Indoor sound environments and visual media displays: A case study on canteens

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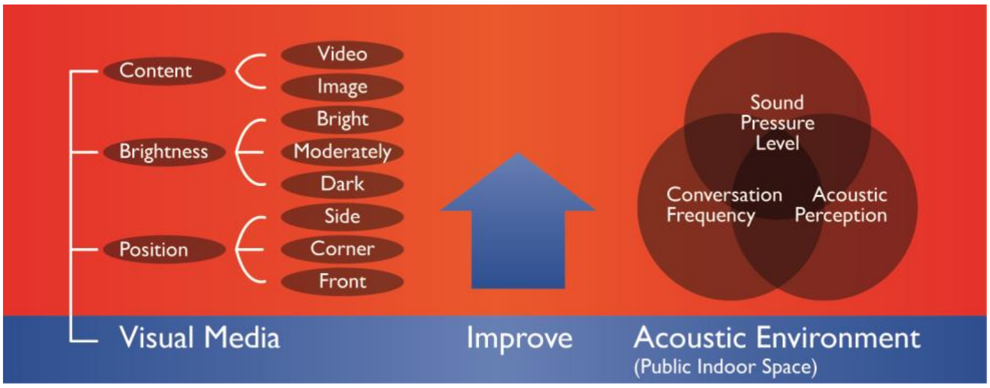
Highlights

- Documentary reduced the sound pressure level by 5.4 dB in 10 seconds.
- Visual media reduced total conversation duration by 2% among 12% of the diners.
- Visual media improved subjective loudness by 0.53 points at 5-point scale.

Abstract

Previous studies have shown that human senses interact with each other. In this study, an experiment was conducted in a dining space to find methods for improving the indoor sound environment through audio-visual interaction. Differences among diners' conversation behaviours were collected on the basis of acoustic measurements before and after displaying visual media content. Acoustic perception and feelings of the diners were analysed through a survey questionnaire. Four types of content (different, dynamic, transformation, foci), three positions (front, corner, side), and three brightness levels (bright, moderate, dark) were compared. It was found that displaying visual media content reduced the sound pressure level by 2.1 dB in 10 seconds. Furthermore, playing media content attracted people's attention and reduced 2% of the total conversation duration among 12% of the diners, indirectly improving the acoustic environment. Last, results of the administered questionnaire show that diners' acoustic comfort and subjective perception of loudness improved within 0.53 points after media playback.

Graphical abstract



Keywords

public indoor space; visual media content; sound pressure level; conversation frequency; subjective evaluation

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1. Introduction

People frequently experience discomfort because of poor sound environments with high sound pressure levels (SPL) [1, 2, 3]. A field study observed that long reverberation times and low speech recognition in canteens directly reduce acoustic comfort in indoor spaces [4]. People talk louder in noisy environments and filter out other noise or stimuli (the cocktail party effect), which considerably reduces acoustic comfort in public indoor spaces [5]. Studies have suggested that people can experience fatigue, tension, irritability, and distress because of low-frequency background noise in indoor spaces [6]. In large cities, such as Wuhan, in many crowded public indoor spaces, people are frequently exposed to an average SPL of more than 65 dB, which is considered harmful to human health [7]. Certain spaces where many people gather at a specific time (e.g., a canteen, a commercial area, an indoor playground) exhibit almost all the aforementioned poor acoustic-environment characteristics [8].

Sound environment quality can be improved by reducing SPL; however, effective and direct noise reduction in crowded and bustling indoor spaces is rarely achieved. Noise reduction can be expensive and has a limited effect [9]. Studies have indicated that human senses interact with each other [10]. Further, studies on soundscape have suggested that an excellent ecological surrounding enables people to have a good experience in an environment [11]. Soundscape preference could be indirectly affected by visual landscape elements through the perceived occurrences and volume of certain sounds. Particularly, people's experiences in green urban landscapes have been reported to be associated with relaxation and reduced anxiety as well as low levels of noise sensitivity, annoyance, and noise-induced stress [12, 13]. In the field of soundscape studies, multisensory integration research [14] has mainly focused on outdoor spaces, such as open and leisure parks and urban green belts. There are only a few studies on soundscapes in public indoor spaces.

Existing studies on soundscapes in urban open spaces have established a solution through audio-visual interaction. Most visual solutions utilise natural landscape elements, such as green vegetation, architecture, and humanistic performance [12, 15, 16]. However, such visual solutions are seldom applied in indoor spaces. In contrast, media solutions could be more easily applied in indoor spaces, in forms such as digital visual elements with humanistic marks, natural symbols, or business publicity. Media display solutions based on appropriate digital imaging technologies provide more advantages than visual solutions applied in open spaces. Such solutions are smaller in scale, can be easily installed, and enable fast image transformation. Fast imaging features provide visual media content with high dynamic transformation, high colour conversion, and high brightness thresholds. In terms of media content on display, colour contrast differences, visual object sizes, and the dispersion of visual focus lead to different gradients of attention [17]. Furthermore, the richness of visual content attracts more attention; people immerse themselves in and are influenced by the media content through related memory and emotional resonance [18].

Studies in psychology, neurology, and medicine have demonstrated that media displays' content, positioning, and brightness levels are key factors that affect human attention [19, 20, 21]. Studies on media display contents have shown that the contents create multidimensional states whose attributes have different effects on people [22]. In public indoor spaces, a sudden video playback may directly change people's conversational patterns. On this basis, researchers have indicated that the amount of focus on a main object and its position relative to the viewer remarkably affect the duration and concentration of a person's attention [23, 24]. Dynamic transformations in videos can quickly attract 'visual attention', because movement captures our attention. This can lead to a relatively low frequency of conversation. Studies on videos have indicated that the human eye pays attention to the emergence of new objects [25]. The more objects there are in a scene, the more attention the video attracts. Event attributes, such as sudden stimuli, unexpected events, and flickers, can attract a high degree of attention. The motor impression formed in the human brain is accomplished through the overlapping of experience and memory, and perception can be indirectly obtained after understanding an image [19]. The brightness level of media contents is another crucial factor. Research has suggested that people are likely to perceive the content when illumination is high; in other words, their ability to notice media content increases when brightness level increases. Illumination and attention are positively correlated until a certain point at which the visual brightness level causes discomfort to the human eye [20]. Colour perception is weakened if the brightness level is insufficient, leading to decreased visual attention [26]. Studies on media content placement have suggested that people can quickly and accurately process information when visual attention is not directed at the display and when the content appears at the focal centre of the eye. Researchers have investigated the mechanisms of human vision. One of the mechanisms that enables effective vision is the ability to extract relevant information at an early processing stage. This ability is called 'selective visual attention'. The amount of information captured by the human eye is too large to process on time, and media content is not as important. Therefore, the human brain filters the information and selects what to process through selective visual attention [27]. Increasing the eccentricity of visual objects increases response time and error rate [21], consequently reducing object recognition performance [28]. As such, displaying visual media content in different positions will change people's viewing angle, and thus change their recognition of visual content [29, 30].

This study aimed to explore possible means to improve sound environments in public indoor spaces (e.g. dining areas) by applying visual solutions. First, SPL variations in the entire environment was measured to determine whether visual media content could play an effective role in reducing SPL. Furthermore, measurements on conversation states were collected to determine whether conversation frequency and patterns are affected by the visual media content in the environment. Finally, variations in subjective evaluation were obtained on a five-point scale to determine whether acoustic comfort and subject loudness are improved by media content [31].

2. Material and methods

2.1. Field survey site

For this study, three types of public indoor spaces were investigated in Wuhan, China: a supermarket, an indoor commercial area, and a student canteen. For each site, during peak periods, the average SPLs over 15 minutes were measured. A comprehensive consideration of various factors revealed that the average SPL of the student canteen was the highest during the peak dining period (an average of 3.4 dB higher than the two other sites). Thus, the canteen was selected for onsite experiments.

The layout of the canteen is presented in Figure 1(a). The canteen space is rectangular with a size of 23,000 mm×18,000 mm×5,200 mm (length × width × height), an area of 414 m^2 (the whole indoor space), and a dining area of 111 m^2. There are 132 seats in the dining area and 28 seats in the sample area. The capita occupied is 0.84 m^2/person during the peak dining period.

The conversation frequencies were recorded in the area near the centre where the 28 seats were located. The monthly average number of people in the canteen during the peak lunch period (12:00 p.m.) was 163.

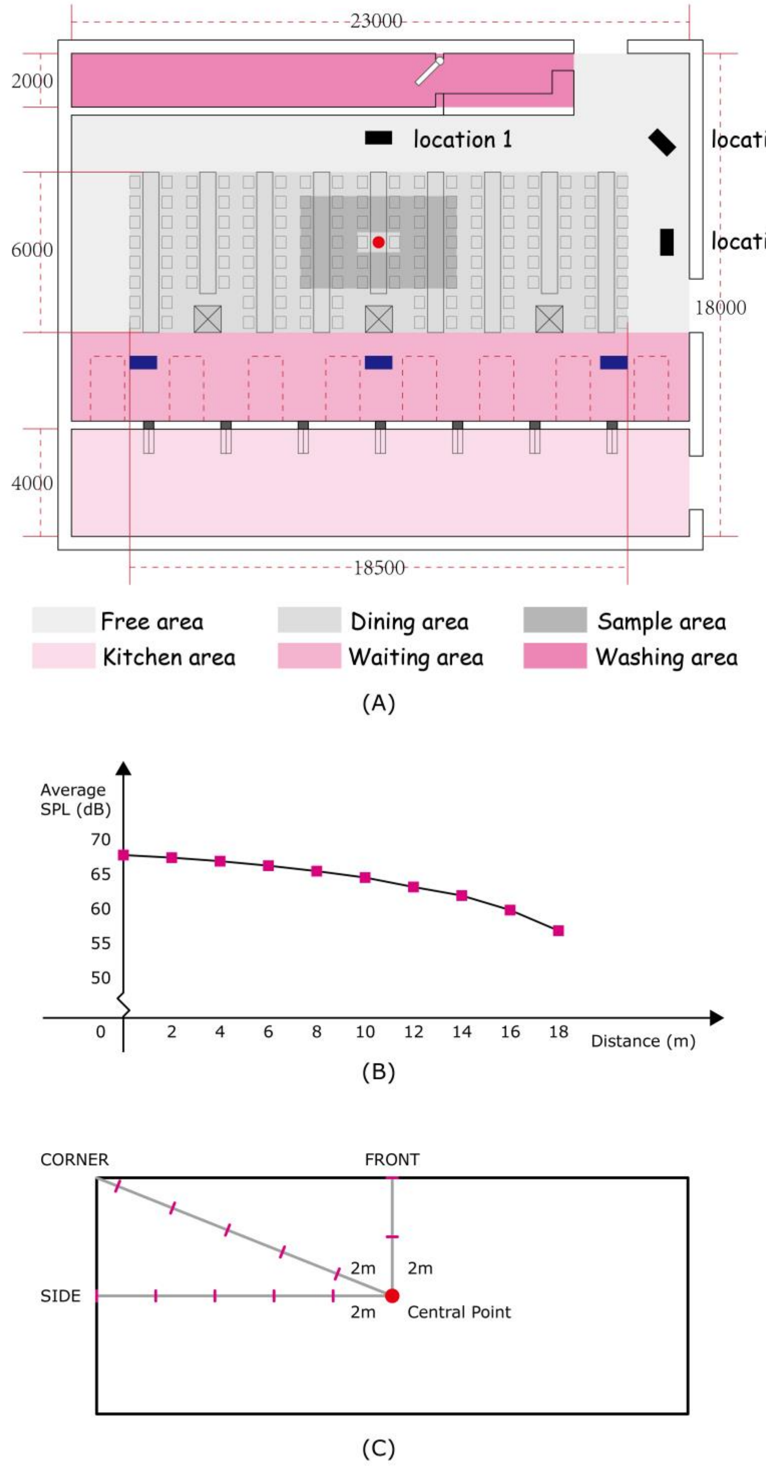

Fig. 1. Basic information about the canteen: (a) layout; (b) spatial attenuation of sound; (c) canteen plan.

Figure 1 shows the placement of the experimental equipment around the canteen. The hardware used to display the media content was a 60-inch LCD TV (Changhong-60D6P), placed at positions 1, 2, and 3. The sound level meter (AWA5688) was placed at the centre of the canteen to measure sound data. Three high-definition cameras (Hikvision-DS-2CC512-IR3) were placed in the 'waiting area' to capture the conversation frequency of the 28 samples in the experimental sample area.

The entire canteen's baseline acoustic-environment parameters were measured. The average SPLs were measured during the peak dining period, from 11:00 a.m. to 12:40 p.m. The base noise, reverberation time, and spatial attenuation of sound were measured when the business was closed, from 10:00 p.m. to 11:00 p.m. A regular dodecahedron nondirectional sound source (AWA5510A) was placed at a corner of the dining area. White noise audio equipment was placed, and the measurement started at the sound source and continued for every two minutes on the diagonal line. A measuring point with a total length of 18 m and a total of 10 points was arranged. An SPL meter (AWA5688) was set to slow mode and A-weight, and a reading of instantaneous data was taken every second. The A-weight SPLs measured at each point were averaged [32].

According to the data collected, the average SPL during the peak dining period was 75.9 dB, the background noise was 32.4 dB, and the reverberation time was 2.58 s (average of 500 Hz and 1000 Hz). The data on the spatial attenuation of sound are shown in Figure 1 (B). According to previous research on acoustic environments, the background-noise SPLs of student canteens are approximately between 70 and 80 dB(A) during peak periods, and their reverberation times are generally two to three seconds. Thus, the experiment site's sound environment was in line with the general situation of a Chinese student canteen [8].

2.2. Sound environment and conversation frequency measurements

Sound data were collected to determine whether the change in visual attention influences the canteen's average SPL and whether the visual method of suddenly starting media playback can improve the objective acoustic comfort of the diners. This process can measure the controlling variable, that is, the gradient of SPL variation produced by the displayed media content.

Sound data were recorded using a sound level meter, which collected SPL exposure before and after implementing the visual media display. The sound level meter was adjusted to collect the A-weight SPLs every second, and the effect of sound variation could be intuitively observed.

In the Chinese student canteen, there was a lot of discussion during peak meal times. The average SPL of peak dining period is typically 15 dB higher than that of non-peak dining period [8]. Therefore, the frequency of conversation during meals is an important factor that affects the acoustic environment. Studies have shown that loud discussions in canteens can cause acoustic discomfort to others; this condition may be caused by excessive SPL and low speech recognition [4], which are clearly linked with the frequency of conversation [33]. Research indicating demographic and social characteristics' influence on acoustic perception are irrelevant for this study [34]; these factors have not been considered as a part of conversation behaviour.

Conversation frequency data were measured for the 28 regular seats in the sampling area (Figure 1). All test seats were occupied during the experiment, as it was peak lunch period. During the measurement process, the HD camera captured the entire dining process of all test-seat users. The companionship scenario was determined according to the number of people sitting around the table. A stopwatch and CCTV were used to measure the conversation duration of each diner. This duration was measured as the period during which a diner's mouth was moving while looking at their companion. Conversation frequency was determined by dividing conversation duration by the duration of the meal.

2.3. Media display settings

The displayed media comprised four types of content at three positions and three brightness levels. A total of 36 experimental groups (4×3×3) were obtained. This experiment aimed to eliminate the influence of the sound from the TV play content. Hence, all visual media contents were played under silent conditions.

Figure 2 shows the displayed media content which comprised two videos and two images. Video 1 was selected from a Chinese documentary programme called 'Aerial Shooting China'. It had multiple foci and high dynamic transformations and was used in the comparison group. Video 2 was an animated Microsoft Windows symbol, with a single focus and low dynamic conversion. Image 1 contained a flying bird as the main content and had a single focus and high dynamic trend. It was used in the comparison group. Image 2 contained an image of a green oil-painting, with multiple foci and low dynamic trend.

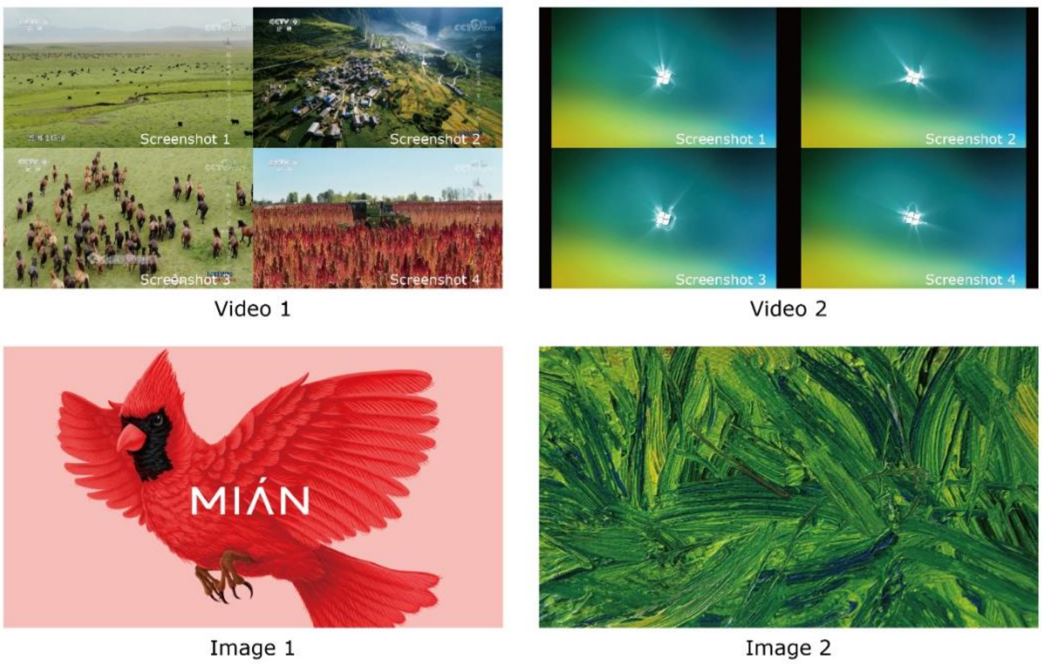

Fig. 2. Media content groups.

In terms of brightness, the four media contents were processed at three levels to obtain 'bright', 'moderate', and 'dark' visuals. The most comfortable brightness level was approximately 401–500 lux for which the subjects reported neutrality [20]. The visual brightness levels perceived by the diners were evaluated using an illuminometer (HCJYET-HT-8500). Three different brightness levels were defined for the human eye, as bright (500 lux), moderate (450 lux), and dark (400 lux).

As seen in Figure 1(c), the rectangular canteen space was divided into three typical sections: ‘corner’, ‘front’, and ‘side’. The visual focus on and distance from the displayed visual media content differs in each case of screen positioning. Placing the visual media content in ‘front’ allows it to be at the centre of the eye's focus and close to one’s eyes. When placed at the ‘corner’, the content is located on the two sides of the eye’s focus and far from one’s eyes. Placed on the ‘side’, the visual focus and visual distance is in between the eyes.

2.4. Questionnaire design

As seen in Table 1, respondents of the distributed questionnaires were required to provide basic demographic information and dining-related information (three questions each) and answer two questions about their subjective evaluation of the acoustic environment.

Basic demographic information included gender, age, and educational background, which allowed us to evaluate the responses by the demographic group. Dining-related information included the number of diners, dining frequency, and meal duration.

Subjective evaluations focused on four areas: the sound volume of conversation, acoustic comfort, subjective loudness, and sound clarity.

After selecting 100 small samples, two major issues (comfort and subjective loudness) were identified and selected for the assessment of the dining area’s acoustic environment. A total of 2,160 valid questionnaires were completed in Chinese. Most respondents were students; gender was equally distributed. The diners in the canteen exhibited diverse states, as revealed by the first six questions. The survey data were analysed and processed using SPSS software [32].

Table 1. Questionnaire.

Content	**Selection and quantitative information**				
Gender	Male	Female			
Age	<18	18–25	25–30	30–45	>45
Education background	High school	Bachelor	Master	Doctor	Lecturer
Number of diners	1	2	3	>3	
Frequency per week	<3	3–4	5–6	7–8	>8
Duration	<15	15–30	>30		
Acoustic comfort	Five-point scale: 1 Very uncomfortable—5 Very comfortable				
Subjective loudness	Five-point scale: 1 Very loud—5 Very quiet				

2.5. Experiment procedure

The experiment started at 11:30 a.m. every day and lasted for an hour. First, a total of 30 questionnaires were distributed to the group in the dining area under the condition of 'no-visual-media and switched-off TV'. After issuing the pre-questionnaire, the sound level meter at the central point was used to measure the sound field for 2 min 30 s to obtain data under the no-visual-media condition. At this point, the TV displaying visual media content was turned on without sound and the sound field data measured with media vision for five minutes. At this point, 30 other questionnaires were provided to the group under the condition 'with visual media'. The entire process was recorded using cameras. The conversation frequencies of 28 samples (9 min each) were recorded. The experiment was conducted for a total of 36 days.

3. Results

3.1. SPL variation

The SPL variation graph is shown in Figure 3. The SPL data (150 s) were collected before playing the visual media content, and 300 s of data were collected after playing. The SPLs of most experiment groups decreased after visual media content was played; the decrease ranged from 0.2 dB to 6.6 dB, with an average of 1.1 dB. The SPLs slowly recovered to their original levels with an average increase of 88%.

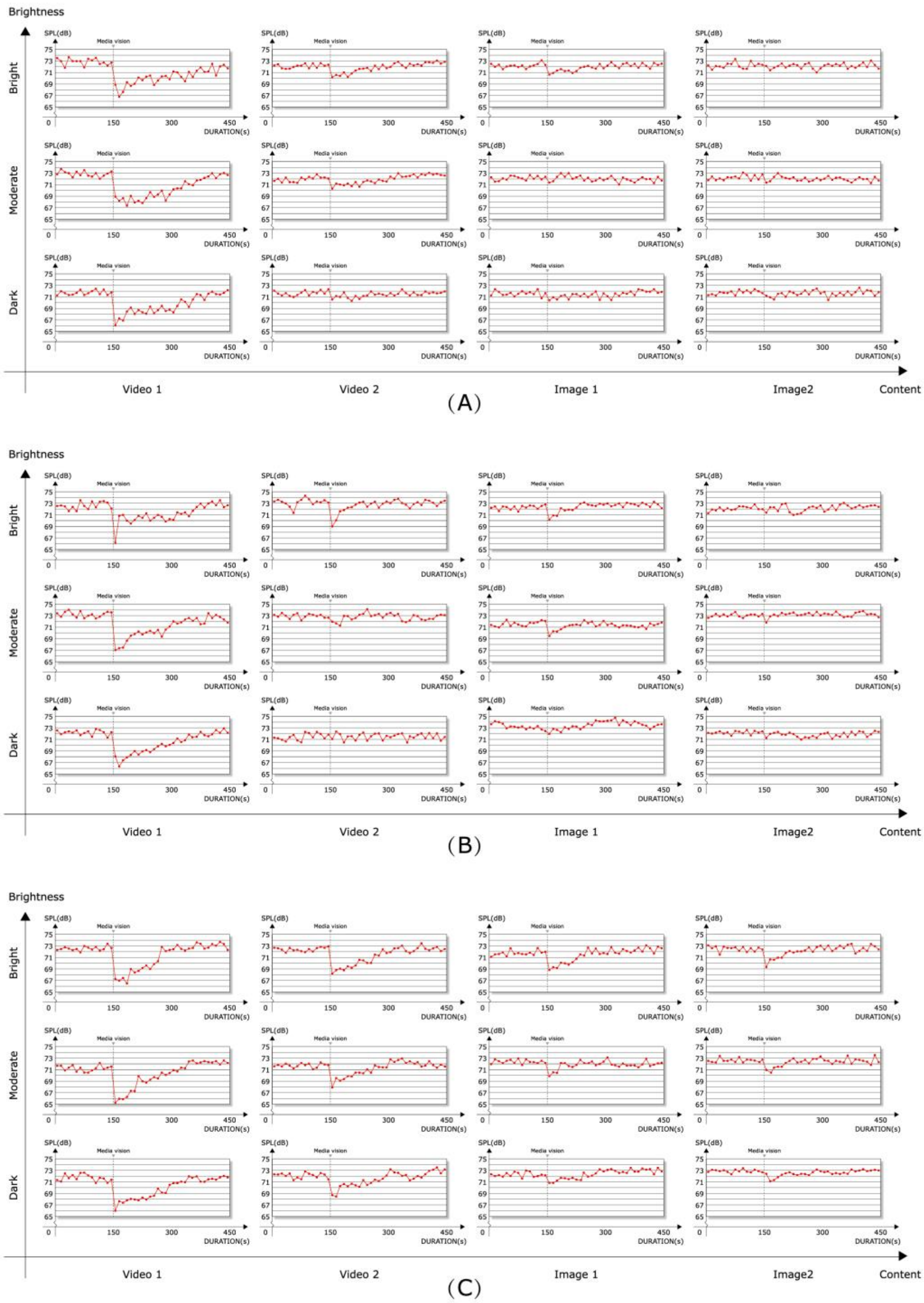

Fig. 3. SPL diagram for all visual content at all brightness levels and positions: (a) side; (b)

corner; (c) front. The outward horizontal and vertical axes represent the visual content and brightness level, respectively. The inward horizontal and vertical axes represent average SPL (dB) and time, respectively. The dotted line is the time node at which the visuals were played, and each red dot represents the average SPL recorded for every 10 s during the experiment.

In terms of position, after playing the visual media contents, the average SPLs for 150 s were reduced by 83%, 58%, and 100%, or by 1.2, 0.7, and 1.5 dB at the 'side', 'corner', and 'front' positions, respectively. In the second 150-second experiment, the average SPLs increased by 83%, 67%, and 83%, and the average SPL increases at the 'side', 'corner', and 'front' positions were 1.1, 0.6, and 1.3 dB, respectively. Compared with the playback at the 'side' and 'corner' positions, that in the 'front' position was the most stable and most effective in reducing the SPL. The 'corner' position had the opposite result. After SPLs were reduced, increases in SPL values were positively correlated in all experiments. Although the visual media content played in the 'front' position was presented at a 90° angle to the diners' eyes, in terms of distance, it was the closest to the diners. As such, it distracted most diners' attention and reduced conversations, leading to reduced SPLs. Although the media content played on the 'side' position was directly viewed by the diners, it distracted the diners less compared to the 'front' position, because in terms of distance, it was far from the diners. However, the 'side' position reduced conversations and SPLs. The media content played at the 'corner' position was presented at a 45° angle to the eyes of half of the diners and was the farthest. Therefore, it was the least distracting and had the lowest effect on reducing SPLs. We can conclude that the distance between the visual media display and the diners is related to the reduction in SPLs to a certain extent.

In terms of content, after playing the visual media content, the average SPL reductions for 150s was 100%, 78%, 67%, and 78% or by 2.8, 0.8, 0.5, and 0.4 dB for Video 1, Video 2, Image 1, and Image 2, respectively. In the second 150-second experiment, the average SPLs increased by 100%, 67%, 67%, and 78%, or by 2.6, 0.6, 0.4, and 0.3 dB for Video 1, Video

2, Image 1, and Image 2, respectively. Compared with the other contents, Video 1 was the most stable and most effective in reducing SPLs, and it had the highest significance. Image 2 had the opposite result. After SPL reductions, SPL increases in all contents showed a positive correlation. Videos could reduce SPLs better than images, because dynamic visuals are more attractive than static visuals. As such, conversations were reduced. The video with large dynamic transformations and large visual focus had a significant effect on reducing SPLs. The influence of the video with small dynamic transformations and single visual focus was insignificant. Playing dynamic images reduced SPLs.

In terms of brightness, after playing the visual media content, the average SPLs for 150s were reduced by 75%, 75%, and 92% or by 0.9, 1.1, and 1.3 dB under the 'dark', 'moderate', and 'bright' brightness levels, respectively. In the second 150-second experiment, the average SPLs increased by 75%, 83%, and 75% or by 0.8, 1.1, and 1 dB under the 'dark', 'moderate', and 'bright' brightness levels, respectively. Compared with the playback using other brightness levels, the 'bright' level was the most stable and most effective in reducing SPLs. The 'dark' level had the opposite result. After SPL reduction, the 'moderate' level had the most significant rebound effect, whereas the 'bright' level had the opposite result. In terms of a comfortable brightness range for the human eye, content with low brightness levels can play a similar role in reducing SPL, although content with high brightness levels was attractive to the diners.

3.2. Variations in conversation status

3.2.1. Variation of conversation frequency

At each position, the conversation frequencies of the diners were measured by observing the 28 seats in the sample area using the CCTV. The frequencies were derived by dividing the conversation duration by the total duration of the experiment [32]. The conversation frequencies of all diners in each experiment were arranged. Data were considered invalid if diners left the seat in advance or if no diners were seated at the beginning of the experiment.

Table2 represents the effect of visual media content for each brightness level on the conversation duration for each position. Positions (a), (b), and (c) represent media content playing at three different positions. The numbers show the percent change in total conversation time for all diners in the sample area before and after playing the visual media content. This table contain the results of 36 experiments. The results show that conversation frequency was reduced after the content was played, by a wide range of 0%–12% and an average of 3.4%. In 11 experiments, the conversation frequency increased from 0% to 4.5% with an average of 1.28%. A one-way ANOVA revealed that the displayed visual media content played an insignificant role in reducing conversation frequency ($p<0.05$).

Table 2. Percent changes in total conversation time: all visual contents under each brightness level for each position.

Position	**Brightness**	**Content**				
		Video 1	Video 2	Image 1	Image 2	Average
Side	Bright	0.4	-3.4	-4.5	2.2	-1.3
	Moderate	-8.7	-2.1	1.2	-4.0	-3.4
	Dark	0.7	-3.3	-3.3	-1.1	-1.7
	Average	-2.5	-2.9	-2.2	-1.0	-2.1
Corner	Bright	0.7	-2.6	1.0	-0.9	-0.5
	Moderate	-0.7	0.8	-4.5	-7.2	-2.9
	Dark	0.6	-0.9	-1.3	4.5	0.8
	Average	0.2	-0.9	-1.6	-1.2	-0.8
Front	Bright	-7.0	-2.1	-0.7	-2.2	-3.0
	Moderate	-12.0	-4.8	-2.4	1.3	-4.4
	Dark	-1.7	-1.2	-2.2	0.7	-1.1
	Average	-6.9	-2.7	-1.7	-0.1	-2.8

In terms of position, the average conversation frequencies decreased by 2.1%, 0.8%, and

2.8%, and the conversation frequencies declined by 67%, 58%, and 83% at the 'side', 'corner', and 'front' positions, respectively. The proportions of decline higher than 3% were 50%, 17%, and 25%, as revealed by the one-way ANOVA (p=0.17, 0.39, and 0.16). This finding confirmed that position is not a significant factor in reducing conversation frequency. The 'side' and 'front' positions were more effective than the 'corner' position in reducing conversation frequency and had a greater relationship with the average distance from the diners' eyes to the media content. For frequencies greater than 3%, the 'side' position appeared to be advantageous, because visual media display's placement was approximately parallel to the line of sight of many diners. The 'corner' position was the farthest from the diners and had a certain angle to its field of view, thus resulting in the lowest reduction in conversation frequencies. It can also be seen that when media content is displayed in front of the diners, they are more willing to watch the content rather than converse.

In terms of content, the average conversation frequencies decreased by 3.2%, 2.2%, 1.8%, and 0.8%, and the conversation frequencies declined by 56%, 89%, 78%, and 56% for Video 1, Video 2, Image 1, and Image 2, respectively. The proportions of decline higher than 3% were 34%, 34%, 34%, and 22%, as revealed by the one-way ANOVA (p=0.05, 0.02, 0.46, and 0.78). The videos reduced conversation frequencies, whereas the effect of the images was insignificant. For conversation frequencies, the degree of influence of media content was positively related to its influence on SPLs. This condition was associated with the analysis of the visual characteristics of media content. Moreover, the effect of Video 1 on conversation frequencies was lower than that on SPLs, which may be attributed to the diners unconsciously seeing the visuals. On this basis, striking contents may lead to considerably intense discussions; however, static video may be more soothing and reduce the will to converse.

In terms of brightness, the average conversation frequencies decreased by 0.71%, 3.59%, and 1.59%, and the conversation frequencies declined by 67%, 75%, and 75% under 'dark', 'moderate', and 'bright' brightness levels, respectively. The proportions of decline higher than 3% were 17%, 50%, and 25%, as revealed by the one-way ANOVA ($p=0.48$, 0.07, and 0.37). This finding confirmed that brightness level is not a significant factor in reducing conversation frequency. Although the 'moderate' and 'bright' levels had the same proportion in conversation frequency reduction, the 'moderate' level had an advantage in frequency reduction by more than 3%, and the average reduction frequency was high in the 'bright' level. The effect of the 'dark' level on conversation frequency was insignificant. A moderately pleasing vision allows for a comfortable viewing experience and reduces conversation frequency.

3.2.2. Variations in the number of diners who talk

Table 3 shows the variations in the number of diners who talked in the sample area before and after media playback. Under the same experimental conditions described in Table 2, Table 3 compares the conversation duration of the diners in each seat for 100 s before and after media playback and shows the number of people with increasing and decreasing conversation durations. The experiments showed that the number of diners who reduced their conversation after media playback ranged from 1 to 10 with an average of 4.5. In five experiments, the number of diners who increased their conversation ranged from one to four with an average of two. A one-way ANOVA revealed that visual media content played a significant role in reducing people's conversations ($p<0.001$).

Table 3. Diagram of the change in the number of diners who talk: all visual contents under each brightness level for each position.

Position	Brightness	Content				
		Video 1	Video 2	Image 1	Image 2	Average
Side	Bright	1	-3	-4	-6	-3.0
	Moderate	-5	4	-6	-1	-2.0
	Dark	-3	-6	0	1	-2.0
	Average	-2.3	-1.7	-3.3	-2.0	-2.3
Corner	Bright	-2	0	0	-3	-1.3

	Moderate	2	-1	-3	-7	-2.3
	Dark	2	-5	-8	-1	-3.0
	Average	0.7	-2.0	-3.7	-3.7	-2.2
Front	Bright	-1	-7	-4	-5	-4.3
	Moderate	-10	-8	-1	-2	-5.3
	Dark	-8	-7	-4	-6	-6.3
	Average	-6.3	-7.3	-3.0	-4.3	-5.3

In terms of position, the averages for the number of diners who reduced their conversation were 2.3, 2.2, and 5.3, and the proportions of the reduced number of diners was 67%, 67%, and 100% at the 'side', 'corner', and 'front' positions, respectively. The proportions of decline higher than 3% were 33%, 17%, and 75%, as revealed by the one-way ANOVA (p=0.008, 0.014, and 0.00005). This finding confirmed that 'front' positioning is a significant factor in reducing conversation and that it has the most influence. The overall conversation frequency slightly decreased, because a few diners significantly increased their conversation possibly because they made several comments about the visual content on display. By contrast, other diners acted as observers. The conversation frequencies did not decrease, whereas SPLs decreased, because a few diners spoke. This effect was particularly evident in the case of 'front' positioning, because several diners closely watched the visual content.

In terms of content, the averages for the number of diners who reduced their conversation were 2.7, 3.7, 3.4, and 3.3, and the proportions of conversation frequency decline was 67%, 67%, 78%, and 89% for Video 1, Video 2, Image 1, and Image 2, respectively. The proportions of decline higher than 3% were 22%, 56%, 56%, and 33 %, as revealed by the one-way ANOVA (p=0.041, 0.002, 0.002, and 0.001). Image 2 significantly increased the number of diners who reduced their conversations. The effect of Video 1 on conversation reduction was unremarkable probably because the documentary stimulated the interest of the diners' conversations. Although the conversation duration has increased, the topics people discuss can be shifted from work or study. Usually people are eager to avoid the pressure of work while eating, and improve their anxiety through casual topics. Documentaries can provide easy topics to relax people, letting them put work thoughts away and become a little bit more social. All visual content led the diners having less conversation. Interestingly, Image 2 reduced the conversation of many diners. This may be the case because a single, content-free vision reduces the discussion topics so that more people are willing to eat in silence.

In terms of brightness, the averages for the number of diners who reduced their conversation were 3.8, 3.2, and 2.8, and the proportions of conversation frequency decline were 75%, 83%, and 75% under 'dark', 'moderate', and 'bright' brightness levels, respectively. The proportions of decline higher than 3% were 58%, 25%, and 42%, as revealed by the one-way ANOVA (p=0.00009, 0.009, and 0.0009). This finding confirmed that the 'dark' and 'bright' modes significantly increased the number of diners who reduced their conversation. The 'dark' brightness level caused many diners to converse less; however, its effect was the least significant, and its effect of SPL reduction was the least evident among the three levels. These might be the case because visuals with low brightness levels were ineffective in influencing the attention of diners, although a few diners were sensitive to the visual content and engaged in many conversations.

3.2.3. Variations in conversation under different companionship scenarios

The observations on conversation states in Table 2 and Table 3 revealed that the experiment conducted at the 'front' position had the most significant effect on the diners. As such, only the test content at the 'front' position was extracted for the analysis of diners under different companionship scenarios. Table 4 and Table 5 represent the effect of each visual content under each brightness level on the percent change in total conversation duration as well as the change in the number of diners who talk at the 'front' position. The two tables display the results of 12 experiments.

Table 4. The percent change in total conversation duration under different companionship scenarios for each visual content under each brightness level at the 'front' position.

Brightness	**Content**									
	Video 1		Video 2		Image 1		Image 2		Average	
Bright	0.0[a]	0.2[b]	-5.4[a]	2.0[b]	-0.1[a]	-3.3[b]	0.0[a]	-1.6[b]	-1.4[a]	-0.7[b]
	-3.0[c]	-2.2[d]	-2.5[c]	0.7[d]	-0.3[c]	0.0[d]	-0.7[c]	13.0[d]	-1.6[c]	2.8[d]
Moderate	0.0[a]	-11.1[b]	0.0[a]	-2.9[b]	0.0[a]	-2.6[b]	-1.4[a]	1.4[b]	0.4[a]	-3.8[b]
	-6.1[c]	0.0[d]	-4.6[c]	0.0[d]	-5.6[c]	-1.0[d]	-1.6[c]	1.2[d]	-4.5[c]	0.0[d]
Dark	-0.8[a]	-6.7[b]	-0.2[a]	-7.0[b]	-1.8[a]	-1.3[b]	0.0[a]	-3.8[b]	-0.7[a]	-4.7[b]
	-5.0[c]	0.0[d]	4.0[c]	0.3[d]	1.7[c]	1.3[d]	1.3[c]	-1.6[d]	0.5[c]	0.0[d]
Average	-0.3[a]	-5.9[b]	-1.9[a]	-2.7[b]	-0.6[a]	-2.4[b]	-0.5[a]	-1.3[b]	-0.5[a]	-3.1[b]
	-4.7[c]	-0.7[d]	-1.0[c]	0.3[d]	-1.4[c]	0.1[d]	-0.3[c]	4.2[d]	-1.9[c]	1.0[d]

[a] 1 diner. [b] 2 diners. [c] 3 diners. [d] >3 diners.

Table 5. The change in the number of diners who talk under different companionship scenarios for each visual content under each brightness level at the 'front' position.

Brightness	**Content**									
	Video 1		Video 2		Image 1		Image 2		Average	
Bright	0[a]	-2[b]	-1[a]	-4[b]	-1[a]	-2[b]	0[a]	-2[b]	-0.5[a]	-2.5[b]
	-1[c]	2[d]	0[c]	-2[d]	-1[c]	0[d]	-4[c]	1[d]	-1.5[c]	0.3[d]
Moderate	0[a]	-8[b]	0[a]	-6[b]	0[a]	-2[b]	1[a]	-2[b]	0.3[a]	-4.5[b]
	-2[c]	0[d]	1[c]	0[d]	1[c]	0[d]	-1[c]	0[d]	-0.3[c]	0.0[d]
Dark	0[a]	-6[b]	-1[a]	-6[b]	-1[a]	-4[b]	0[a]	-4[b]	-0.5[a]	-5.0[b]
	0[c]	-2[d]	0[c]	0[d]	1[c]	0[d]	1[c]	-3[d]	0.5[c]	-1.3[d]
Average	0.0[a]	-5.3[b]	-0.7[a]	-5.3[b]	-0.7[a]	-2.7[b]	0.3[a]	-2.7[b]	-0.3[a]	-4.0[b]
	-1.0[c]	0.0[d]	0.3[c]	-0.7[d]	0.3[c]	0.0[d]	-1.3[c]	-0.7[d]	-0.4[c]	-0.3[d]

[a] 1 diner. [b] 2 diners. [c] 3 diners. [d] > 3 diners.

With the companionship scenarios of ‘1 diner’, ‘2 diners’, ‘3 diners’, and ‘>3 diners’, with respect to conversation frequency, six, nine, nine, and three of the above experiments showed that diners decreased their average conversation frequencies, with a wide range from 0.2% to 11.1% and averages of 1.62%, 4.48%, 3.27%, and 1.6%. Zero, three, three, and five of the above experiments showed that diners increased their average conversation frequencies from 0.2% to 13%, with averages of 0%, 1.2%, 2.33%, and 3.3%, respectively. In 10 experiments, the conversation frequencies decreased by more than 3%, and in only two experiments, the conversation frequencies increased by more than 3%. For the change in the number of diners who talk, in four, twelve, five, and three of the above experiments, the number of diners who decreased their conversation time ranged from 1 to 8, with averages of 1, 4, 1.8, and 2.3 for the ‘1 diner’, ‘2 diners’, ‘3 diners’, and ‘>3 diners’ states. In one, zero, four, and two experiments, the number of diners who increased their conversation time ranged from 1 to 2, with averages of 1, 0, 1, and 1.5. Eight experiments showed that more than three diners reduced their conversation duration, and none of the experiments showed that diners increased their conversation duration by three. This result was obtained because in the ‘2 diners’ and ‘3 diners’ scenarios, the diners were likely to stop talking and focus on the vision. The ‘1 diner’ companionship scenario did not initiate any communication before and after vision playing, and the ‘>3 diners’ companionship scenario generated discussion on and interaction with the visual content given a greater number of diners.

For the total conversation duration, Video 1 considerably affected the ‘2 diners’ scenario. By contrast, the other visual content did not significantly affect other companionship scenarios. For the proportion of diners who reduced their conversations, Video 1 and Video 2 had the largest influence under the ‘2 diners’ scenario, followed by Image 1 and Image 2. The other visual content did not significantly influence other scenarios. When diners eat together, displaying visual content will affect their social interactions and relationships. It could have different influences in different scenarios. For ‘2 diners’ scenario of close relationship, they don't need to use too many topics to break the embarrassment of silence, so when they pay attention to visual media it will reduce the conversation time. On the other hand, discussions about the visual content would occur in cases where the number of diners was large, because in this case, people want to socialize and discuss more.

From the perspective of brightness, the 'dark' and 'moderate' levels caused a remarkable decrease in conversation duration under the '2 diners' scenario, with a singular lack of the effects of other brightness levels on other companionship scenarios. The 'moderate' or 'dark' visual brightness levels influenced diners to focus on the visual content and reduce their conversation duration, whereas the 'bright' level played a minimal role.

3.3. Variations in subjective evaluations

Table 6 and Table 7 present the results of the respondents' subjective assessments about acoustic comfort with and without the display of visual media content under the same experiment conditions as those in Table 3. In the questionnaire about acoustic comfort, 1 was defined as the 'most uncomfortable' and 5 as the 'most comfortable' feeling toward the acoustic environment. Similarly, 1 was equivalent to 'very loud', whereas 5 corresponded to 'very quiet' in the questionnaire about subjective loudness. In terms of acoustic comfort, in 23 experiments, diners increased their average points within a range of 0.03-0.53, with an average of 0.204. In nine experiments, diners reduced their average points within a range of 0.03-0.4, with an average of 0.119. Media content played an insignificant role in improving the evaluation of acoustic comfort, as revealed by the one-way ANOVA ($p<0.005$). In terms of subjective loudness, in 25 experiments, diners increased their average points within a range of 0.03-0.53, with an average of 0.22. In 10 experiments, diners reduced their average points within a range of 0.03-0.27, with an average of 0.123. Media vision played a significant role in improving the evaluation of subjective loudness, as revealed by the one-way ANOVA ($p<0.005$).

Table 6. Diagram of the change in average points of acoustic comfort assessment: all visual contents under each brightness level for each position.

Position	Brightness	Content				
		Video 1	Video 2	Image 1	Image 2	Average
Side	Bright	0.40	0.00	-0.06	0.33	0.17
	Moderate	0.00	0.00	0.00	-0.40	-0.10
	Dark	0.10	0.30	0.03	-0.03	0.10
	Average	0.16	0.10	-0.01	-0.03	0.06
Corner	Bright	0.24	0.07	-0.13	0.33	0.11
	Moderate	0.33	-0.04	0.30	-0.07	0.13
	Dark	0.53	0.23	-0.20	0.07	0.16
	Average	0.36	0.09	-0.01	0.11	0.14
Front	Bright	0.13	0.20	0.06	0.04	0.11
	Moderate	0.16	0.06	0.17	-0.07	0.08
	Dark	0.24	0.07	0.30	-0.07	0.14
	Average	0.18	0.11	0.18	-0.03	0.11

Table 7. Diagram of the change in average points of subjective loudness evaluation: all visual contents under each brightness level for each position.

Position	Brightness	Content				
		Video 1	Video 2	Image 1	Image 2	Average
Side	Bright	0.03	-0.13	0.43	0.10	0.11
	Moderate	0.10	-0.07	-0.10	0.24	0.03
	Dark	0.23	0.27	0.13	-0.06	0.14
	Average	0.10	0.02	0.15	0.09	0.09
Corner	Bright	0.10	0.20	0.24	-0.27	0.07
	Moderate	0.20	0.14	0.23	-0.14	0.10
	Dark	0.20	-0.16	0.07	-0.20	-0.02
	Average	0.17	0.06	0.18	-0.20	0.05

Front	Bright	0.33	0.24	0.06	0.10	0.18
	Moderate	0.37	0.30	0.17	-0.07	0.20
	Dark	0.53	-0.03	0.27	0.00	0.19
	Average	0.41	0.17	0.16	0.01	0.19

In terms of position and acoustic comfort, the average points given by diners increased by 0.056, 0.138, and 0.108, and the proportions of increased points were 42%, 67%, and 83% in the experiments conducted at the 'side', 'corner', and 'front' positions, respectively. Point increase proportions higher than 0.2 were 25%, 50%, and 17%, as revealed by the one-way ANOVA (p=0.361, 0.031, and 0.055). For subjective loudness, the average points given by diners increased by 0.098, 0.051, and 0.189, and the proportions of increased points were 67%, 67%, and 75% in the experiments conducted at the 'side', 'corner', and 'front' positions, respectively. Point increase proportions higher than 0.2 were 33%, 17%, and 50%, as revealed by the one-way ANOVA (p=0.068, 0.423 and 0.009). Media content was shown in the 'front' position during the experiments and had a remarkable effect on acoustic comfort (high sound comfort) and noise loudness (low noise perception). When a single factor is considered, the playback of Video 1 and Image 1 at the 'front' of the canteen had the best effect on improving sound comfort. For noise loudness reduction, Video 1 outperformed the other content. Playing media content at the 'side' and 'corner' sections of the canteen had certain effects; however, these effects were not as evident as those in the 'front' position. The results from the position experiments were consistent with the effects of SPL and the previously measured conversation durations.

In terms of content and acoustic comfort, the average points given by diners increased by 0.237, 0.099, 0.052, and 0.014, and the proportions of increased points were 89%, 67%, 56%, and 44% in the experiments that used Video 1, Video 2, Image 1, and Image 2, respectively. Point increase proportions higher than 0.2 were 56%, 22%, 22%, and 22%, as revealed by the one-way ANOVA (p=0.001, 0.097, 0.403, and 0.838). Video 1 significantly improved acoustic comfort. For subjective loudness, the average points given by diners increased by 0.232, 0.084, 0.167, and -0.033, and the proportions of increased points were 100%, 56%, 89%, and 33% in the experiments that used Video 1, Video 2, Image 1, and Image 2, respectively. Point increase proportions higher than 0.2 were 44%, 33%, 44%, and 11%, as revealed by the one-way ANOVA (p=0.001, 0.313, 0.064, and 0.622). Video 1 significantly improved the subjective loudness and had the best effect on sound comfort evaluations and noise loudness reduction, regardless of the brightness variation or the difference in position. This may be due to that fact that the documentary is based on real life, as creation materials, with real people and real things as the performance objects, the storytelling effect is particularly strong. On the other hand, many wonderful aerial shots and multiple transformation of split lens perspective can make diners feel shocked, to attract their relatively long-term attention, so that they could ignore some effects of noise when they are focusing on something else, so as to improve their comfort. Image 1 had a huge influence on subjective loudness when media content was played at the 'corner' position. Image 1 improved acoustic comfort for the experiments conducted in 'front' of the room. Compared with the effects of Video 1 and Image 1, the lack of focus and the dynamic images in Video 2 and Image 2 (which had a red background) caused people to pay minimal attention to them, thus having small negative effects.

In terms of brightness and acoustic comfort, the average points given by diners increased by 0.131, 0.037, and 0.134, and the proportions of increased points were 75%, 42%, and 75% in the experiments under 'dark', 'moderate', and 'bright' brightness levels, respectively. Point increase proportions higher than 0.2 were 42%, 17%, and 33%, as revealed by the one-way ANOVA (p=0.044, 0.532, and 0.012). For subjective loudness, the average points given by diners increased by 0.104, 0.114, and 0.119, and the proportions of increased points were 58%, 67%, and 83% in the experiments under 'dark', 'moderate', and 'bright' brightness levels, respectively. Point increase proportions higher than 0.2 were 33%, 33%, and 33%, as revealed by the one-way ANOVA (p=0.153, 0.05, and 0.105). No such conditions occurred, because people cannot clearly see the media content under the 'dark' brightness level, and they feel dazzled when the brightness level is 'bright'. As a result, people unconsciously avoided looking at the media content. The two tables showed that visual media content is effective in ‘dark’ and ‘bright’ levels of brightness in all cases. By contrast, the effect of intermediate brightness is poor possibly because people are likely to unconsciously focus on bright visual media content and carefully concentrate on dark media vision content for longer time periods.

4. Conclusions

This study examined the influence of displaying visual media content in sound environments through objective measurements and a subjective survey. The experiment site was a large canteen, and measurements were taken for three output indicator modes: average SPL, conversation frequency, and subjective acoustic experience. The following conclusions were drawn from the results.

Firstly, the SPL variation measured after media display intervention performed well in terms of reducing SPL (averaged at 1.7 dB) in most of the experiments. Among them, the position and brightness factors reduced the SPL within a range of 0.3-0.4 dB. The video with multiple foci and high dynamic transformations had a more evident effect (>2.3 dB) compared with that of other visual media content. In these cases, although displaying visual media content could reduce the SPL in a small range, compared with other effective methods [12], such an impact is negligible.

Secondly, the videos attracted the attention of 12% of the diners and reduced the total conversation duration by 2.7%. Although the effect of reducing total conversation duration was not significant, a certain number of diners stopped communicating and paid attention to visual information, which somewhat reducing the negative cocktail party effect on the acoustic environment. All media vision content exhibited a good effect under the condition of moderate brightness and proximity to the crowd centre, having a minimum angle with the crowd's line of sight.

Finally, in accordance with the variations in subjective evaluation before and after media content playback, the questionnaire results were more consistent compared with the conclusions drawn from the SPL data and conversation frequency analyses. Playing Video 1 had a significant effect on improving the acoustic comfort and noise loudness (averaged >0.23 points, $p<0.001$), resulting in a 'comfortable sound' evaluation and 'low noise' perception. The questionnaire results indicated that displaying visual media content had an effect in subjective evaluations, regardless of the variations in brightness levels or positioning of media displays.

This study proved that displaying visual media content has a certain level of effect on the acoustic environment of indoor public spaces, although it is rather limited in reducing SPL and reducing conversation frequency. Future research can explore whether information vision can change people's conversation patterns and improve people's mood. The experiment was only based on a single typical Chinese canteen. The gathering condition of the crowd was relatively simple, and the gathering time was concentrated. Future research should conduct experiments in places with rich gathering states and uniform gathering times. Furthermore, the data on educational backgrounds and ages of the sample in this study are skewed, because the canteen is in a school. Future related research should be conducted in typical public indoor spaces and must obtain substantial sample data to cover a comprehensive social public scene. Finally, the area of the site in this study was 414 m^2. Sites of different sizes should be investigated to gain additional insights.

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