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Combined effects of sound and illuminance on indoor environmental perception

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ABSTRACT

Cross-modal effects of sound and illuminance were investigated in an indoor environmental chamber with 60 university students (30 men and 30 women) aged 18–26 years. A within-subject factorial design was employed with four independent variables: noise level (45, 55, 65, and 75 dBA), noise type (Music, Water, Babble, and Fan), illuminance level (150, 500, and 1000 lx), and sex (female or male). The test conditions represented daily indoor environments, which was moderately noisy and did not present severe lighting conditions. Acoustic (loudness, annoyance, pleasantness, and naturalness) and visual (brightness and relaxation) semantic attributes were assessed using an 11-point numeric scale. The illuminance level of the ambient lighting system did not affect acoustic perception. Brightness was not altered by sound, but relaxation was affected by sound. Cross-modal interactions were asymmetric between sound and illuminance in indoor environmental settings. Women were more sensitive to the perception of both acoustic and illuminance stimuli than men, at high level of stimulation.

1. Introduction

Cross-modal interaction in hearing and vision has been investigated as a part of multisensory interaction. Multisensory interaction research has exploded over the last few decades in cognitive neuroscience and neurophysiology [1]. Spatial and temporal factors influence multisensory integration [2], and the effects of both semantic and synesthetic congruency on multisensory information processing have been studied [3,4].

Effects of sound on visual perception have been studied with relatively simple audiovisual stimuli in early studies. Broadbent [5] reported that performance on light-watching became relatively less efficient with continuous exposure to noise using two visual vigilance tasks. Marks [6] found that most subjects matched pure tones to visual brightness of gray surfaces. Shams et al. [7] showed that visual perception (number of flashes) could be qualitatively altered by sound (number of beeps). The perceived duration [8], intensity [9], and contrast detection [10,11] of a visual stimulus has been shown to be influenced by accompanying sound signals. Scheier et al. [12] have shown that visual temporal resolution can either be improved or degraded by sound, depending on the temporal relationship of these variables. In contrast, Odgaard et al. [13] and Marks et al. [14] reported that brightness did not seem to be enhanced by sound.

Effects of vision on acoustic perception have been also studied with relatively simple audiovisual stimuli. It is well known that the spatial location of a visual stimulus can modify the apparent location of a simultaneously presented sound [15] (for example, in visual capture or ventriloquism). Saldana and Rosenblum [16] suggested that only discontinuous visual stimuli have a strong effect on the perception of the sound. Odgaard et al. [17] reported that white noise presented with light tended to be rated as louder than noise presented alone. Marks et al. [14] observed that the effect of visual stimulation on auditory pitch and loudness discrimination in an unspeeded discrimination test. If the time constraint leads to a reduction of the number of items attempted by all participants to < 90%, the test is considered as speeded [18]. Of note, Odgaard et al. [13] and Marks et al. [14] reported that visual perception was unaffected by sound. The asymmetry of cross-modal interactions that occurs in unspeeded discrimination contrasts with the bidirectional interactions observed in speeded identification. Shared sensory mechanisms underlie the cross-modal interactions, but these mechanisms change as a function of the task.

A caveat of these experiments in cognitive neuroscience is that they do not involve commonly occurring, realistic audiovisual situations. For instance, the auditory stimuli that were used in these studies were white noise or pure tones, and the visual stimuli were flashes [19]. Currently, research on the cross-modal interactions between hearing and vision is very popular in the context of multimedia applications [20], and has also been extended to environmental approaches. More

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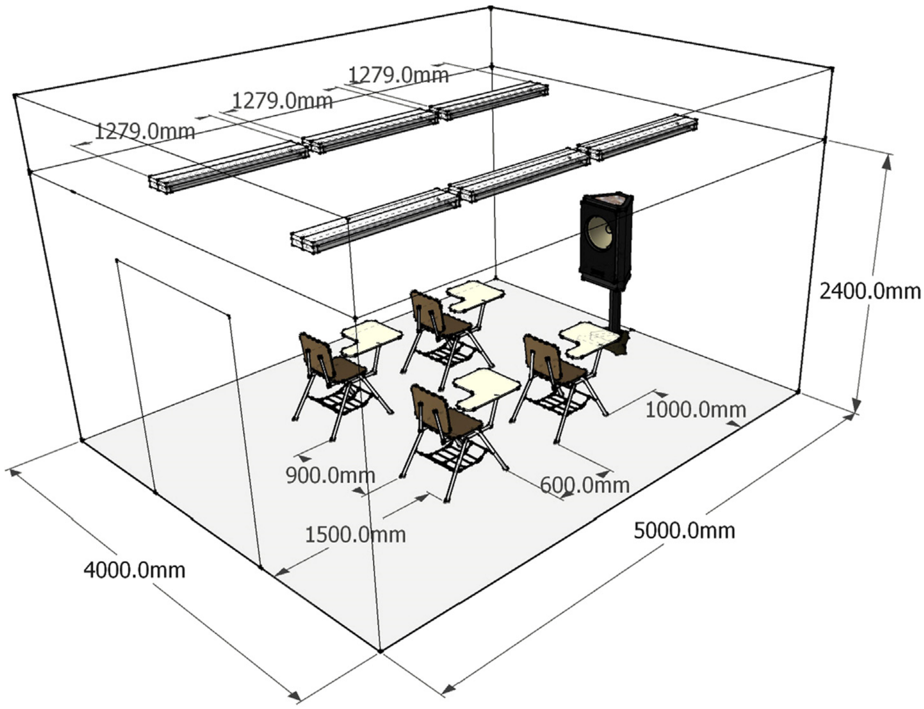

Fig. 1. Layout of the lighting fixtures and test laboratory.

realistic audiovisual stimuli have been involved in these more recent experiments, including scenes and environmental sounds [21–23]. Visual stimuli have been subdivided to analyze cross-modal interactions in environmental approaches. In this study, audiovisual interactions in indoor environmental approaches are reviewed.

Studies on audiovisual interactions in indoor environmental settings have been developed with subdivided visual stimuli and noise using various levels of sensation, perception, cognitive performance, and productivity. However, the results seem to be inconsistent. Knez and Hygge [24] found no interactions between noise and color temperature of light, but separate main effects were found for irrelevant speech (38 and 66 dBA) and light (3000 and 4000 K at 500 lx) on cognitive performance. The participants' long-term memory recall was better in silence than in the irrelevant speech condition, and in the warm-white lighting (3000 K) than in the cool-white lighting (4000 K). Veitch [25] attempted to integrate light and noise to examine their interactional effects on reading comprehension. The illumination levels were 200, 400, and 600 lx with standard cool-white fluorescent lights and the office noise levels were approximately 50 and 70 dBA. No main effects of noise, illuminance, gender, or any effects of interactions of these variables were observed on cognitive performance. One possible explanation for this was that the condition of allowing the participants to leave at any time they chose may have neutralized the effects of the uncontrollable, unpredictable noise on cognitive performance [25]. Hygge and Knez [26] found interactions between broadband low-frequency noise (38 and 58 dBA) and light (300 and 1500 lx with a color temperature of 3000 K) on cognitive performance as well as perception. The main findings for the effects of noise and light were better free recall scores and higher activation scores in the low noise condition at 1500 lx than 300 lx. Akbari et al. [27] examined the relationship between lighting (lx at the height of 30 in. from the surface of the work station) and noise level (Leq 8 h of daily and 40 h of weekly exposure) on human productivity in the automotive assembly industry. Noise levels in the workplace have negative effects on workers' productivity which leads to a decrease in the organization's productivity and a corresponding decrease in the quality and quantity of services and products. Lighting did not have an effect on human productivity and changes in lighting were not related to changes in human productivity. Ma and Nie [28] reported that the influence of brightness on noise annoyance caused by road traffic noise was obvious in the indoor environment. The effect of color on the evaluation of noise annoyance was not significant, although color (red, yellow, cyan, and green) and brightness showed an interaction effect on the evaluation of noise annoyance. Low brightness significantly increased subjective measures of noise annoyance. However, they did not quantify brightness in their experimental setting.

Liebl et al. [29] suggested that the effects on cognitive performance and well-being must be considered separately since these effects are rarely consistent. The interaction effects of background speech (24 and 94% word intelligibility) and lighting conditions (static and dynamic lighting at 55–60 lx) on cognitive performance have not been reported. Nevertheless, these variables were found to have an interaction effect on perceived performance during task processing. The participants perceived that performance was better if background speech of low intelligibility was combined with static lighting.

The objective of this study is to explore the cross-modal effects of indoor sounds and illumination levels on the sensation and perception of each sensory modality in indoor settings. In short, the present study investigates how acoustic factors influence visual judgments and how visual factors influence auditory judgments which thus far have not been examined in more realistic indoor settings. To date, no study has assessed the combined effects of sound and illuminance on human perception of both sensory modalities simultaneously. This study is based on the hypothesis that cross-modal interaction is possible between sound and light. We used a 4 × 4 × 3 × 2 (sound levels × sound types × illuminance levels × gender) within-subjects design. Gender was included because gender differences exist in individual sound and visual perception [30,31].

2. Methods

2.1. Experimental conditions

The experiment was run in a test laboratory (4.0 m × 5.0 m × 2.4 m), furnished as a small classroom. The test laboratory in this study was built for indoor environmental research. The