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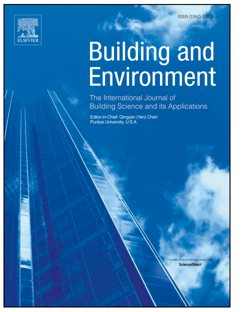

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Effects of sound types and sound levels on subjective environmental evaluations in different seasons

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Abstract[1]: Human beings live in an environment where various factors act together, therefore, it is essential to s[illegible] on environmental evaluations. In this study, the effects of the interaction between sound types and sound levels on acoustic, thermal, and overall evaluations were explored by simulating typical outdoor temperatures in different seasons in a controllable environmental chamber. The results indicated that the acoustic evaluations were significantly higher for birdsong and slow-dance music than for dog barking, conversation, and traffic sound; additionally, the acoustic evaluations at the low sound level were always higher than those at the high sound level. In terms of the thermal evaluations, there was a significant variation in different seasons. In summer, birdsong and slow-dance music effectively improved subjects' thermal evaluations, while a high sound level of dog barking, conversation, and traffic sound resulted in a decrease; in the transition season, all types of sounds resulted in a decline in the thermal evaluations; meanwhile, in winter and summer, dog barking, conversation, traffic sound and slow-dance music at the low sound level produced higher thermal comfort and thermal acceptability. In terms of the overall evaluations, birdsong and slow-dance music at the low sound level improved overall comfort, while dog barking, conversation, and traffic sound resulted in a significant decrease. For dog barking, conversation, traffic sound and fast-dance music, the overall evaluations at the low sound level were higher than those at the high sound level.

Keywords: severe cold region, sound type, sound level, interaction, subjective evaluation, different seasons

1. Introduction

With regards to environmental evaluations by human beings, the effects of different levels of an environmental factor have been extensively studied. For example, several studies have been conducted to investigate the effects of thermal environments on thermal evaluations [1–3], the effects of acoustic environments on acoustic evaluations [4–7] as well as the effects of smell environment on odour evaluations [8,9]. However, studies on the combined effects of multiple factors and their interactions on subjective evaluations, such as the effects of acoustic environments on thermal evaluations or the effects of thermal environments on acoustic evaluations, as well as the combined effects of the thermal-acoustic environment on overall evaluations are scarce. Since human beings live in an environment where various factors act together, it is necessary to study the comprehensive effects of multiple factors on the human body as well as the human perception of the environment, especially the effects of the interaction between different factors.

Studies on the effects of multiple factors began with the exploration of the aviation environment in the 1950s. With the improvement of living standards and technology, the researches focus gradually expanded from the aviation environment to the production and living environments. During the early stages of studies on the effects of multiple environmental factors on the human body, some scholars studied the effects of noise and temperature on the perception of the quality of the indoor physical environment, work efficiency, and performance [10–14].

Regarding studies on the effects of the acoustic environment on thermal and overall evaluations, the sound type that was usually employed was noise. Fanger et al. observed that noise had no significant effect on thermal comfort [15], while Nagano and Horikoshi reported that noise had a significant effect on thermal

[1]Abbreviations: TSV, Thermal Sensation Vote; TCV, Thermal Comfort Vote; TAV, Thermal Acceptability Vote; SLV, Subjective Loudness Vote; ACV, Acoustic Comfort Vote; SPV, Sound Preference Vote; OCV, Overall Comfort Vote; OAV, Overall Annoyance Vote; LAeq, A-weighted equivalent continuous sound pressure level; S.D., Standard deviation.

comfort and overall comfort, meanwhile, noise level resulted in a slight increase in thermal sensation [16,17].

Pellerin and Candas observed that under warm conditions, noise could induce a change in thermal comfort, and the unpleasantness of the thermal environment increased as the noise level increased [18,19]. Guan et al. found that although noise had no significant effect on thermal sensation at 20 and 25 °C, thermal comfort increased 1.85 scales when there was an increase from 55 to 85 dB at 30 °C, meaning that thermal comfort worsened when the noise increased [20]. Some scholars have studied the effects of different sound types and sound levels. Dalton et al. investigated whether specific sound types and sound levels had effects on driving-related tasks, the results showed that loud sound level had an effect on simple vigilance, whereas hard rock music possibly had an effect on tasks that require concentration and attention [21]. Yang and Moon revealed that the effects of sound types and sound levels on thermal comfort were significant [22]. Guan et al. found that thermal comfort, acoustic comfort, and overall comfort were better in a music sound environment than in a noisy environment with the same sound pressure level [23]. These studies were all carried out in the controllable indoor environment; however, there was a lack of related studies on the outdoor environment. Jin et al. studied the combined effects of the thermal-acoustic environment on subjective evaluations in urban squares, and the results indicated that a higher level of traffic noise resulted in lower thermal comfort. Additionally, traffic noise had an effect on overall comfort during both the transition season and summer [24].

Additionally, some scholars have studied the effects of multiple factors, including noise and temperature, on human comfort [25–28]). Hygge and Knez explored the effects of interactions between broadband low-frequency noise and light on both perception and cognitive performance [29]. Wong et al. proposed the empirical expressions to evaluate an overall indoor environmental quality that is acceptable for an office at certain operative temperature, carbon dioxide concentration, equivalent noise level, and illumination level [30]. Buratti et al. proposed an index for the evaluation of environmental comfort, taking into account thermal, acoustic, and lighting conditions [31]. Horie et al. studied the combined effects of noise, lighting, and thermal conditions on subjective comfort. The study revealed that the negative effects caused by an increase in indoor temperature from 27 to 30 °C were the same as those caused by the increase in the noise level from 40 to 70 dB [32]. Clausen et al. explored the effects of noise, temperature, air quality, and odour on human comfort. They observed that within a temperature range of 23–29 °C, the effect of a change in temperature by 1 °C was similar to that of a change in noise level by 3.9 dB [33]. Yang and Moon indicated that under steady-state thermal and illumination conditions with time-varying sound stimuli, acoustic factors had the most significant effect on indoor environmental comfort [34]. These studies were also carried out in an indoor environment to better control the variation in the factors being examined. The sound types and sound levels selected in previous studies are shown in Table 1.

Table 1. Sound types and sound levels selected in previous studies

Study	Sound type	Sound level (dB/A)
Witterseh et al.[13]	fans mixing the air	35.0/ 50.0
Clausen and Wyon[14]	traffic noise	45.0/ 55.0
	conversations/no conversations	
Fanger et al.[15]	fans in the air conditioning system	40.0
	white noise	85.0
Nagano and Horikoshi [16]	air-conditioning noise	46.8
	traffic noise	59.2/ 73.1/ 80.0/ 95.4

	air-conditioning noise	46.6
	[illegible]	[illegible]
Pellerin and Candas [18]	background noise	35.0
	fan noise	85.0
Pellerin and Candas [19]	fan noise	35.0/60.0/75.0
Guan et al. [20]	construction noises	55.0/ 65.0/ 75.0/ 85.0
Yang and Moon [22]	babble sound/ fan noise	45.0/60.0
Guan et al. [23]	fan noise/pure music	50.0/65.0/80.0
Jin et al. [24]	traffic noise	55.0-60.0/ 60.0-65.0/ 65.0-70.0/ 70.0-75.0
Huang et al. [27]	fan noise	45.0/50.0/55.0/ 60.0/ 65.0
Hygge and Knez [29]	ventilation noise	38.0/ 58.0
Clausen et al. [33]	traffic noise	40.0-75.0
Yang and Moon [34]	babble/ fan/ music/ water sounds	45.0/55.0/ 65.0/ 75.0

When exploring the effects of multiple factors on the human body and when performing environmental evaluations, most scholars selected different sound levels of a particular sound (mostly traffic noise or fan noise) as the experimental condition. Thus, studies on the effects of the interaction between sound types and sound levels have not yet been conducted adequately. Regarding temperature setting, most related studies chose to use different indoor temperature conditions in a specific season (mostly summer); however, systematic comparisons with respect to outdoor temperature conditions in different seasons are rather limited. The significant variations in climate throughout the year in severe cold regions, causes significant differences in the outdoor thermal environment in different seasons, the thermal and acoustic environments have the significant effects on the environmental evaluations of urban residents performing leisure activities, and the demand for improvement is high. Therefore, it is necessary to study the effects of multiple factors on environmental evaluations in different seasons. This study aims to explore the effects of sound types and sound levels, as well as the effect of their interaction on acoustic evaluations, thermal evaluations, and overall evaluations in different seasons based on the environmental evaluation of the subjects. Considering the limitations of previous related studies and the particularity of the climatic conditions in severe cold regions, typical outdoor temperatures of winter, transition season, and summer were simulated in a controllable environmental chamber with different sound types and sound levels, and a subjective questionnaire survey was administered. The temperature conditions inside the chamber objectively corresponded to the daytime outdoor temperature conditions of the different seasons, and the sounds employed were all generated from common acoustic sources in daily life.

2. Method

2.1 Experimental conditions

This study was conducted in a controllable environmental chamber (as shown in Fig. 1), in which the outdoor dynamic or steady climatic environment in severe cold regions could be simulated. The adjustable parameters of the chamber included temperature, humidity, wind speed, and illumination. Therefore, the study in the chamber was not limited to natural conditions, such as geographical locations or seasonal conditions. The ranges of the adjustable environmental parameters in the environmental chamber are shown in Table 2. During the experiments, the operative temperatures were set at 0, 20, and 30 °C, which represent the average diurnal air temperatures in winter, the transition season, and summer in severe cold regions, respectively. There are many factors affecting the outdoor thermal environment, of these, seasonal temperature differences are the most significant and can be felt intuitively. Although simply simulating outdoor temperature in the chamber did not fully represent actual outdoor thermal conditions, the advantage of doing this is that allows the variables to be controlled more and effectively to avoid the interference of too many factors and is propitious for a clearer analysis of the results. The mean radiant temperature was assumed to equal the operative temperature, and to reduce the interference of wind sound in the experiment, the wind speed was set below 0.5 m/s. To monitor the indoor environment, a fixed measurement point (a Portable Kestrel 5500 weather station) was set in the environmental chamber. The difference between the operative temperature and the actual temperature was always maintained at ±1 °C, indicating that the thermal environment in the environmental chamber was stable.

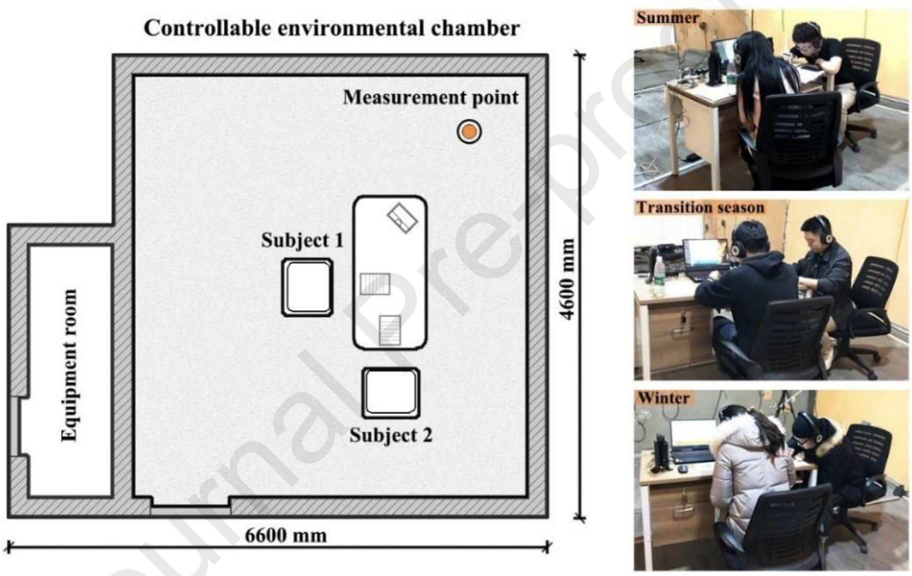

Fig. 1. Schematic diagram of the controllable environmental chamber and the experimental setup.

Table 2. Environmental parameters in the controllable environmental chamber.

Parameter	Range	Precision	Season	Operative temperature (°C)	Measured temperature (°C)	Measured relative humidity (%)	Illumination (Lux)	Background sound level (dB/A)
Air temperature	-40–40 °C	0.1 °C	**Winter**	0.00	0.89	30.3	300	38.1
Relative humidity	20–90%	3%	**Transition season**	20.00	20.12	51.7	300	36.8
Wind speed	0–10 m/s (air outlet)	1%	**Summer**	30.00	30.08	54.2	300	36.3

2.2 Sound stimuli

In related studies, most of the sound types employed were one or two mechanical sounds, such as fan noise and traffic noise (As shown in Table 1); therefore, studies on the effects of different sound types were still relatively limited, and the reasons given for selecting particular sound levels were inadequate. To adequately study the effects of different sound types, the acoustic sources were selected to include mechanical, natural, and anthropogenic sounds, with which people are familiar in daily life. Additionally, given that square dance has become one of the most important leisure activities for the elderly in recent years, square dance music has also become a common sound source. This usually includes slow-dance music and fast-dance music, where the former is used when two people are dancing, and the latter is used for a group dance. There are certain differences in the characteristics between the two kinds of sounds: fast-dance music has a higher frequency range and a stronger beat. Thus, a total of six sound types, namely, birdsong, dog barking, conversation, traffic sound, slow-dance music, and fast-dance music, were used. The representative 40-s samples of each of the six sound types were edited and used as the sound stimuli in the experiment. Using Adobe Audition software, the sound pressure level was adjusted at 10 dB(A) intervals. Based on the sound loudness vote pre-experiment (2, quiet; 1, slightly quiet; 0, neutral; -1, slightly loud; and -2, loud;), the sound pressure levels that were gauged as quiet, neutral, and loud were selected to represent three sound levels, i.e., low, medium, and high, respectively. The sound pressure levels of the sound stimuli are shown in Table 3.

As the cubage of the environmental chamber was small, sound coloration might have occurred due to resonance when the loudspeaker was used to play audios, resulting in a distorted sound signal. Therefore, as this could have affected the subjective evaluation negatively, Sennheiser RS170 headphones were used to play the sound samples. Although the use of headphones might have exerted a certain influence on the thermal evaluations, the subjects were dressed according to the uniform requirements in the same ambient temperature, the influence of the headphones on the thermal evaluations was basically concordant and could be ignored to a certain extent.

Table 3. Sound pressure levels of sound stimuli.

Sound level	**Low**			**Medium**			**High**		
	Max (dB/A)	**Min (dB/A)**	**LAeq (dB/A)**	**Max (dB/A)**	**Min (dB/A)**	**LAeq (dB/A)**	**Max (dB/A)**	**Min (dB/A)**	**LAeq (dB/A)**
Birdsong	53.1	33.6	43.5	63.9	42.7	53.6	73.7	52.3	63.3
Dog barking	56.1	27.4	41.9	66.7	37.5	52.1	77.9	46.7	62.3
Conversation	46.7	37.9	42.4	57.5	47.9	52.7	67.5	57.3	62.5
Traffic sound	45.9	37.2	41.8	56.9	47.0	51.9	67.2	57.1	62.2
Slow-dance music	46.9	39.7	43.3	57.4	48.9	53.3	68.1	58.7	63.4
Fast-dance music	49.1	36.5	42.9	59.1	45.9	52.7	70.1	55.2	62.7

2.3 Questionnaires

In this study, the questionnaire method was used to explore the subjective evaluations of the subjects under different environmental conditions. As shown in Table 4, Owing to the comprehensive consideration of the questionnaire content of previous studies [17, 18, 23], the acoustic evaluations investigated included Subjective Loudness Vote (SLV), Acoustic Comfort Vote (ACV), and Sound Preference Vote (SPV). The thermal evaluations investigated included Thermal Sensation Vote (TSV), Thermal Comfort Vote (TCV), and Thermal Acceptability Vote (TAV), and the overall evaluations investigated included Overall Comfort Vote (OCV) and Overall Annoyance Vote (OAV). The overall evaluations (OCV and OAV), which were determined by various factors, including the physical environment among others, represents the comfort and annoyance of human beings under the combined effects of the multiple factors.

In this study, a 7-point Likert scale was used to explore the subjective evaluations accurately. However, the options ‘very hot’ and ‘very cold’ were added to the TSV to reflect extreme weather conditions in winter and summer in severe cold regions, respectively. Thus, in this study, the thermal sensation was evaluated using a 9-point Likert scale [20].

Table 4. Subjective evaluations of the questionnaire surveys.

Score	-4	-3	-2	-1	0	1	2	3	4
TSV	Very cold	Cold	Cool	Slightly cool	Neutral	Slightly Warm	Warm	Hot	Very hot

Score	-3	-2	-1	0	1	2	3
TCV	Very uncomfortable	Uncomfortable	Slightly uncomfortable	Neutral	Slightly comfortable	Comfortable	Very comfortable
TAV	Very unacceptable	Unacceptable	Slightly unacceptable	Neutral	Slightly acceptable	Acceptable	Very acceptable
SLV	Very loud	Loud	Slightly loud	Neutral	Slightly quiet	Quiet	Very quiet
ACV	Very uncomfortable	Uncomfortable	Slightly uncomfortable	Neutral	Slightly comfortable.	Comfortable	Very comfortable
SPV	Very disliked	Disliked	Slightly disliked	Neutral	Slightly liked	Liked	Very liked
OCV	Very uncomfortable	Uncomfortable	Slightly uncomfortable	Neutral	Slightly comfortable.	Comfortable	Very comfortable
OAV	Very annoyed	Annoyed	Slightly annoyed	Neutral	Slightly pleasant	Pleasant	Very pleasant

2.4 Subjects

This experiment received research ethics approval from the institution. All the subjects participated voluntarily in the experiment and were informed in advance of the extreme temperature conditions in the environmental chamber. Taking into account the statistical power level, the effect size ($1-\beta = 0.9$, $\alpha = 0.05$, effect size = 0.25), and the experimental conditions, a total of 96 subjects were recruited (32 for each season). All the subjects were graduate students with self-reported normal audition and with no physical discomfort, such as fever or cold, on the day of the experiment. These subjects (female, 47.9%; male, 52.1%; average age, 26.2 (S.D. = 2.8, Min = 22, Max = 34)), were recruited from the universities as volunteers. Their average metabolic rate during sedentary reading was 1.1–1.2 met, their average clothing insulations were 1.83, 0.88, and 0.45 clo for winter, the transition season, and summer, respectively.

2.5 Procedures

To avoid the influence of thermal experiences and psychological expectations on the subjective evaluations, the seasons simulated in the environmental chamber corresponded to actual seasons (i.e., summer, the transition season, and winter); thus, the experiments were performed in July, September, and December, respectively. Two subjects could participate in the experiment at the same time. Sound insulation could be achieved in the chamber and during the experiment, the door was closed. Apart from the necessary experimental equipment, there were no other objects in the chamber that could interfere with the attention of the subjects [35].

During the study, the implementation procedure was divided into two parts, the thermal adaptation part and experimental part. During the thermal adaptation part, the subjects were granted access into the environmental chamber after the thermal environment was stable. The subjects were advised not to eat or exercise before the experiment, and to dress according to the standard season requirements. The subjects were required to sit in the chamber for 30 min [16], after which they needed to complete a set of questionnaire survey without audio play. The experimental part was divided into 3 stages based on different sound levels (low, medium, and high), and six 40-s audios played during each stage. While each audio was playing, the subjects were required to complete a set of questionnaire surveys. The subjects' response speed had been pre-calculated to ensure that the questionnaire could be completed within the audio playtime. The interval between each audio playtime was 10 s, and the interval between each of the three stages was 60 s. To avoid the influence of play sequence, the order of audio play during each stage was random. All subjects for each season were required to experience 19 operative conditions (three sound levels*six sound types + no sound stimuli). Although each subject's awareness of the sound was stronger in the chamber than in actual outdoor environment, the subjective evaluations were required to be completed while the audios were playing, therefore, their attention was focused more on answering the questionnaire rather than listening to the sounds. Thus, the sound stimuli in the chamber were background sounds similar to those in an outdoor environment.

3. Results

3.1 Effects of sound types and sound levels on the acoustic evaluations

Fig. 2 shows the average values of the acoustic evaluations relative to the condition of without sound stimuli (subtracted from the evaluation values obtained in the absence of sound stimuli). It can be found that the acoustic evaluations were highly consistent in different seasons. Regarding SLV, regardless of the changes in sound level, in three seasons, it was always significantly lower than that without the sound stimuli. The subjects felt louder, and the average differences in winter, the transition season, and summer were 1.6–2.7, 2.1–3.3, and 2.5–3.4, respectively. The effects of dog barking, conversation, traffic sound, and fast-dance music were always more significant. Regarding ACV and SPV, regardless of the changes in sound level in the three seasons, dog barking, conversation, and traffic sound always resulted in a significant decreased in ACV and SPV, and the average differences in winter, the transition season, and summer were 1.6–2.5 and 1.5–2.2, 1.8–2.9 and 1.5–2.4, and 2.0–2.9 and 1.7–2.4, respectively. However, low-sound level birdsong and slow-dance music resulted in a significant improvement in ACV and SPV, with a difference of 0.5–1.4.

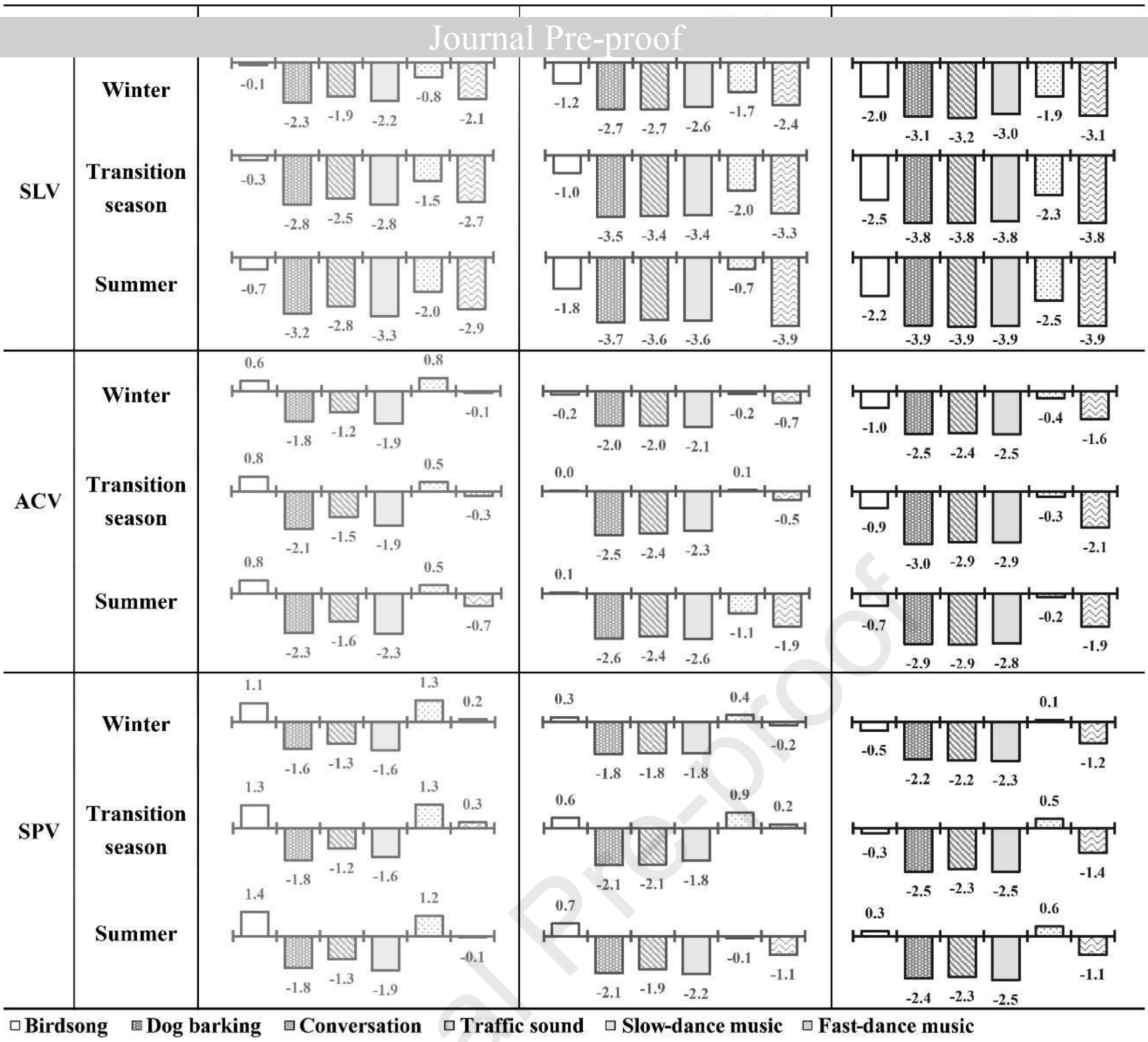

Fig. 2. Average values of the acoustic evaluations relative to the condition of without sound stimuli.

Table 5 shows the significances of the effects of sound types and sound levels on the acoustic evaluations. To determine the differences in the ratings of the groups to three variables (sound types, sound levels, and sound types*sound levels), repeated measures analyses of variance were performed. The results showed that in the three seasons, the main effect of sound types and sound levels, and the interaction between them all had significant effects on SLV, ACV, and SPV ($p < 0.01$). As shown in Fig. 3, owing to the existence of interaction, only the effects of the interaction on the acoustic evaluations were analysed, and simple effects tests (by writing syntax code) were performed.

Table 5. Significances of the effects of sound types and sound levels on the acoustic evaluations.

Subjective evaluation	Season	Winter			Transition season			Summer		
	Factor	Level	Type	Level* Type	Level	Type	Level* Type	Level	Type	Level* Type
SLV	df	1.668	3.533	5.662	1.454	3.156	6.238	2.000	2.942	5.014
	F	79.906	42.382	3.560	93.228	59.544	6.251	50.677	78.596	14.207
	Sig.	**0.000**	**0.000**	**0.003**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
ACV	df	1.490	2.543	6.594	1.645	3.127	6.253	1.708	3.151	5.429
	F	47.450	47.876	3.341	56.787	68.477	4.405	63.614	60.028	6.909
	Sig.	**0.000**	**0.000**	**0.003**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
SPV	df	1.679	2.924	5.700	1.726	3.277	6.769	2.000	3.387	5.653

	F	46.266	55.078	2.986	50.793	75.945	5.464	48.193	68.903	4.301
	Sig.	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.001

Fig. 3 shows the average values of the acoustic evaluations owing to the interaction between the sound types and sound levels (The error bars represent the S.D. of the average values). Regarding SLV, there was an interaction between sound types and sound levels in all three seasons. With respect to sound types, regardless of the changes in sound level, birdsong and slow-dance music contributed to higher SLV than dog barking, conversation, traffic sound and fast-dance music, and the subjects didn't feel so loud when they heard the first two sound types. For low-sound level and medium-sound level birdsong as well as slow-dance music, the subjects even felt slightly quiet ($p < 0.01$). With respect to sound levels, in winter and the transition season, when the sound types were traffic sound and slow-dance music, the SLV at the low sound level was higher than that at the high sound level, with an average difference of 0.9 in winter and 0.8 in the transition season ($p < 0.01$). When the sounds were the other four types, SLV decreased significantly with increasing sound level, i.e., the higher the sound level, the louder the subjects felt ($p < 0.01$). In summer, when the sound types were conversation and fast-dance music, SLV decreased significantly with the increasing sound level ($p < 0.05$), and when the sound types were the other four types, the SLV at the low sound level was higher than that at the high sound level, and the difference with respect to birdsong even reached 1.5, while the differences with respect to the other three sound types were about 0.6 ($p < 0.01$).

Regarding ACV and SPV, interactions between sound types and sound levels were observed in all three seasons, and the effects of the interactions were consistent in all the seasons. With respect to sound types, regardless of the changes in sound level in the three seasons, ACV and SPV for birdsong and slow-dance music were significantly higher than those for dog barking, conversation, and traffic sound. For birdsong and slow-dance music at low and medium-sound levels, ACV ranged between 0.0 and 1.5, while SPV ranged between 0.0 and 1.0, and the subjects felt slightly comfortable and slightly liked ($p < 0.01$). However, ACV for fast-dance music was always higher than that for dog barking, with an average difference of 1.3–1.6 ($p < 0.05$). With respect to sound levels, in winter, when the sound type was birdsong, both ACV and SPV decreased significantly with increasing sound level ($p < 0.05$), and when the sound types were dog barking, traffic sound, and slow-dance music, ACV and SPV at the low sound level were higher than those at the high sound level, ($p < 0.01$). In the transition season, when the sound type was birdsong, ACV and SPV decreased significantly with increasing sound level, and when the sound types were conversation, traffic sound, slow-dance music and fast-dance music, ACV and SPV at the low sound level were significantly higher than those at the high sound level ($p < 0.01$), and the difference in ACV when the sound type was fast-dance music even reached 1.8. For two types of low-sound level dance music, the subjects felt slightly comfortable ($p < 0.01$). In summer, when the sound types were birdsong and conversation, ACV and SPV decreased significantly with increasing sound level ($p < 0.05$). When the sound types were dog barking, traffic sound, and slow-dance music, ACV and SPV at the low sound level were higher than those at the high sound level ($p < 0.01$).

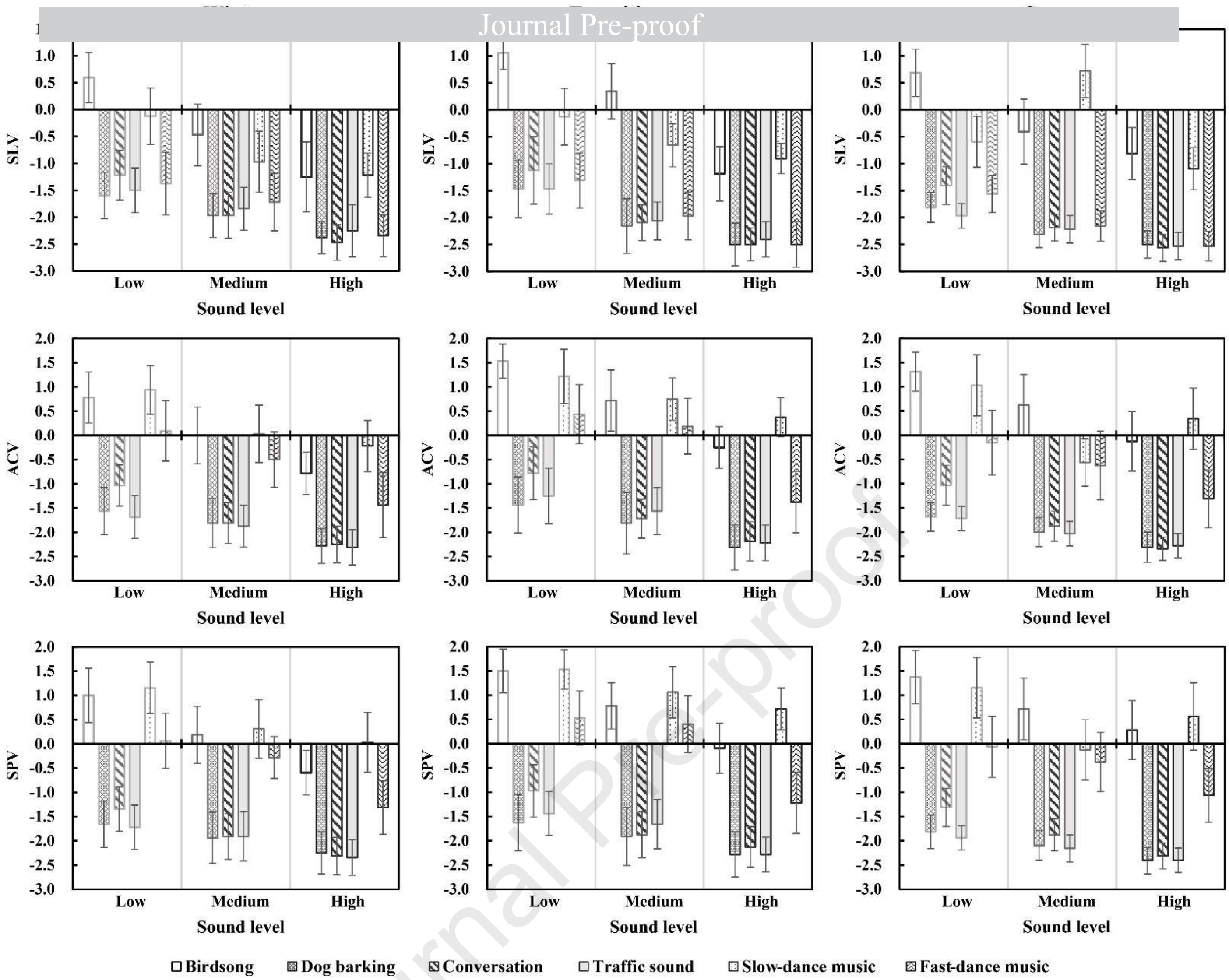

Fig. 3. Average values of the acoustic evaluations owing to the interaction between the sound types and sound levels.

It was observed that sound types and sound levels, as well as the interaction between them all had effects on the subjects' acoustic evaluations to a varying extent. In the three seasons, regardless of the changes in sound level, birdsong and slow-dance music resulted in higher acoustic evaluations than dog barking, conversation, and traffic sound. However, there were no significant differences between the effects of the former two sound types or those of the latter three sound types. Additionally, there was no significant difference in the effects of the two kinds of dance music on ACV and SPV. Regardless of the changes in sound type, the acoustic evaluations at the low sound level were significantly higher than those at the high sound level, and when the subjects heard the birdsong in winter and in the transition season, as well as conversation sound in summer, there was a decrease in the acoustic evaluations with the increasing sound level.

3.2 Effects of sound types and sound levels on the thermal evaluations

Fig. 4 shows the average values of the thermal evaluations relative to the condition of without sound stimuli (subtracted from the evaluation values obtained in the absence of sound stimuli). The thermal evaluations, which varied remarkably in the three seasons, were obviously different from the acoustic evaluations. In terms of TSV, TSV at the high sound level was slightly lower than that observed without the sound stimuli in winter, and the average difference was about 0.3. In the transition season, regardless of the changes in sound level, TSV was slightly higher than that obtained in the absence of sound stimuli, and the average difference was about 0.3. In summer, TSV at low and medium sound levels was lower than that obtained in the absence of sound stimuli, and the average difference was 0.4. However, high-sound level dog barking, conversation, and traffic sound resulted in a slight increase in TSV. In terms of TCV, TCV at medium and high sound levels was lower than that observed in the absence of sound stimuli in winter, and the average difference was 0.2–0.5. In the transition season, regardless of the changes in sound level, TCV was always significantly lower than that observed in the absence of sound stimuli, and the average difference ranged between 1.1 and 1.3. In summer, for medium and high-sound levels, birdsong, slow-dance music, and fast-dance music resulted in the increase in TCV, while other sound types resulted in the decline in TCV. In terms of TAV, in winter and the transition season, regardless of the changes in sound level, TAV was always lower than that observed in the absence of sound stimuli, with an average difference of 0.5–1.2 and 0.8–1.3, respectively. In summer, regardless of the changes in sound level, birdsong and slow-dance music increased TAV, while other sound types resulted in the decrease.

The results showed that in winter, the sound had no obvious effects on the thermal evaluations, and this could be attributed to the poor sensitivity of the subjects to the environment at low temperatures. In the transition season, all the sounds resulted in an increase in TSV, and decreases in TCV and TAV. It meant that the subjects were more sensitive to the sounds when they were exposed to a good thermal environment. Jin et al. observed that higher-level traffic sound decreased residents' TCV, and such an effect was most pronounced in the transition season [20], demonstrating that the subjects were more sensitive to sounds in the transition season. In summer, high-sound level dog barking, conversation, and traffic sound slightly intensified hot sensation, decreasing TCV and TAV. However, regardless of the changes in sound level, in summer, birdsong and slow-dance music always decreased TSV and an increased TCV and TAV.

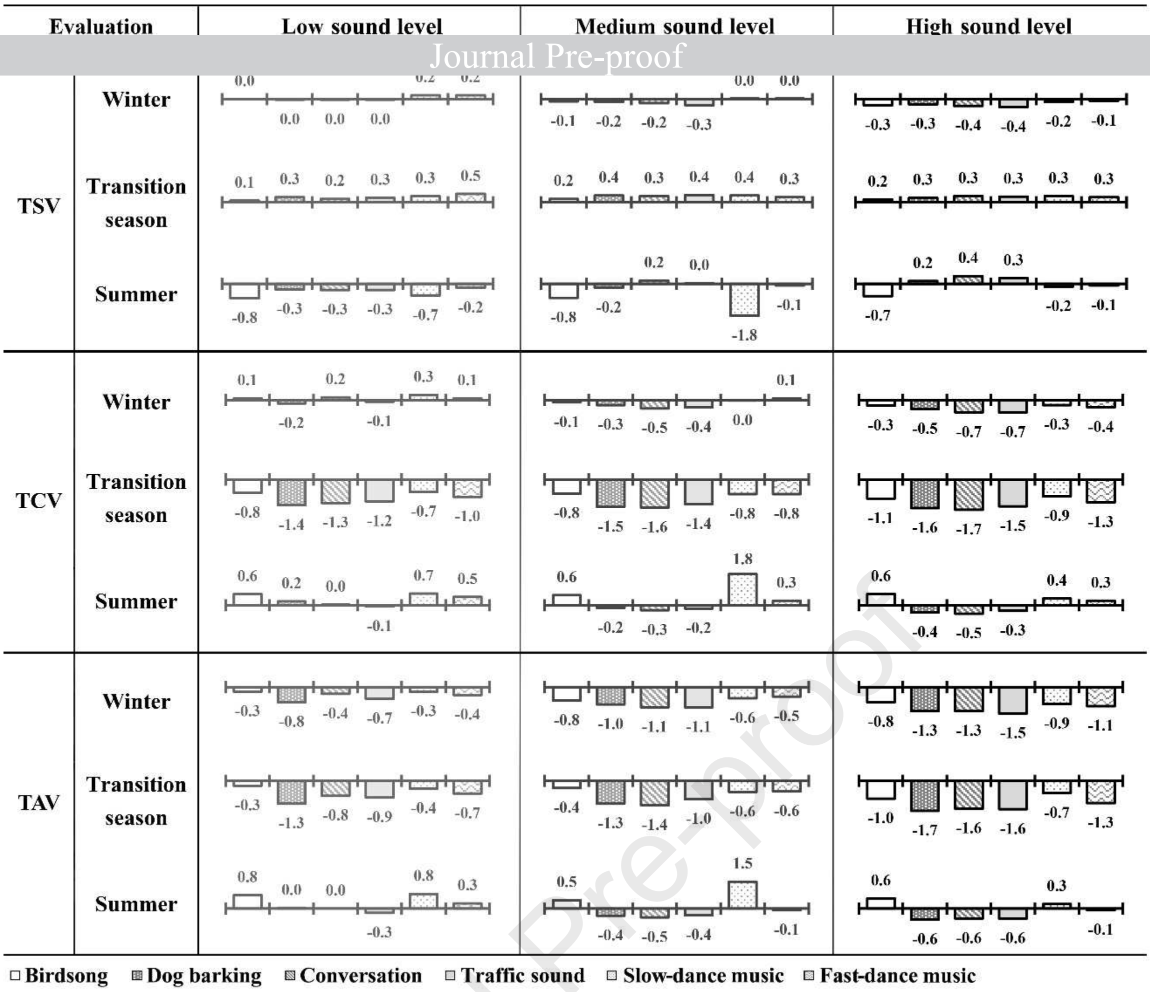

Fig. 4. Average values of the thermal evaluations relative to the condition of without sound stimuli.

Table 6 shows the significances of the effects of sound types and sound levels on the thermal evaluations. In winter and summer, the main effect of sound types and sound levels had significant effects on TSV ($p < 0.01$); however, the interaction between the sound types and sound levels only had a significant effect on TSV in summer ($p < 0.01$). In the transition season, the main effect of sound types and sound levels, as well as the interaction between them exerted no effects on TSV ($p > 0.05$). However, the main effect of sound types and sound levels had remarkable effects on TCV and TAV in the three seasons. Additionally, the interaction between sound types and sound levels had obvious effects on TCV and TAV in winter and summer ($p < 0.05$ and $p < 0.01$, respectively). When there was interaction, only the effects of the interaction on the thermal evaluations were analysed, and simple effects tests were performed (as shown in Fig. 5). When there was no interaction, the effects of the main effect on the thermal evaluations were analysed, and post hoc tests (Bonferroni) were performed.

Table 6. Significances of the effects of sound types and sound levels on the thermal evaluations.

Subjective evaluation	Season	Winter			Transition season			Summer		
	Factor	Level	Type	Level * Type	Level	Type	Level * Type	Level	Type	Level * Type
TSV	df	1.383	2.551	6.478	2.000	5.000	6.492	1.565	4.432	4.412
	F	6.452	5.554	0.276	0.303	2.116	1.214	10.133	16.737	9.132
	Sig.	**0.008**	**0.003**	0.955	0.740	0.066	0.298	**0.001**	**0.000**	**0.000**
TCV	df	1.412	3.206	6.870	1.473	2.427	5.489	2.000	3.614	6.017
	F	16.679	6.778	2.442	4.981	11.129	0.742	6.798	21.264	8.326

	Sig.	**0.000**	**0.000**	**0.021**	**0.019**	**0.000**	0.605	**0.002**	**0.000**	**0.000**
TAV	df	1.413	3.413	6.828	1.652	2.474	6.867	2.000	5.000	5.569
	F	17.995	9.162	2.087	10.936	12.027	1.645	7.440	22.434	3.602
	Sig.	**0.000**	**0.000**	**0.048**	**0.000**	**0.000**	0.126	**0.001**	**0.000**	**0.003**

Fig.5 shows the average values of the thermal evaluations owing to the interaction between the sound types and sound levels (The error bars represent the S.D. of the average values). Regarding TSV, even though there was no interaction in winter, the main effect of sound types and sound levels had significant effects on the thermal evaluations, and there was a difference between the effects of dog barking and fast-dance music ($p = 0.015 < 0.05$); meanwhile, TSV at the low sound level was slightly higher than that at other sound levels ($p < 0.05$). In summer, there was an interaction between the sound types and sound levels, none of the sounds at the low sound level had any effects on TSV ($p > 0.05$). When the sound levels were medium and high, TSV for birdsong was significantly lower than that for conversation and traffic sound ($p < 0.01$), and TSV for slow-dance music was significantly lower than that for conversation ($p < 0.05$). With respect to sound levels, when the sound types were birdsong, dog barking, and fast-dance music, sound level had no effects on TSV ($p > 0.05$). When the sound types were the other three types, TSV at the low sound level was significantly lower than that at the high sound level ($p < 0.01$), with an average difference of 0.7. In the transition season, sound types and sound levels, as well as the interaction between them had no effect on TSV ($p > 0.05$).

Regarding TCV, there was an interaction between the sound types and sound levels in winter and summer. In winter, when the sound levels were medium and high, TCV for slow-dance music was higher than that for conversation sound ($p < 0.05$). With respect to sound levels, when the sound types were birdsong, dog barking, and fast-dance music, TCV at the low sound level was significantly higher than that at the high sound level ($p < 0.05$), with an average difference of 0.5, and when the sound types were conversation, traffic sound, and slow-dance music, TCV at the low sound level was higher than that at other sound levels ($p < 0.01$), with an average difference of 0.6. In summer, regardless of the changes in sound level, TCV for birdsong and slow-dance music was always higher than that for conversation and traffic sound. Additionally, when the sound types were birdsong and fast-dance music, sound levels had no effects on TCV ($p > 0.05$), and when the sounds were the other four types, TCV at the low sound level was higher than that at the high sound level ($p < 0.05$), with an average difference of 0.5. In the transition season, even though no interaction was observed, the main effect of sound types and sound levels had significant effects on TCV. The effects of birdsong and slow-dance music were different from those of dog barking, conversation, and traffic sound ($p < 0.05$), while there was always a difference in the effects of medium and high sound level on TCV ($p = 0.013 < 0.05$).

Regarding TAV, there was an interaction between sound types and sound levels in winter and summer. In winter, when the subjects heard the slow-dance music at low and medium sound levels, TAV was between 0.0 and 1.0, and the subjects felt slightly acceptable. However, the other sound types resulted in TAV values that were less than 0 ($p < 0.05$). With respect to sound levels, when the sound types were conversation and traffic sound, TAV at the low sound level was higher than that at other sound levels, with an average difference of 0.5 ($p < 0.05$), and when the sounds were the other four types, TAV at the low sound level was significantly higher than that at the high sound level, with an average difference of 0.6 ($p < 0.05$). In summer, the subjects judged birdsong and slow-dance music at low and medium sound levels to be slightly acceptable, while the TAV for other sound types was less than 0 ($p < 0.01$). Additionally, when the sound types were birdsong and fast-dance music, sound levels exerted no effects on TAV ($p > 0.05$), and when the sound was any of the other four types, TAV at the low sound level was higher than that at the high sound level, with an average difference of 0.6 ($p < 0.05$). In the transition season, even though there was no interaction, the main effect of sound types and sound levels had significant effects on TAV. The effects of birdsong and slow-dance music were different from those of dog barking, conversation, and traffic sound ($p < 0.01$); meanwhile, the effect of the high sound level was different from those of the other sound levels ($p < 0.01$).

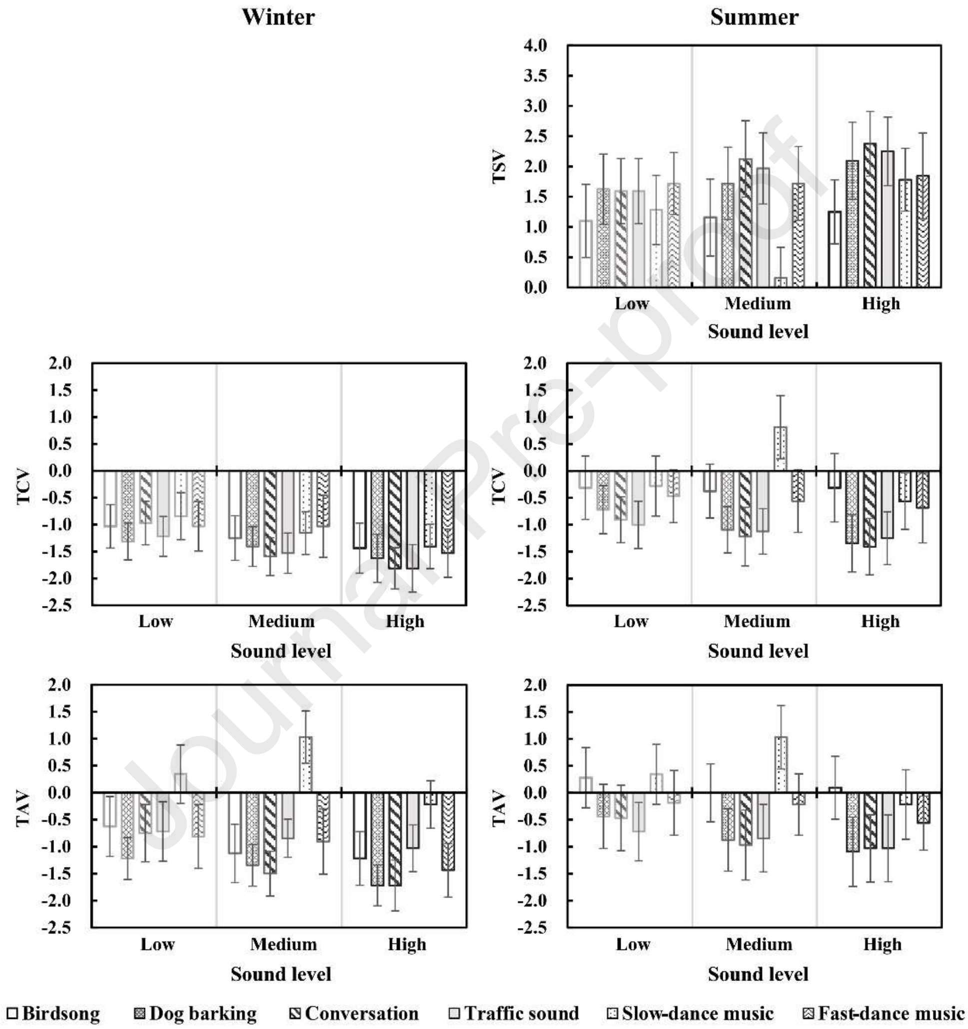

Fig. 5. Average values of the thermal evaluations owing to the interaction between the sound types and sound levels.

Based on the results obtained, it could be concluded that sound types and sound levels, as well as the interaction between them all had effects on the subjects' thermal evaluations to varying extents. Regarding sound types, there was a difference between the effects of dog barking and fast-dance music in winter. In summer, when the sound levels were medium and high, the TSV for birdsong and slow-dance music was significantly lower than that for conversation sound, but TCV and TAV were always higher than those for conversation sound. In the transition season, the effects of birdsong and slow-dance music on TCV and TAV were different from those of dog barking, conversation, and traffic sound; however, there were no significant differences between the effects of the former two sound types and those of the latter three sound types. With respect to sound levels, in winter, when the sound types were birdsong, dog barking, slow-dance music, and fast-dance music, TCV and TAV at the low sound level were significantly higher than those at the high sound level, and when the sound types were conversation and traffic sound, TCV and TAV at the low sound level were significantly higher than those at other sound levels. In summer, when the sound types were birdsong and fast-dance music, sound levels did not have any effects on the thermal evaluations. However, when the sound types were conversation, traffic sound, and slow-dance music, TSV was lower, TCV and TAV were higher at the low sound level; in the transition season, there were differences between the effects of medium and high sound level on TCV and TAV.

3.3 Effects of sound types and sound levels on the overall evaluations

Fig. 6 shows the average values of the overall evaluations relative to the condition of without sound stimuli (subtracted from the evaluation value obtained in the absence of sound stimuli). The overall evaluations were similar to the acoustic evaluations, but were obviously different from thermal evaluations, and were consistent in the different seasons. Regarding OCV, regardless of the changes in sound level in the three seasons, dog barking, conversation, and traffic sound always resulted in the significant decreased in OCV, and the average differences in winter, the transition season, and summer were 0.6–1.3, 1.5–2.6, and 0.8–1.4, respectively; however, low-sound level birdsong and slow-dance music increased OCV, and the difference ranged between 0.3 and 1.2. Regarding OAV, in summer, low-sound level birdsong, and slow-dance music resulted in the increase in the subjects' OAV to a certain degree. Additionally, regardless of the changes in sound levels in the three seasons, all the sounds led to the decrease in OAV, and the subjects felt more annoyed; The effects of dog barking, conversation, and traffic sound were also more pronounced.

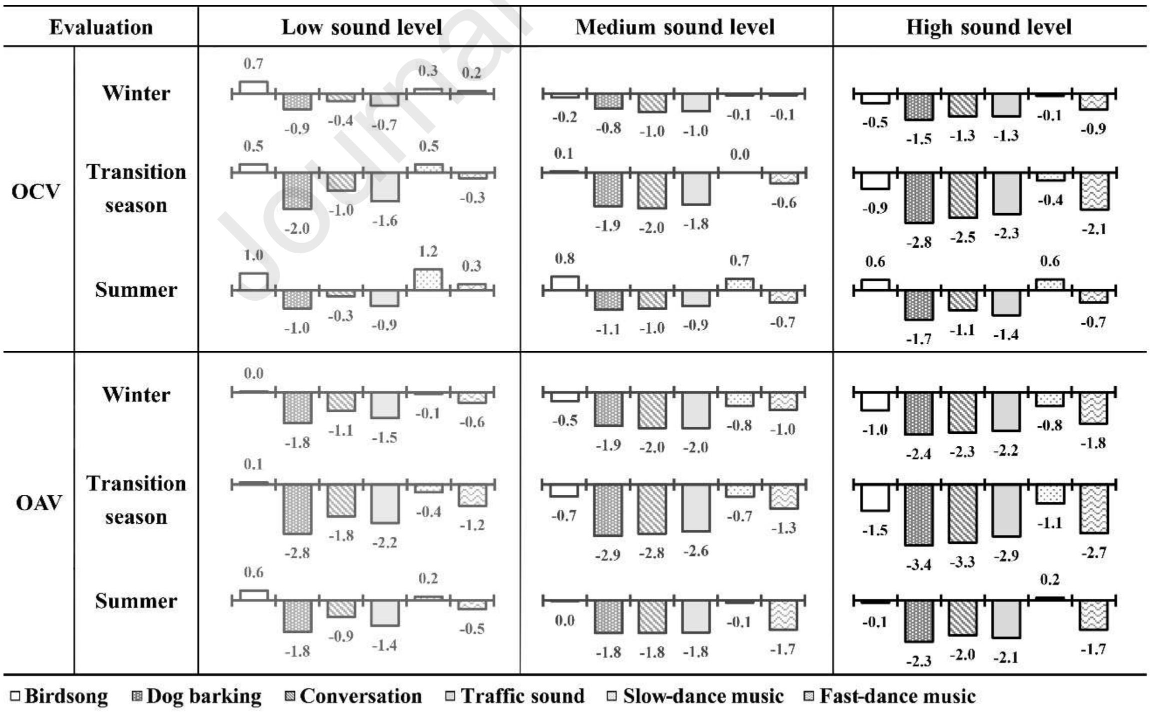

Fig. 6. Average values of the overall evaluations relative to the condition of without sound stimuli.

Table 7 shows the significances of the effects of sound types and sound levels on the overall evaluations. It is evident that in the three seasons, the main effect of and the interaction between sound types and sound levels significantly affected OCV and OAV ($p < 0.01$). As shown in Fig. 7, owing to the presence of interaction, only the effects of the interaction on the overall evaluations were analysed and simple effects tests were performed.

Table 7. Significances of the effects of sound types and sound levels on the overall evaluations.

Subjective evaluation	Season	Winter			Transition season			Summer		
	Factor	Level	Type	Level * Type	Level	Type	Level * Type	Level	Type	Level * Type
OCV	df	1.474	2.895	7.164	1.651	2.682	6.707	2.000	3.717	10.000
	F	24.796	32.911	3.431	48.437	48.243	5.079	20.649	50.125	2.509
	Sig.	**0.000**	**0.000**	**0.002**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.007**
OAV	df	1.610	3.083	6.086	1.481	3.045	7.209	1.711	3.301	6.712
	F	37.669	43.702	2.803	55.831	56.175	5.634	38.683	55.798	6.715
	Sig.	**0.000**	**0.000**	**0.012**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

Fig. 7 shows the average values of the overall evaluations owing to the interaction between the sound types and sound levels (The error bars represent the S.D. of the average values). Regarding OCV and OAV, there was an interaction between sound types and sound levels in the three seasons, and the effects of the interaction were relatively consistent. With respect to sound types, regardless of the changes in sound level in the three seasons, OCV and OAV for birdsong and slow-dance music were significantly higher than those for dog barking, conversation, and traffic sound; however, there were no significant differences between the effects of the former two sound types and those of the latter three sound types. For birdsong and slow-dance music at low and medium sound levels, both OCV and OAV were between 0.0 and 1.5, and the subjects felt slightly comfortable and pleasant. Additionally, fast-dance music always resulted in higher OCV and OAV than dog barking, with an average difference of 0.8 in winter and 1.2 in the transition season and summer ($p < 0.05$). With respect to sound levels, in winter and the transition season, regardless of the changes in sound type, OCV and OAV at the low sound level were higher than those at the high sound level, with an average difference of 0.8 and 1.1, respectively ($p < 0.01$). In summer, when the sound type was birdsong, sound levels had no effect on OCV ($p > 0.05$), and when the sound type was slow-dance music, sound levels also had no effect on OAV ($p > 0.05$). Additionally, when the sound types were dog barking, conversation, traffic sound, and fast-dance music, OCV and OAV at the low sound level were significantly higher than those at the high sound level, with an average difference always maintained at about 0.7 ($p < 0.01$ and $p < 0.05$).

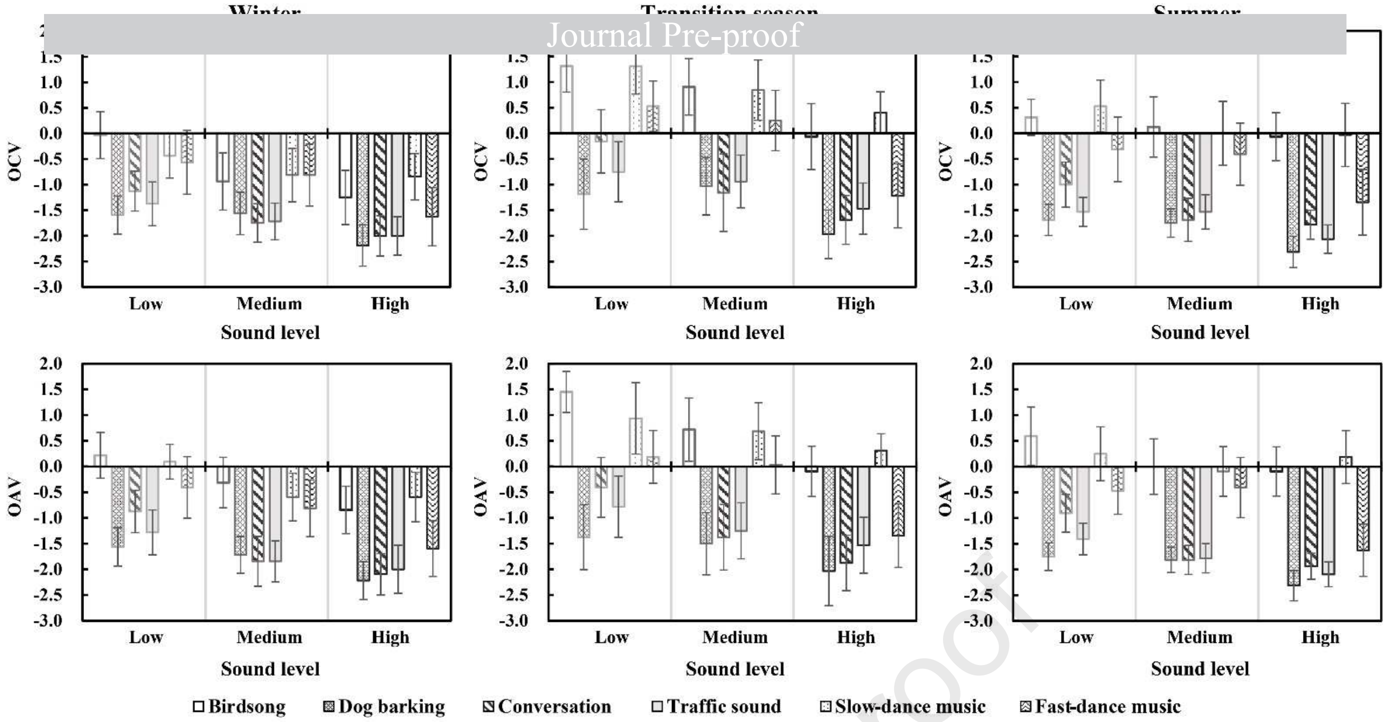

Fig. 7. Average values of the overall evaluations owing to the interaction between the sound types and sound levels.

4. Discussion

4.1 Differences in the effects of sound types and sound levels

In previous studies, some researchers have explored the effects of multiple sound types and sound levels on subjective evaluations. Although they did not study the interaction between sound types and sound levels, there were still had some consistencies between the results of their work and this study. In terms of sound levels, the results of this study and previous work [16,17, 22,23,34] both showed that for some sound sources, the TCV, ACV and OCV at the low sound level were significantly higher than those at the high sound level.

In terms of sound types, Yang and Moon [22,34] found that sound types had significant effects on TCV, ACV, and OCV. The average values were ranked as follows: fan noise＜babble sound＜water sound＜music, and when the sound types were water sound and music, the average values of the evaluation were relatively close. Guan et al. [23] indicated that at the same sound level, the TCV, ACV, and OCV in a musical environment were better than those in a noisy environment. Thus, it was seen that music was beneficial to the improvement in comfort vote—a result which was consistent with the results of this study. In addition, the subjective evaluations of birdsong and slow-dance music were better and closer (in terms of acoustic and overall evaluations in all three seasons and thermal evaluation in summer); the reason for this phenomenon might be the frequency range and variability in the sounds.

As there are more middle- and high-frequency components and higher variability in birdsong and slow-dance music, peoples' preference and acceptance of these sounds seemed to be more significantly higher; while, a stronger beat might have weakened the improvement of subjective evaluations to a certain extent. The mechanisms of the effects of sound types on subjective evaluations require in-depth studies by selecting more sound samples, whereas this study focuses more on the interaction of sound types and sound levels on thermal and overall evaluations, ad on the comprehensive comparisons under different seasonal conditions

4.2 Applications in related fields

Based on the results of this study, it is recommended that the effects of sounds on thermal evaluations are considered, particularly for urban public spaces where the thermal environments are poor and difficult to improve. The introduction of birdsong and slow-dance music at appropriate sound levels could improve residents' thermal evaluations in summer to a certain extent, i.e., relief of hot sensation and thermal discomfort. In winter and summer, with respect to the sounds that the preference of residents are not high, such as dog barking, conversation, and traffic sound, the thermal comfort and thermal acceptance at the low sound level are significantly higher.

4.3 Limitations and further study

Although simply simulating outdoor temperature in a chamber can allow effective control of the variables and avoid the interference of too many factors, it is necessary and significant to study the effects of various factors of the thermal environment on subjective evaluations. In future studies, the thermal environment setting will be considered more comprehensively to reduce the discrepancy between the physical environment in the chamber and the actual outdoor environment or increase the feasibility of conducting field measurements in the outdoor environment.

5. Conclusions

In this study, by simulating typical outdoor temperatures in different seasons (winter, transition season, and summer) in a controllable environmental chamber and administering a questionnaire survey, the subjective environmental evaluations, i.e., acoustic, thermal, and overall evaluations of subjects exposed to different sound types and sound levels were explored, the effects of sound types, sound levels and the interaction between the factors in different seasons on the subjective environmental evaluations were also investigated. The results can provide a certain reference for the environmental design of urban open spaces.

(1) Sound types and sound levels, as well as the interaction between them all had significant effects on the subjects' acoustic evaluations, and these effects were relatively consistent in different seasons. With respect to sound types, regardless of the changes in sound level in the three seasons, birdsong and slow-dance music always resulted in higher acoustic evaluations than dog barking, conversation, and traffic sound. However, there were no obvious differences between the effects of the former two sound types and those of the latter three sound types. Low-sound level birdsong and slow-dance music could effectively improve ACV and SPV; however, dog barking, conversation, and traffic sound always resulted in a remarkable decrease in acoustic evaluations. With respect to sound levels, regardless of the changes in the sound type in three seasons, acoustic evaluations at the low sound level were significantly higher than those at the high sound level.

(2) Sound types and sound levels, as well as the interaction between them all had effects on the subjects' thermal evaluations to a certain degree, and these effects varied greatly in the different seasons. With respect to sound types, in summer, birdsong and slow-dance music could effectively improve the thermal evaluations; in the transition season, all types of sounds led to a decrease in the thermal evaluations. With respect to sound levels, in winter and summer, when the sound types were dog

barking, conversation, traffic sound, and slow-dance music, TCV and TAV at the low sound level were significantly higher than those at the high sound level; and in the transition season, there were differences in the effects of the main effect of sound levels (medium and high sound level) on TCV and TAV.

(3) Sound types and sound levels, as well as the interaction between them all had significant effects on the subjects' overall evaluations. With respect to sound types, regardless of the changes in sound level in the three seasons, birdsong and slow-dance music always resulted in higher overall evaluations than dog barking, conversation, and traffic sound. Additionally, low-sound level birdsong and slow-dance music could effectively improve OCV; however, dog barking, conversation, and traffic sound always resulted in an obvious decrease in the overall evaluations. With respect to sound levels, in the three seasons, when the sound types were dog barking, conversation, traffic sound, and fast-dance music, the overall evaluations at the low sound level were significantly higher than those at the high sound level.

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References

[1] I. Knez, S. Thorsson, Influences of culture and environmental attitude on thermal, emotional and perceptual evaluations of a public square, International Journal of Biometeorology, 50(2006) 258–268 https://doi.org/10.1007/s00484-006-0024-0

[2] T.P. Lin, Thermal perception, adaptation and attendance in a public square in hot and humid regions, Building and Environment, 44(10) (2009) 2017–2026 https://doi.org/10.1016/j.buildenv.2009.02.004

[3] M. Luo, X. Zhou, Y. Zhu, J. Sundell, Revisiting an overlooked parameter in thermal comfort studies, the metabolic rate, Energy and Buildings, 118(2016) 152–159 https://doi.org/10.1016/j.enbuild.2016.02.041

[4] W. Yang, J. Kang, Acoustic comfort evaluation in urban open public spaces, Applied Acoustics, 66(2) (2005) 211-229 https://doi.org/10.1016/j.apacoust.2004.07.011

[5] S.C. Lee, J.Y. Hong, J.Y. Jeon, Effects of acoustic characteristics of combined construction noise on annoyance, Building and Environment, 92(2015) 657-667 https://doi.org/10.1016/j.buildenv.2015.05.037

[6] J. Kang, Q. Meng, H. Jin, Effects of individual sound sources on the subjective loudness and acoustic comfort in underground shopping streets, Science of the Total Environment, 435-436 (2012) 80-89 https://doi.org/10.1016/j.scitotenv.2012.06.105

[7] J.Y. Hong, Z.T. Ong, B. Lam, et al., Effects of adding natural sounds to urban noises on the perceived loudness of noise and soundscape quality, Science of The Total Environment, 711(2020), available online https://doi.org/10.1016/j.scitotenv.2019.134571

[8] J. Xiao, M. Tait, J. Kang, A perceptual model of smellscape pleasantness, Cities, 76(2018) 105-115, https://doi.org/10.1016/j.cities.2018.01.013

[9] R.S. Herz, I know what I like: Understanding odor preferences, In J. Drobnick (Ed.), The smell culture reader, 2006, 190-203, Berg Publishers: Oxford.

[10] R.D. Dean, C.L. McGlothen, Effects of combined heat and noise on human performance, physiology and subjective estimates of comfort and performance, Proceedings of the Institute of Environmental Science Annual Technical Meeting, Mount Prospect, (1965) 55–64.

[11] P.A. Bell, Effects of noise and heat stress on primary and subsidiary task performance, Human Factors, 20(6) (1978) 749-752 https://doi.org/10.1177/001872087802000614

[12] D.P. Wyon, R. Kok, M.I. Lewis, G.B. Meese, Combined noise and heat stress effects on human performance, Indoor Climate, Copenhagen, (1978) 857–881.

[13] T. Witterseh, D.P. Wyon, G. Clausen, The effects of moderate heat stress and open-plan office noise distraction on SBS symptoms and on the performance of office work, Indoor Air, 14(s8) (2004) 30-40 https://doi.org/10.1111/j.1600-0668.2004.00305.x

[14] G. Clausen, D.P. Wyon, The Combined Effects of Many Different Indoor Environmental Factors on Acceptability and Office Work Performance, HVAC & R Research, 14(1) (2008) 103-113 https://doi.org/10.1080/10789669.2008.10390996

[15] P.O. Fanger, N.O. Breum, E. Jerking, Can colour and noise influence man's thermal comfort ?, Ergonomics, 20(1) (1977) 11-18 https://doi.org/10.1080/00140137708931596

[16] K. Nagano, T. Horikoshi, New index of combined effect of temperature and noise on human comfort: summer experiments on hot ambient temperature and traffic noise, Archives of Complex Environmental Studies, 13 (2001) 3-4.

[17] K. Naganoa, T. Horikoshi, New comfort index during combined conditions of moderate low ambient temperature and traffic noise, Energy and Buildings, 37(3) (2005) 287-294 https://doi.org/10.1016/j.enbuild.2004.08.001

[18] N. Pellerin, V. Candas, Combined effects of temperature and noise on human discomfort, Physiology & Behavior,,78(1) (2003) 99-106 https://doi.org/10.1016/s0031-9384(02)00956-3

[19] N. Pellerin, V. Candas, Effects of steady-state noise and temperature conditions on environmental perception and acceptability, Indoor Air, 14(2) (2004) 129-136 https://doi.org/10.1046/j.1600-0668.2003.00221.x

[20] H. Guan, S. Hu, G. Liu, L. Zhang, The combined effects of temperature and noise on the comfort perceptions of young people with a normal Body Mass Index, Sustainable Cities and Society, 54(2020), available online https://doi.org/10.1016/j.scs.2019.101993

[21] B.H. Dalton, D.G. Behm, A. Kibele, Effects of sound types and volumes on simulated driving, vigilance tasks and heart rate, Occupational Ergonomics, 7(3) (2007) 153-168

[22] W. Yang, H.J. Moon, Cross-modal effects of noise and thermal conditions on indoor environmental perception and speech recognition, Applied Acoustics, 141 (2018) 1-8 https://doi.org/10.1016/j.apacoust.2018.06.019

[23] H. Guan, S. Hu, M. Liu, M. He, Z. Mao, G. Liu, People's subjective and physiological responses to the combined thermal-acoustic environments, Building and Environment, 172(2020), available online https://doi.org/10.1016/j.buildenv.2020.106709

[24] Y. Jin, H. Jin, J. Kang, Combined effects of the thermal-acoustic environment on subjective evaluations in urban squares, Building and Environment, 168 (2020), available online https://doi.org/10.1016/j.buildenv.2019.106517

[25] E.L. Krüger, P.H.T. Zannin, Acoustic, thermal and luminous comfort in classrooms, Building and Environment, 39(9) (2004) 1055-1063 https://doi.org/10.1016/j.buildenv.2004.01.030

[26] V. Mellert , I. Baumann, N. Freese, R. Weber, Impact of sound and vibration on health, travel comfort and performance of flight attendants and pilots, Aerospace Science and Technology,12(1) (2008) 18-25

https://doi.org/10.1016/j.ast.2007.10.009

[27] L. Huang, Y. Zhu, Q. Ouyang, B. Cao, A study on the effects of thermal, luminous, and acoustic environments on indoor environmental comfort in offices, Building and Environment, 49 (2012) 304-309 https://doi.org/10.1016/j.buildenv.2011.07.022

[28] M. Ba, J. Kang, A laboratory study of the sound-odour interaction in urban environments, Building and Environment, 147(2019) 314-326 https://doi.org/10.1016/j.buildenv.2018.10.019

[29] S. Hygge, I. Knez, Effects of noise, heat and indoor lighting on cognitive performance and self-reported affect, Journal of Environmental Psychology, 21(3) (2001) 291-299 https://doi.org/10.1006/jevp.2001.0222

[30] L.T. Wong, K.W. Mui, P.S. Hui, A multivariate-logistic model for acceptance of indoor environmental quality (IEQ) in offices, Building and Environment, 43(1) (2008) 1-6 https://doi.org/10.1016/j.buildenv.2007.01.001

[31] C. Buratti, E. Belloni, F. Merli, P. Ricciardi, A new index combining thermal, acoustic, and visual comfort of moderate environments in temperate climates, Building and Environment, 139 (2018) 27-37 https://doi.org/10.1016/j.buildenv.2018.04.038

[32] G. Horie, Y. Sakurai, T. Narguchi, N. Matsubara, Synthesized evaluation of noise, lighting and thermal conditions in a room, Proceedings of the International Conference on Noise Control Engineering, Krakow, Poland, (1985) 491–496.

[33] G. Clausen, L. Carrick, P.O. Fanger, S.W. Kim, T. Poulsen, J.H. Rindel, A Comparative Study of Discomfort Caused by Indoor Air Pollution, Thermal Load And Noisec, Indoor Air, 3(4) (1993) 255-262 https://doi.org/10.1111/j.1600-0668.1993.00006.x

[34] W. Yang, H.J. Moon, Combined effects of acoustic, thermal, and illumination conditions on the comfort of discrete senses and overall indoor environment, Building and Environment, 148 (2019) 623-633 https://doi.org/10.1016/j.buildenv.2018.11.040

[35] Y. Pan, Z.H. Meng, Influence of attention on visual and auditory masking effect in condition of visual-auditory dual tasks, ACTA ACUSTUCA, 2 (2013) 215-223.

Highlights

1. In summer, birdsong and slow-dance music at different sound levels effectively improve subjects' thermal evaluation.
2. In the transition season, all types of sounds result in a decline in the thermal evaluation.
3. In winter and summer, for conversation and slow-dance music, thermal comfort at the low sound level is significantly higher than that at the high sound level.
4. Birdsong and slow-dance music at the low sound level improve overall comfort, while dog barking, conversation, and traffic sound result in a significant decrease.
5. For dog barking, conversation, traffic sound, and fast-dance music, the overall evaluations at the low sound level are higher than those at the high sound level.

Declaration of interests

☑The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: