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Differences in thermal-acoustic perception in various office behaviors

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ABSTRACT

Thermal-acoustic interaction has vital research value in the development of soundscape prediction models. Previous studies on thermal–acoustic interaction have been focused mainly on perceptual changes. However, the differences in office behaviors warrant attention. We conducted an experimental study to explore the effects of various office behaviors (such as resting, reading, writing, and typing) on the thermal–acoustic interactive perception. The results showed that (at near thermal neutral temperature) (1) sound types affected thermal evaluation, acoustic evaluation, and overall evaluation. The sound of water significantly reduced the score for thermal sensation. (2) Behavior types affected thermal sensation, acoustic comfort, and overall comfort. Reading contributed to significantly lower scores than other behaviors for the three indicators. This indicated that when reading, people are more demanding of the environment. (3) The interaction of sound types and behavior types affected overall annoyance. Therefore, we recommend adjusting the office environment effectively and establishing more effective soundscape prediction models.

Keywords: Office behaviors, Thermal-acoustic interaction, Perception

1. INTRODUCTION

Office behaviors play an important role in the lives of people who spend time in an office every day; thus, a good office environment is crucial. Researchers have conducted numerous studies on office comfort, such as the thermal, acoustic, and visual comfort of the indoor environment (1-9). In a study of multiple environmental factors, it was found that temperature and noise have a veto power on indoor satisfaction (1), so the thermal and acoustic environments of the office space are particularly important. Several scholars have studied the interactive effects of thermal and acoustic environments on human comfort (2, 3, 6-9).

Fanger studied individuals' thermal sensation with 40 dBA background noise and 85 dBA white noise at a room temperature of 25 °C and found that sound had no effect on thermal neutral temperature (6). Tiller et al. found that noise affected thermal comfort, while temperature did not affect acoustic perception (PMV -1, -0.5, 0, 0.5 and 1)(7). Nagano and Horikoshi investigated the interaction between temperature and noise under high and low temperature conditions and found that

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noise did not affect thermal sensation but did affect thermal comfort, and temperature affected acoustic sensation (8, 9). Yang and Moon found that noise had no effect on thermal sensation, but noise level and type had significant effects on thermal comfort, and thermal environment had no effect on subjective loudness and noisiness, but the effect of PMV (PMV -1.53, 0.03, 1.53 and 1.83) on acoustic comfort and annoyance was statistically significant (2). Guan et al. found that acoustic conditions affected thermal comfort but not thermal sensation, and acoustic comfort was not affected by temperature in the near thermal neutral zone. Their laboratory experiments were based on the PMV equation, setting room temperatures at 18, 22, and 26 °C, corresponding to slightly cold, neutral, and slightly warm sensations, respectively (3). They also found that total comfort was mainly affected by temperature and sound pressure level (SPL), as well as by temperature* SPL interaction (3).

The concept of comfort has been used in studies of indoor environmental quality, mainly to investigate physical/physiological sensations and the perception of physical factors such as acoustics, thermal conditions, lighting, and indoor air quality (1, 4, 5). However, most studies did not restrict human behavioral states, and subjects were allowed to read or rest and practice other low metabolic rate office behaviors (1-5).

In terms of thermal environment research, metabolic rate has been investigated as a research index and found to be different for various office behaviors (10-14). ASHRAE 55 established metabolic rates for different office activities: sitting and resting (1.0 met), reading (1.0 met), writing (1.0 met), typing (1.1 met), sitting and filing (1.2 met), standing and filing (1.4 met), walking about (1.7 met), and lifting or pacing (2.1 met). Additionally, the researchers found that different office behaviors resulted in different perceptions (15). Pronk found that 34 participants felt significantly less discomfort from prolonged fixed sitting postures and more comfortable at work after a 5-week sit–stand office experience (16). Yang et al. found that different activity levels (metabolic rates) had significant effects on human thermal sensation, whereby differences in thermal comfort were found (17).

Because of the diversity of office worker behaviors, the original study was not able to predict the comfort of people practicing different behaviors. Therefore, it is necessary to study the effects of different office behaviors on thermal-acoustic perception. The purpose of this study is to investigate the variability of thermal-acoustic perception under different sound source conditions and behavioral states. The combined effects of acoustic and behavioral states on thermal sensation, thermal comfort, subjective loudness, acoustic comfort, overall comfort, and overall annoyance are investigated through laboratory experiments.

2. METHODS

2.1 Experimental Chamber

The experiment was conducted in the indoor climate chamber (L*W*H:4200*4200*3100 mm) of the Harbin Institute of Technology (HIT), furnished as a small office. The air temperature, relative humidity (RH), and air velocity were controlled by independent air-conditioning systems. The indoor temperature was set at 0-40 ± 0.1 °C and relative humidity at 20-90 ± 3%, which met the requirements for the experiment. The airflow started from the ceiling louvers and returned via the air inlet at the lower part of the sidewall. Sound stimuli were played through headphones to avoid the influence of room reverberation on the experiment.

2.2 Participants

After considering the level of statistical power, effect size ($1-\beta = 0.8$, $\alpha = 0.05$, effect size = 0.25), and the experimental conditions, 40 university students (17 males and 23 females) were recruited for the experiment, and each participated in a range of 1-3 experimental phases. The experiment was divided into three phases: 20, 23, and 26 °C, with sample sizes of 30 (15 males and 15 females), 30 (16 males and 16 females), and 30 (15 males and 15 females), respectively. On the day of the experiment, all subjects were graduate students who reported normal hearing and no physical discomfort such as fever or cold. The details of the participants are shown in Table 1. According to ASHRAE 55 standards (15), participants were advised to wear a clothing ensemble of approximately 0.96 clo, usually consisting of a pair of trousers, a long-sleeved shirt, a suit jacket, socks, underwear, and sneakers, for a total heat resistance of approximately 1.1 clo, including the chair.

Table 1 – Details of participants

	Mean (S.D.)	Max	Min
Age	24.16 (1.62)	28	22
Height (mm)	170 (7.21)	183	155
Weight (Kg)	60.17 (10.52)	95	44
BMI	20.55 (2.50)	28	17

2.3 Experimental Conditions

According to the PMV equation, three room temperature levels (20, 23, and 26 °C) were selected, corresponding to slightly cold, neutral, and slightly hot sensations, respectively. As people perform various activities, their energy metabolic rate increases at the level of the basal metabolism. The metabolic rate has an impact on thermal evaluation, and the body's neutral temperature decreases to maintain the body's homeostasis when the metabolic rate increases (18-20). In a quiet state, the human metabolism is more stable in an environment at 20-30 °C. Previously, Yang et al. demonstrated that there was no significant difference in metabolic rate between sitting and typing work at ambient temperatures of 20, 23, and 26 °C (17). For each temperature level, a constant relative humidity of 45% was set and the wind speed was less than 0.1 m/s. To ensure equivalent room air temperature and mean radiant temperature, each thermal condition was set at least 15 h before the test. This room was an indoor room. The average radiant temperature was assumed to be equal to the air temperature. The metabolic rate was approximately 1.0 met (1.0met¼58.2W/m2) and the clothing insulation was 1 clo (1clo¼0.155m2K/W).

Five sound sources (traffic noise, air-conditioning noise, music, speech, and water) were selected as sound samples because they represented typical sound sources in the office environment (3, 4). In this paper, traffic noise refers to the noise of the main road (vehicles with an average speed of 50 km/h). Air-conditioning noise refers to the noise generated by air conditioners (dimensions: 0.5 m*1.75 m*0.335 m; mechanical noise levels: 22-46 dB (internal), 42-56 dB (external) recorded in the anechoic chamber). The music was "Souvenir d'enfance," calm music with no apparent emotional value, downloaded from the music material library (21). The voice was a Chinese recording introducing architectural design. The water was recorded in a park in Harbin on a sunny, windless afternoon with the sound of rushing water. To avoid the effect of SPL changes on the results, we used Adobe Audition software to adjust the SPL of the six sound samples to 65 dBA. The SPL was chosen with reference to the median daytime noise exposure level measured through loudspeakers (22). Meanwhile, 65 dBA has been used as an intermediate value several times in previous thermal–acoustic interaction studies (3, 4).

Four work behaviors with lower metabolic rates were selected (resting, reading, writing, and typing), according to the ASHRAE 55-2020 standard that established typical activities in the office environment, including sitting and resting (1.0 met), reading (1.0 met), writing (1.0 met), and typing (1.1 met), etc. Meanwhile, Yang et al. demonstrated no significant difference in metabolic rate for sitting and typing work at ambient temperatures of 20, 23, and 26 °C. Since the participants were all graduate students in architecture, the materials for the reading task were books on architecture, and the writing task was a summary transcription of the contents of architecture books (17). The materials for the typing task were provided by Kingsoft Typing 2013, a typing practice software launched by Kingsoft.

2.4 Experimental Design and Procedure

A between-subjects factorial design was used in this study. The experiment included 3 independent variables: room temperature (20, 23, and 26 °C), type of sound source (traffic noise, air-conditioning noise, music, speech, and water sounds), and office behavior (resting, reading, writing, and typing). Subjects were randomly divided into 4 groups, and they participated in almost all experiments. Four people in each group participated in the experiment at the same time, where they experienced five types of acoustic environments and performed four different office behaviors at the same temperature.

All experiments were conducted at a room temperature of 23 °C at the beginning, then at 20 °C and finally at 26 °C. The clothing insulation of each subject was visually inspected before the start of each experiment to ensure it did not deviate significantly from the 0.96 clo requirement (4). Four participants (maximum size of four per group) were provided with a demonstration of how to complete the work task and fill out the questionnaire. To avoid potential experimental bias, the experimental conditions were not communicated to the participants. The participants then entered and remained in the room for 30 minutes to acclimatize to the thermal environment (23, 24). According to previous studies, the psychological response reached a steady state within 30 minutes (17), so subjects performed the corresponding office behavioral task during the 30 minutes. After the adaptation, the subject continued to perform the corresponding office behavior, and then the sound was played for 1.5 minutes. After the sound stopped, the subject filled in the questionnaire and the test ended. Subjects rested for 1 minute and then began the test for the next condition (see Figure 1). Subjects completed four office behavior tasks at the same temperature during the day. Thermal sensation (TSV), thermal comfort (TCV), subjective loudness (SLV), acoustic comfort (ACV), overall comfort (OCV), and overall annoyance (OAV) were assessed using a 7-point Likert scale at the end of each acoustic environmental condition period.

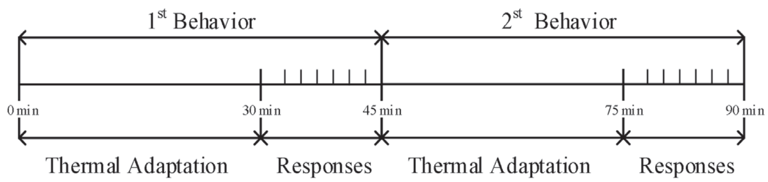


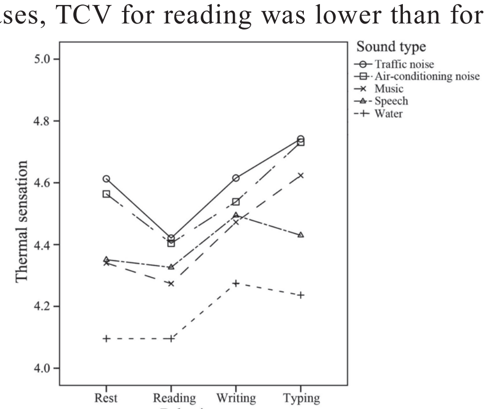
Figure 1 – Experimental procedure for each session

A factorial analysis of variance (ANOVA) was used to fit the 6 subjective environmental comfort attributes of the experiment to the 2 independent variables of type of sound source and type of behavior. ANOVA is a powerful statistical test and was used in this case, although the normality of the subjective scores could not be guaranteed (25). The Bonferroni post hoc test was applied.

3. RESULTS

3.1 Effects of Sound Source under Different Behaviors on Thermal Evaluation

The effects of sound types and behavior types on the thermal evaluation included the effects on TSV and TCV. Figure 2 shows the average TSV values under different acoustic environments and behavior types. The comparison of different sound types indicated that there were differences in TSV. Traffic noise and air-conditioning noise contributed to higher TSV than music, speech, and water. TSV for water was the lowest. Meanwhile, there were differences in TSV values under different behaviors. Reading contributed the lowest value of TSV under any kind of sound. When playing traffic noise, air-conditioning noise, and music, TSV for typing was highest. However, writing contributed to higher TSV than the other behavior types while playing speech and water. Figure 3 shows the average TCV values under different acoustic environments and behavior types. There were differences in the TCV under different sound types. Music and water contributed to higher TSV than speech, traffic noise, and air-conditioning noise. The effects of behaviors on TCV were not obvious. In most cases, TCV for reading was lower than for the other behaviors, and for typing it was higher.



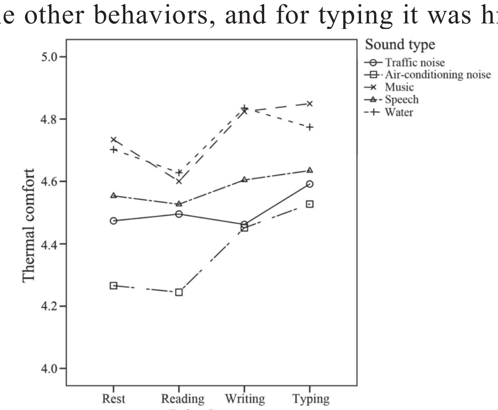


Figure 2 – The TSV of different conditions　　Figure 3 – The TCV of different conditions

Table 2 shows the significance of the indicators (TSV and TCV) under the main effects and interaction. The ANOVA of TSV revealed that the main effects of both sound types and behavior types on TSV were highly significant ($p < 0.01$), but the interactions had no effect on TSV ($p > 0.05$). Regarding TCV, only the main effect of sound types was significant ($p < 0.01$).

Table 2 – The results of two-way ANOVA for TSV and TCV

Subjective evaluation		Sound type	Behavior type	Sound type *Behavior type
TSV	Df	4	3	12
	F	7.594	4.000	0.218
	Sig.	0.000	0.008	0.992
TCV	Df	4	3	12
	F	7.234	2.329	0.234
	Sig.	0.000	0.073	0.997

Table 3 lists the means and Bonferroni's post hoc test results to supplement Table 2. There were effects of sound source type on TSV. Water contributed to lower scores than the others with statistical significance. For the effect of behavior types on TSV, the scores were statistically significantly lower when reading and higher when typing. In terms of the effects of sound types on TCV, the scores were significantly higher when playing water and music, and significantly lower under air-conditioning noise. There was no significant difference in TCV for different behaviors.

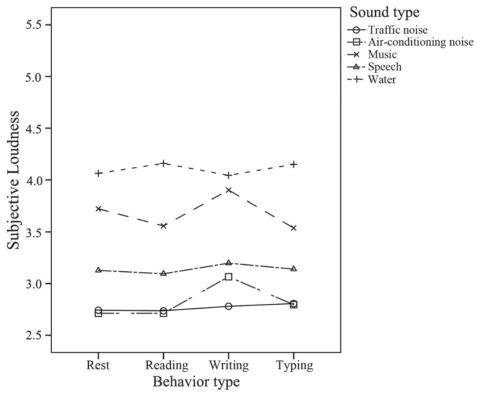
Table 3 – Means and Bonferroni's post-hoc test results for TSV and TCV

(Means with different letters are significantly different. $P < 0.05$, $A > B > C > D > E$)

		N	Thermal Sensation		Thermal Comfort	
			Mean	Group	Mean	Group
Sound type	Traffic noise	372	4.5968	A	4.5054	BC
	Air-conditioning noise	372	4.5591	A	4.3710	C
	Music	373	4.4263	A	4.7507	A
	Speech	373	4.3995	A	4.5791	AB
	Water	372	4.1747	B	4.7339	A
Behavior type	Rest	473	4.3923	AB		
	Reading	469	4.3044	B		
	Writing	455	4.4791	AB		
	Typing	465	4.5527	A		

3.2 Effects of Sound Source under Different Behaviors on Acoustic Evaluation

The effects of sound types and behavior types on the acoustic evaluation included the effects on SLV and ACV. Figure 4 shows the average SLV values under different acoustic environment and behavior types. There were differences in SLV under different sound types. Music and water contributed to higher TSV than speech, traffic noise, and air-conditioning noise. The effects of behaviors on SLV were not obvious. In most cases, SLV was lower when reading and higher when writing and typing. Figure 5 shows the average ACV values under different acoustic environments and behavior types. The comparison of different sound types indicated that there were differences in the ACV. Water and music contributed to higher ACV than speech, traffic noise, and air-conditioning noise. Meanwhile, there were differences in ACV under different behaviors. In most cases, reading accounted for the lowest ACV value, except for traffic noise.



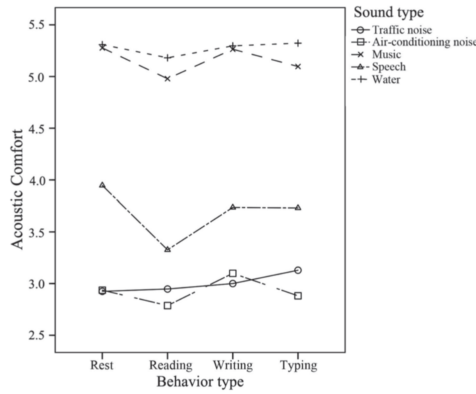


Figure 4 – The SLV of different conditions   Figure 5 – The ACV of different conditions

Table 4 shows the significance of the indicators (SLV and ACV) under the main effects and interaction. The ANOVA of SLV revealed that only the main effect of sound types on SLV was significant ($p < 0.01$), but the main effect of behavior types and the interactions had no effect on SLV ($p > 0.05$). In terms of ACV, the main effects of both sound types and behavior types were highly significant ($p < 0.01$), but the interaction had no effect on ACV ($p > 0.05$).

Table 4 – The results of two-way ANOVA for SLV and ACV

Subjective evaluation		Sound type	Behavior type	Sound type *Behavior type
SLV	Df	4	3	12
	F	129.002	2.026	1.008
	Sig.	0.000	0.108	0.439
ACV	Df	4	3	12
	F	509.476	6.163	1.349
	Sig.	0.000	0.000	0.184

Table 5 lists the means and Bonferroni's post hoc test results to supplement Table 4. There were effects of sound source type on SLV. Water and music contributed to higher scores than speech, air-conditioning noise, and traffic noise with statistical significance. For the effect of behavior types on SLV, the scores did not differ significantly. There were also effects of sound source type on ACV. ACV was significantly higher when playing water and music than speech, air-conditioning noise, and traffic noise with statistical significance. For the effect of behavior types on ACV, the scores were statistically significantly lower when reading.

Table 5 – Means and Bonferroni's post-hoc test results for SLV and ACV

(Means with different letters are significantly different. $P < 0.05$, $A > B > C > D > E$)

		N	Subjective Loudness		Acoustic Comfort	
			Mean	Group	Mean	Group
Sound type	Traffic noise	372	2.7661	D	3.000	C
	Air-conditioning noise	372	2.8199	D	2.9247	C
	Music	373	3.6783	B	5.1528	A
	Speech	373	3.1394	C	3.6836	B
	Water	372	4.1048	A	5.2769	A
Behavior type	Rest	473			4.0810	A
	Reading	469			3.8436	B

Writing	455	4.0791	A
Typing	465	4.0323	A

3.3 Effects of Sound Source under Different Behaviors on Overall Evaluation

The effects of sound types and behavior types on the overall evaluation included the effects on OCV and OAV. Figure 6 shows the average OCV values under different acoustic environment and behavior types. The comparison of different sound types indicated that there were differences in the OCV. Music and water contributed to higher OCV than speech, traffic noise, and air-conditioning noise. Meanwhile, there were differences in OCV under different behaviors. In most cases, reading accounted for the lowest OCV value, except for traffic noise. Figure 7 shows the average OAV values under different acoustic environments and behavior types. There were differences in OAV under different sound types. Water and music contributed to higher OAV than speech, traffic noise, and air-conditioning noise. In terms of the effects of behavior types on OAV, the scores for reading were significantly lower than for other behaviors when playing water sounds, except traffic noise. OAV was higher for resting, writing, and typing when playing air-conditioning noise and speech, and for writing and resting when playing music and water. OAV for typing was highest when traffic noise was played.

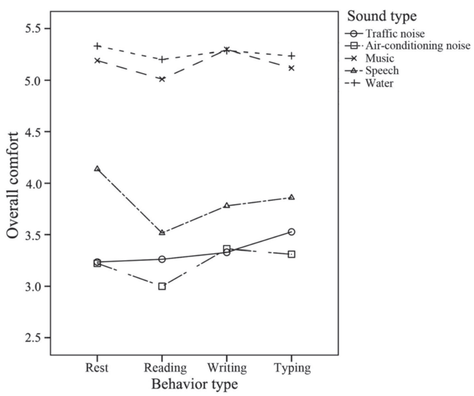


Figure 6 – The OCV of different conditions

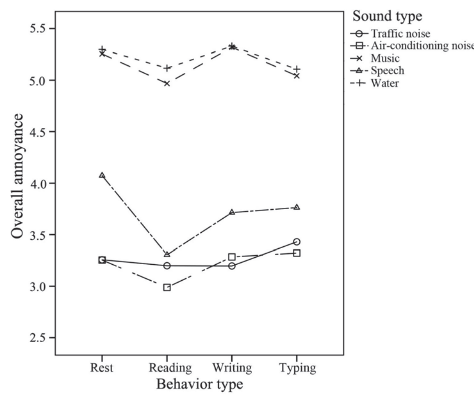


Figure 7 – The OAV of different conditions

Table 6 shows the significance of the indicators (OCV and OAV) under main effects and interaction. The ANOVA of OCV revealed that the main effects of both sound types and behavior types on TSV were highly significant ($p < 0.01$), but the interactions had no effect on TSV ($p > 0.05$). In terms of OAV, the main effect of the two and the interactions were all significant ($p < 0.05$).

Table 6 – The results of two-way ANOVA for OCV and OAV

Subjective evaluation		Sound type	Behavior type	Sound type *Behavior type
OCV	Df	4	3	12
	F	342.672	5.286	1.495
	Sig.	0.000	0.001	0.119
OAV	Df	4	3	12
	F	354.382	8.410	1.885
	Sig.	0.000	0.000	0.032

Table 7 lists the means and Bonferroni's post hoc test results to supplement Table 6. There were effects of sound types on OCV. Water and music contributed to higher scores than speech, traffic noise and air-condition noise with statistical significance. For the effect of behavior types on OCV, the scores were statistically significantly lower when reading.

Table 7 – Means and Bonferroni's post-hoc test results for OCV

(Means with different letters are significantly different. P < 0.05, A > B > C > D > E)

		N	Overall comfort	
			Mean	Group
Sound type	Traffic noise	372	3.3387	C
	Air-conditioning noise	372	3.2231	C
	Music	373	5.1528	A
	Speech	373	3.8231	B
	Water	372	5.2634	A
Behavior type	Rest	473	4.2260	A
	Reading	469	3.9979	B
	Writing	455	4.2110	A
	Typing	465	4.2108	A

In terms of the effects of sound types on OAV, owing to the presence of interaction, only the effects of the interaction on OAV were analyzed, and simple effects tests were performed. Table 8 lists the means and Bonferroni's post hoc test results to supplement Table 6. There were differences in effects of behavior types on OAV when playing different sounds. When playing traffic noise and water, behavior types had no significant effect on OAV, while the scores for reading were lower than for other behaviors under conditions of air-condition noise, music, and speech with statistical significance. OAV for rest was significantly higher than other behaviors when speech was played, but for air-conditioning noise and music, scores at rest were not significantly different from writing and typing.

Table 8 – Means and Bonferroni's post-hoc test results for OAV

(Means with different letters are significantly different. $P < 0.05$, A > B > C > D > E)

		N	Overall Annoyance			
			Rest	Reading	Writing	Typing
Sound type* Behavior type	Traffic noise	372	3.258 A	3.200 A	3.198 A	3.430 A
	Air-conditioning noise	372	3.255 AB	2.989 B	3.286 A	3.323 A
	Music	373	5.255 AB	4.968 B	5.319 A	5.043 AB
	Speech	373	4.074 A	3.305 C	3.714 B	3.763 B
	Water	372	5.298 A	5.117 A	5.330 A	5.108 A

4. CONCLUSION

In this study, the effects of sound types and behavior types on thermal evaluation, acoustic evaluation, and overall evaluation were investigated to measure thermal–acoustic perception under different acoustic environments and behaviors.

First, the sound types affected the thermal evaluation, acoustic evaluation, and overall evaluation. In terms of TSV, the sound of water reduced significantly the score. In the other subjective evaluation indexes, the effect of sound source type was consistent. The scores for music and water were higher than for speech; the scores for traffic noise and air-conditioning noise were the lowest. This suggested that people show consistency in different indicators of thermal–acoustic perception for their sound type preferences.

Second, the behavior types affected TSV, ACV, and OCV. In terms of TSV, the scores for reading were the lowest and for typing were the highest. In terms of ACV and OCV, reading contributed more to the significantly lower scores than other behaviors. This indicated that when reading, subjective perception scores are lower and people are more demanding of the environment.

Finally, the interaction of sound types and behavior types affected overall annoyance.

When playing traffic noise and water, behavior types had no significant effect on OCV. OCV for reading was lower than for other behaviors when playing air-conditioning noise, music, and speech with statistical significance. This indicated that air-conditioning noise, music, and speech are more likely to cause human discomfort and increase irritation when reading. Therefore, a more positive acoustic environment should be provided in the office for people when reading. We can improve human comfort while reading by playing water sounds and reducing air-conditioning noise and speech, etc.

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REFERENCES

1. Huang L, Yingxin Z, Ouyang Q, Bin C. A study on the effects of thermal, luminous, and acoustic environments on indoor environmental comfort in offices. BUILD ENVIRON. 2012;49:304-9.
2. Yang W, Moon HJ. Cross-modal effects of noise and thermal conditions on indoor environmental perception and speech recognition. APPL ACOUST. 2018;141:1-8.
3. Guan H, Hu S, Lu M, He M, Mao Z, Liu G. People's subjective and physiological responses to the combined thermal-acoustic environments. BUILD ENVIRON. 2020;172:106709.
4. Yang W, Moon HJ. Combined effects of acoustic, thermal, and illumination conditions on the comfort of discrete senses and overall indoor environment. BUILD ENVIRON. 2019;148:623-33.
5. Wu H, Sun X, Wu Y. Investigation of the relationships between thermal, acoustic, illuminous environments and human perceptions. Journal of Building Engineering. 2020;32:101839.
6. Fanger PO, Breum NO, Jerking E. Can Colour and Noise Influence Man's Thermal Comfort? ERGONOMICS. 1977 1977-01-01;20(1):11-8.
7. Tiller D, Wang LM, Musser A, Radik MJ, ^editors. Combined effects of noise and temperature on human comfort and performance. Ashrae Conference; 2010. Pub Place; Year Published.
8. Nagano K, Horikoshi T. 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. 2001(13):1-8.
9. Nagano K, Horikoshi T. New comfort index during combined conditions of moderate low ambient temperature and traffic noise. Energy & Buildings. 2005;37(3):287-94.
10. Beers EA, Roemmich JN, Epstein LH, Horvath PJ. Increasing passive energy expenditure during clerical work. EUR J APPL PHYSIOL. 2008;103(3):353-60.
11. Levine JA, Miller JM. The energy expenditure of using a \"walk-and-work\" desk for office workers with obesity. BRIT J SPORT MED. 2007;41(9):558-61.
12. Cox RH, Guth J, Siekemeyer L, Kellems B, Brehm SB, Ohlinger CM. Metabolic cost and speech quality while using an active workstation. J PHYS ACT HEALTH. 2011;8(3):332-9.
13. Reiff C, Marlatt K, Dengel DR. Difference in caloric expenditure in sitting versus standing desks. J PHYS ACT HEALTH. 2012;9(7):1009.
14. Mansoubi M, Pearson N, Clemes SA, Biddle SJ, Bodicoat DH, Tolfrey K, et al. Energy expenditure during common sitting and standing tasks: examining the 1.5 MET definition of sedentary behaviour. BMC PUBLIC HEALTH. 2015;15(1).
15. ANSI/ASHRAE/IES Standard 55-2017. Thermal environmental conditions for human occupancy. Atlanta, GA: American Society of Heating, Ventilation, Refrigerating and Air Conditioning Engineers. 2017.
16. Pronk NP, Katz AS, Lowry M, Payfer JR. Reducing Occupational Sitting Time and Improving Worker Health: The Take-a-Stand Project, 2011. PREV CHRONIC DIS. 2012;9:110323.
17. Yang L, Gao S, Zhao S, Zhang H, Arens E, Zhai Y. Thermal comfort and physiological responses with standing and treadmill workstations in summer. BUILD ENVIRON. 2020;185:107238.

18. Mcnall PE, Jaax R, Nevins RG. Thermal comfort conditions for three levels of activity. 1967.
19. Gonzalez RR. Exercise physiology and sensory responses. Studies in Environmental Science. 1981;10:123-44.
20. Gagge AP, Stolwijk JA, Saltin B. Comfort and thermal sensations and associated physiological responses during exercise at various ambient temperatures. ENVIRON RES. 1969 1969-01-01;2(3):209.
21. Meng Q, An Y, Yang D. Effects of acoustic environment on design work performance based on multitask visual cognitive performance in office space. BUILD ENVIRON. 2021;205:108296.
22. Kraus U, Breitner S, Hampel R, Wolf K, Cyrys J, Geruschkat U, et al. Individual daytime noise exposure in different microenvironments. ENVIRON RES. 2015;140:479-87.
23. Soebarto V, Zhang H, Schiavon S. A thermal comfort environmental chamber study of older and younger people. BUILD ENVIRON. 2019;155(MAY):1-14.
24. Hodder SG, Parsons K. The effects of solar radiation on thermal comfort. INT J BIOMETEOROL. 2007;51(3):233-50.
25. David, V., Budescu, Mark, I., Appelbaum. Variance Stabilizing Transformations and the Power of the F Test. JOURNAL OF EDUCATIONAL AND BEHAVIORAL STATS. 1981.