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Cross-modal effects of noise and thermal conditions on indoor environmental perception and speech recognition

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ABSTRACT

Cross-modal effects of noise and thermal conditions on subjective indoor environmental perception and speech recognition were investigated with 24 native Korean speakers in an indoor environmental chamber. Sixteen combinations of four Predicted Mean Votes (PMV) values (−1.53, 0.03, 1.53, 1.83), two noise levels (45 dBA, 60 dBA) and two noise types (babble, fan) were tested at the noise exposure times of 2 min and 55 min. Speech-to-noise ratios (SNRs) were set to 0, 5 and 10 dB for speech recognition tests based on the presented noise levels. It was found that noise had no effect on thermal sensation and thermal conditions had no effect on loudness and noisiness. However, effects of noise level and type on thermal comfort and effects of PMV on acoustic comfort and annoyance were statistically significant. Thermal comfort decreased with increased noise level. At thermoneutrality, acoustic comfort increased and annoyance decreased. Speech recognition was affected by not only SNR ratio but also by the PMV values according to the room acoustical conditions.

1. Introduction

Acoustic sensation and perception have typically been studied by examining the acoustic factor individually. Only minimal research has been carried out on the combined effects of acoustical and other environmental factors [1–8]. In real buildings, multiple indoor environmental parameters such as temperature, humidity, air quality, lighting, and acoustics influence human sensation and perception simultaneously. Human sensation and perception of an indoor environment are associated elaborate processes physiologically and psychologically. Recently, increased indoor noise levels has become a major issue since indoor thermal devices such as air conditioners, humidifiers, and dehumidifiers have been commonly used in indoor environments. The perception of noise is understood as being caused by interactions between the thermal and acoustic conditions in a room. However, the cross-modal effects of indoor thermal and acoustic conditions have not yet been clearly investigated.

Although noise and temperature interact in dwellings, there is a lack of scientific evidence of the cross-modal effects of thermal and acoustic conditions on human sensation and perception. The semantic parameters used in previous studies did not consider psychological differences between sensation and perception. Sensation is a mental process resulting from the immediate external stimulation of a sense organ, and perception is the awareness of the elements of the environment through physical sensation [9]. For subjective assessment, semantic parameters need to be categorized into sensation and perception in order to verify the hypothesis in this study, which suggests that the cross-modal effects of thermal and acoustic conditions might differ between human sensation and perception. The other hypothesis in this study suggests that if acoustic sensation and perception are affected by the thermal conditions in a room, cognitive performance with acoustic stimuli would also be affected by the thermal conditions, as shown in the speech recognition test.

Thermal sensation was determined by asking the participants about their thermal experiences using adjective semantic parameters such as hot/warm/cool/cold and dry/humid. Thermal comfort is the human experience of satisfaction with the thermal environment and it is based by a person's thermal sensation [10]. Thus, thermal comfort refers to the perception process in which the brain interprets thermal sensation. In previous studies, thermal sensation was not affected by noise [1,2,5,6,8]. However, effect of noise on thermal comfort was reported by Nagano and Horikoshi [2,6].

Acoustic semantic parameters were less systematic and more complex than thermal parameters. Adjective semantic attributes of soft/loud are straightforward for assessing the loudness sensation of acoustic stimuli. Noisiness (noisy/quiet) might be categorized as either sensation or perception depending on the types of sound and individuals because noise is defined as a sound, that is loud or unpleasant, or that causes disturbance. Annoyance and pleasantness are attributes used for the perception process in which the brain interprets the noisiness and

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loudness of a sound. Acoustic acceptability or comfort is the awareness of the combined results of the sound through loudness, noisiness and annoyance perceptions.

Noisy or quiet sensation, annoyance, acoustic comfort or acoustic pleasantness were mixed in each previous study. The noisy sensation and quiet sensation were significantly affected by temperature in Nagano and Horikoshi [2]. Acoustic comfort was affected by temperature in Nagano and Horikoshi [6]. Witterseh et al. [5] reported that temperature had no effect on noise acceptability and acoustic environment perception (too quiet – too noisy). Pellerin and Candas [4] observed effect of temperature on acoustic perception (extremely low – extremely high noise level) and acoustic comfort estimate (extremely unpleasant – extremely pleasant). Tiller et al. [7] reported that the ratings of building or office noise were not affected by the ambient temperature. Yang et al. [8] observed that annoyance was affected by temperature. Until now, consistent results have not been found in the effects of temperature on acoustic sensation and perception.

It has been widely documented that speech recognition among cognitive tasks is definitely affected by noise [11–13]. The signal-to-noise ratio (SNR), speech transmission index, and the useful-to-detrimental ratio could be used to measure speech intelligibility in rooms. However, speech recognition affected by other indoor environmental parameters, especially thermal condition, has not been examined thoroughly. Johnson and Sleeper [14] found that the ability to understand human speech is significantly impaired under hot conditions for long periods of time. They tested military chemical protective clothing combinations with hoods over a period of seven hours. Gomez-Agustina et al. [15] investigated the effect of thermal conditions on speech in underground environments. They found that speech related parameters decreased with rising temperature and humidity values on underground platforms. However, since they dealt with a large-scale space with voice alarm systems, their results could not be directly compared to those obtained in moderate indoor environments. Furthermore, they used computer simulations and objective measurements to evaluate voice alarm systems; subjective speech recognition results were thus not reported as they were beyond their research scope. Studies other than that by Gomez-Agustina et al. [15] concerning temperature effects on speech have not yet been found.

As a preliminary study in cross-modal effects of acoustical and thermal conditions on human sensation and perception separately, the first aim of this article is to evaluate cross-modal effects of indoor noise and PMV(Predicted Mean Votes) on sensation and perception of each modality. The second aim is to investigate combined effects of indoor thermal and acoustical conditions on speech recognition. The scope of the study is limited to moderate thermal and acoustic environments that are typically found in rooms.

2. Methods

2.1. Participants

Twenty-four university students (12 men and 12 women) aged 19–27 years were voluntarily recruited. Participants were informed of the nature of the study before participating and were rewarded after completing sixteen 1.5 h-long test sessions. All were native Korean speakers with normal hearing (0–25 dB HL). Before the experiment, the hearing threshold level of the participants was tested with an audiometer (GSI 18). The dress code included full length cotton trousers, a long-sleeve flannel shirt, a cotton T-shirt, and undergarments, all of which are typically worn by men and women in classrooms.

2.2. Indoor environmental chamber

The research was carried out in an indoor environmental chamber (4.0 m × 5.0 m × 2.4 m = 48 m^3) at Dankook University, as shown in Fig. 1. The chamber was designed to resemble a room inside a large experimental laboratory with control systems and measurement data acquisition systems. Table 1 lists the architectural and mechanical information of the indoor environmental chamber. The chamber consists of packaged air-conditioners, ventilation fans, humidifiers, dehumidifiers,

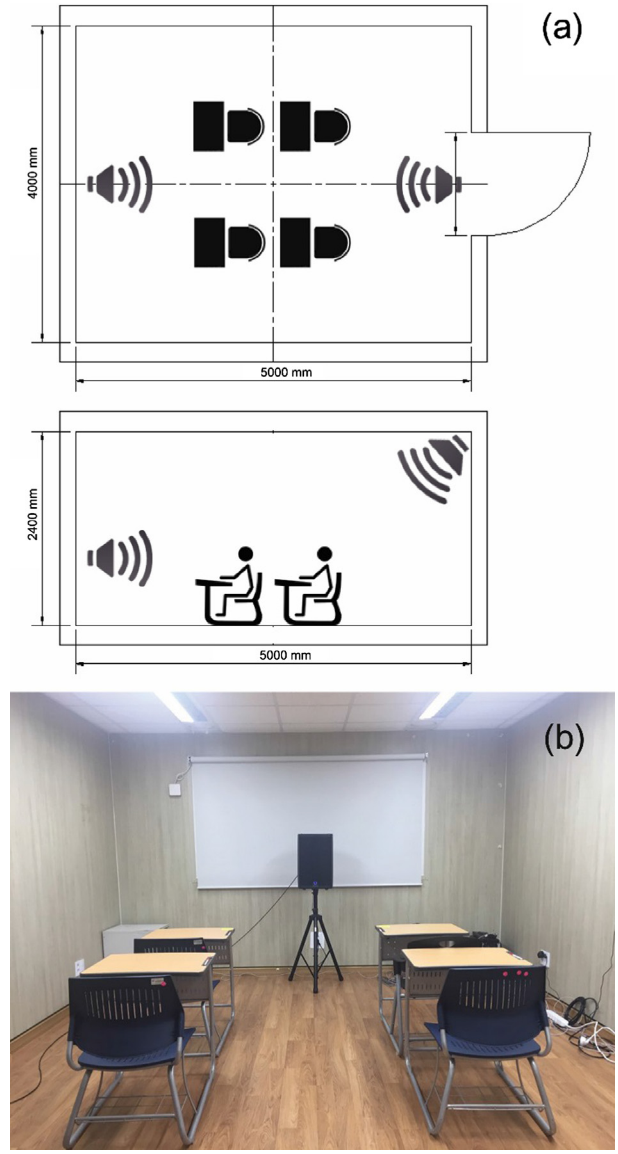

Fig. 1. Indoor environmental chamber (a) Layout (b) Photo.

Table 1
Indoor environmental chamber configurations.

	Description		
Room	Size	4.0 m × 5.0 m × 2.4 m (face-of-finish to face-of-finish)	
	Materials	Laminate floor on concrete and urethane layers	
		Urethane panel with gypsum lapping	
		Double glazed window with 5 mm glass panes and 5 mm air cavity	
Control System	VRF System	Rated Total Cooling Capacity	2.3 kW
		Rated Total Heating Capacity	2.6 kW
	Humidity Control	Humidifier	Max 3 l/hr
		Dehumidifier	Max 30 l/day
	Ventilation	Supply Air Flow Rate	0.03 m^3/s
		Exhaust Air Flow Rate	0.03 m^3/s