Visitors also undergo a highly emotional experience when watching videos, thereby making the content of visual-audio interactions a topic that warrants further study.

The human voice (r_s=0.67, p<0.01) and music (r_s=0.57, p<0.01) are the main sound sources that affect the average SLP ($L_{Aeq,\ 5\text{-}min}$) of indoor walkways surrounded by shops and restaurants. Meanwhile, outdoor walkways are surrounded by high-rise office buildings and busy roads, with traffic noise (r_s=0.77, p<0.01) being the main sound source. This finding is consistent with that of Hong and Jeon (2020). Interestingly, background music is negatively associated with the temporal variability SPL L_{A10}-L_{A90} ($r_s = -0.48$, $p < 0.01$) of indoor walkways yet is positively associated with the L_{A10}-L_{A90} (r_s =0.57, p <0.01) of outdoor walkways. The background music coming from shops was identified as the main sound source for indoor walkways with low SPL. By contrast, the background sound on outdoor walkways comes from random sources, such as buskers, and has a high SPL that leads to high temporal variances.

4.3. Relationship between multi-media and subjective evaluation

The visitors' visual attention rate for texts, images, and videos was divided by the area covered by each visual element on walkway facades to measure the attention efficiency for each element. Texts, images, and videos obtained visual attention rates of 105%, 51%, and 85% respectively. Combined with the data shown in Fig. 8, visitors gaze at a single text object for no more than 1 s, at a single image object for 1 s to 3 s, and a video element for more than 3 s. These results indicate that those AOI elements that capture the attention of visitors are frequently changing. However, results of the correlation analysis indicate that images (r_s=0.78, p<0.01) and videos (r_s=0.63, p<0.01) can significantly improve the comfort level of visitors, whereas text cannot (r_s=−0.14, p>0.05).

The above data on eye movement and comfort experience suggests further that the visual media environment of walkways requires further improvements. Increasing the number of images or videos and reducing the amount of text not only improve visitors' comfort but also allow them to focus on visual media elements available on walkways, thereby enhancing the branding impact of merchants.

The most important sound sources on indoor walkways are human voices and background music. Human voices increased the average SPL ($L_{Aeq,\ 5\ min}$) of walkways (r_s=0.67, p<0.01) and significantly increased the annoyance of visitors (r_s=0.47, p<0.01). Meanwhile, background music reduced the temporal variability SPL (L_{A10}-L_{A90}) of the acoustic environment of walkways (r_s=−0.48, p<0.01) and significantly reduced the annoyance of visitors (r_s=−0.41, p<0.01). The most important sound sources on outdoor walkways are traffic noise and natural sound. Traffic noise increased the $L_{Aeq,\ 5\ min}$ of walkways (r_s=0.77, p<0.01) and significantly reduced the visitors' comfort level (r_s=−0.68, p <0.01), whereas nature sound reduced the $L_{Aeq,\ 5\ min}$ of walkways (r_s=−0.59, p<0.01) and significantly increased the visitors' comfort level (r_s=0.48, p<0.01). The above results highlight the positive impact of background music on the comfort level of indoor walkways. Using visual media that combine videos and music can optimize the experience of visitors. Meanwhile, natural sound and traffic noise on outdoor walkways positively and negatively affect visitors' comfort, respectively. "Visual media" reported the best match with "natural sound and images," whereas "visual media video" reported the best match with traffic noise. All these design interactions can be used as a reference for optimizing the layout design of walkways.

4.4. Implications

Given that the unique multi-media systems in urban business districts provide massive amounts of information to visitors, this study broadens the scope of research on urban visual-audio environments by collecting data on the interaction between visitors and multi-media through in-situ experiments. These practical data are used to establish a theoretical framework that guides the design of visual-audio interactive multi-media in such areas.

The objective quantitative data and subjective evaluation data from this study can guide the formulation of a human-centered sustainable design for urban business districts. Investigating visitors' visual engagement based on their eye-tracking data can help quantify their attention to different types of visual media and identify the visual content they engage with the most. Analyzing such data can guide merchants and designers in accurately identifying the types, locations, and sizes of visual media and further rationalize the planning and optimization of visual media designs. For example, on indoor walkways, increasing the proportion of videos in prominent areas can attract more visitors. Meanwhile, on outdoor walkways, the amount of text can be reduced and the size of images can be increased to enhance the comfort of visitors. The combination of different visual-audio elements is optimally ranked according to the visitors' subjective comfort evaluation of their real-time visual-audio environment, thus guiding merchants and designers in creating multi-media content. Matching appropriate soundscapes, planning sound source locations and sound pressure levels in specific visual media environments, and installing appropriate visual media with specific soundscapes can make the visual-audio environment in business districts very harmonious and comfortable. For example, in video-intensive outdoor business districts, sound barriers can be set up to minimize interference from traffic noise. Meanwhile, on indoor business walkways with background music, more images may be arranged near sound sources to enhance the visitor experience.

The data collected from this study can also guide policymakers in planning and designing business areas with an appropriate visual-audio environment. For example, the indoor shopping areas instead of outdoor shopping areas should be recommended to design near busy roads with a high traffic volume to enhance the visitor experience, and more visual media should be installed on outdoor business walkways to attract more visitors.

4.5. Future research

This study analyzes the physiological and psychological effects of multi-media on the walkways of typical business district areas. Future research may refer to the findings of this work to analyze the impact of multi-media on the specific behavioural patterns of different group visitors (e.g. elder or children, male and female), their walking paths on different walkways, or the duration of their stay in a visual-audio interaction scenario. The impact of multi-media on visitors' behavior on walkways can also guide merchants in optimizing the design of visual-audio systems to attract more buyers. Future studies should also examine the color system adopted by visual media on walkways. By studying the effect of specific colours on visitors' behavior through eye-movement experiments and by combining eye-movement data with psychology research, merchants can optimize the design of their visual systems to promote their brand and attract more consumers.

Conclusions

This study performs an in-situ eye-tracking experiment and a subjective evaluation to study the influence of multi-media in urban business districts on human physiology and psychology. This study differs from previous studies that focus on the traditional landscape (e.g., green spaces, roads, and buildings) by taking visual media (e.g., texts, images, and videos) in urban business districts as research objects to understand the impact of multi-media (including visual media) on visitors in urban business districts. This study also proposes an innovative comfort evaluation method based on visitors' visual-audio perception in urban environments that can generate the necessary data for future investigations of the visual-audio interactions in-situ scenarios.

Novel findings are obtained from visitors' visual engagement and subjective evaluations. As the most important visual system on walkways, visual media received the longest visual gaze time from visitors. Using more animations in visual media can effectively engage visitors. The visual-audio environment of walkways is another key factor that influences visitor experience and combining background music with other visual media can provide the best visitor experience. The multi-media on walkways also affect the visitors' eye movements as reflected in the changes in their physiological conditions and their attention to different visual-audio interactions. In terms of subjective comfort evaluation, 64.4% of the participants felt more comfortable on indoor walkways than on outdoor walkways. The visual-audio interactions analysis reveals that visual media need a matching sound element to enhance the comfort of visitors. A favourable visual-audio interaction not only improves visitors' comfort on walkways but also promotes the branding of merchants. Meanwhile, an examination of the impact of different visual-audio elements on indoor and outdoor walkways reveals that visitors tend to visit and stay longer in shops with the most positive comfort levels.

The findings of this work are expected to contribute optimal solutions for designing the visual elements of walkways and for promoting friendly, inclusive, green, and sustainable urban planning.

Declaration of Competing Interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript

entitled, “Physiological and psychological influence of multi-media in urban business districts”.

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