Factors influencing audio-visual comfort evaluation in the metro commercial space

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ABSTRACT

Metro commercial spaces have a potential audio-visual problem because of lack of outside openings. China has built plenty metro commercial entities with its rapid urban development, in which the audio-visual comfort has been concerned as current situation is not good. In order to improve space quality and then enhance staying willing in the metro commercial space, this paper illustrates a study of influencing factors on aural and visual comfort in the metro commercial space. The study takes three metropolises (Shenzhen, Hong Kong and Guangzhou) into account and investigated 103 metro commercial cases. In the study, the spatial differences on aural and visual comfort were firstly examined, and then physical factors of the acoustic and visual environments were considered. It is found that correlations of various acoustic and visual environmental factors on aural and visual comfort were not significant as the correlation value is rather low. If taking spatial differences into account, closer relations could be found. It discovered that visual environmental factors could influence aural comfort, and the vice versa. The factors of saturation, brightness, illuminance and roughness from the visual environment, and sound level and sources from the acoustic environment, are significantly influence aural and visual comfort especially to a typical spatial type of the metro commercial space.

1. INTRODUCTION

With rapid urbanization in China, more and more metro commercial spaces have been developed companying with metro development, which is highlighted in the Chinese metropolises. However, usage of such commercial space is not good as others because of poor aural and visual environmental comfort due to no natural elements. This problem hinders healthy development of metro industrial market but less studies focused on this facet. Many studies on metro development issues concerned

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on land use, developing models, spatial organizations etc. [1-4], which are more looking at planning problems in a macro scale of metro development. These studies have not involved detail works of environmental issues to a metro commercial space, however, which is important to aid designers for proposing well designs to achieve environmental physical comfort and enhance the space usage and commercial values.

To the visual environment, Sun conducted field studies in the underground streets and found that color and scale are important to influence the design preference to the underground commercial streets [5]. Color has also been found significant to the visual environmental comfort in the New York commercial spaces [6]. Lighting is found to play a role to influence the visual comfort in commercial spaces [7]. To the acoustic environment, acoustic and psychoacoustic parameters were studied more and found more related with subjective evaluation of a soundscape of the public and commercial spaces [8]. Similar results have also been found in the study of urban open spaces [9]. To the underground commercial street, Meng & Kang found that reverberation effect, spatial form, density, and acoustic factors influence on aural comfort evaluations more [10]. To the interactive study of aural and visual perceptions, Yu found that loudness has negative effect both on aural and visual comfort in the study of the square in Shenzhen [11]. Joynt studied visual effect of vegetation barriers on noisy feelings and found that greenery elements providing aesthetic pleasure and then reducing noisy perceptions [12].

Previous studies proved that physical factors of the acoustic and visual environment could have much influence on subjective comfortable feelings of aural and visual. It is then considered that studying influencing factors on aural and visual comfort in a metro commercial space, variations of the audio-visual environments have to be systematically studied. Supported by the National Natural Science Foundation of China, Tao & Yu et al. have already explored the Shenzhen and Hong Kong metro commercial spaces. Their study showed that the acoustic environmental factors were not only influence on aural comfort but also visual comfort, which is similar with the other authored studies [13]. However, their study was only carried on in two cities, Shenzhen and Hong Kong. That is far enough to cover varied situations of the Chinese metro commercial spaces. This study is then to involve more metro commercial spaces in Guangzhou, which is one of the four important Chinese metropolises with an advanced metro industrial.

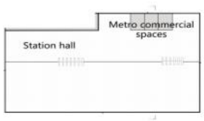
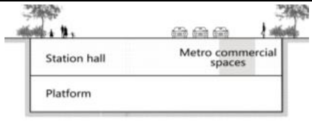
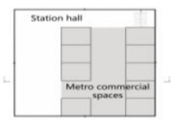
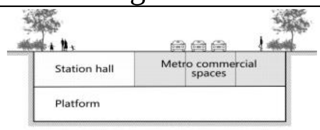
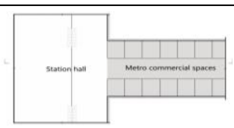
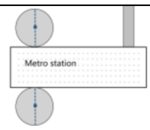
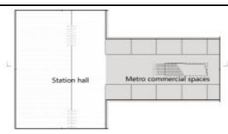
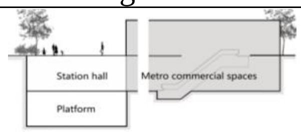
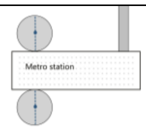
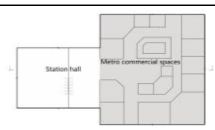
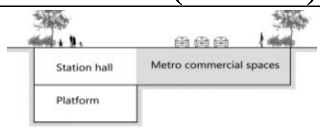
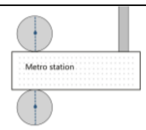
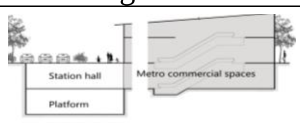
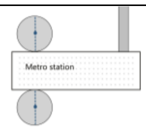
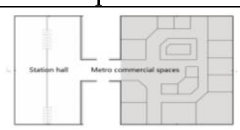
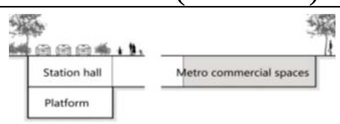
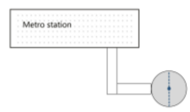
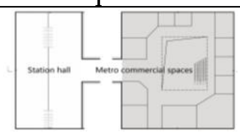
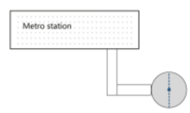
2. METHODOLOGY

The study takes three metropolises, Shenzhen, Hong Kong, Guangzhou as study cities. Field studies of Shenzhen and Hong Kong have been done earlier, and Guangzhou is the new city included for more situations. Field studies were taken in three phases. In the Phase I, all metro commercial spaces of the study city have been looking through using GPS maps, and observations in real sites were carried. Totally, 31, 22, and 50 metro commercial spaces have been observed in the Shenzhen, Hong Kong, and Guangzhou respectively. Following works of the Phase I, the Phase II made in-situ measurements to the typical metro commercial spaces obtained through cluster analyses to the all cases of the Phase I. In general, 7, 6, and 6 typical metro commercial spaces have been measured to get physical factors of the acoustic and visual environment. After exploring the physical factors of the acoustic and visual environment to the 19 typical cases, study models according to the protypes of audio-visual environment were extracted. Three protypes of audio-visual environment is found that have been used in the Phase III social surveys. In the Phase III, 4 study cases of each city have been chosen to conduct social surveys as they stand for different protypes of spatial forms and also audio-visual environments.

2.1. The Phase Ⅰ to extract spatial protypes of metro commercial spaces

In the Phase I, metro maps have been thoroughly examined in order to get knowledge of metro commercial distributions of each study city. To the Shenzhen and Hong Kong, these have been done in the previous study [14]. Using the same method, metro commercial spaces of Guangzhou have also been thoroughly examined. Combing all metro commercial spaces of the three cities, 103 cases have been got. As the spatial form is essential to determine aural and visual comfort feeling of an environment. Typical spatial forms have been investigated according to plan, section variations of a space and also the connection ways of the metro station and the commercial space. To the plan variation, three differences can be found that are the point plan, linear plan, and square plan. To the section variation, two differences can be found, which are the single floor and the multiple floors. To the variation of the station and commercial space connection, three differences can also be found, which are the commercial inside the station hall, the commercial directly connecting with the station, the commercial indirectly connecting with the station.

Table 1: 8 spatial protypes of metro commercial spaces in Shenzhen, Hong Kong and Guangzhou

No.	Plan	Section	Connection	Case numbers		
				SZ	HK	GZ
1	 Point	 Single floor	 Inside the station	1	6	22
2	 Linear	 Single floor	 Inside the station	0	1	0
3	 Linear	 Single floor	 Direct connection	7	2	9
4	 Linear	 Multi-floors (no atrium)	 Direct connection	5	0	0
5	 Square	 Single floor	 Direct connection	0	0	5
6	 Square	 Multi-floors (no atrium)	 Direct connection	17	6	3
7	 Square	 Single floor	 Indirect connection	1	0	9
8	 Square	 Multiple floors	 Indirect connection	0	7	2

Note：1. SZ-Shenzhen, HK-Hong Kong, GZ-Guangzhou.

2. - Metro station; - Metro commercial space

The 8 typical spatial protypes are named as SP1 (point- single floor-inside the station), SP2 (linear-single floor-inside the station), SP3 (linear-single floor-direct connection), SP4 (linear-multiple floors-no atrium-direct connection), SP5 (square-single floor-direct connection), SP6 (square-multiple floors-no atrium-direct connection), SP7 (square-single floor-indirect connection) and SP 8 (square-multiple floors-indirect connection). From Table 2, it could be found that there are 5 spatial protypes (SP1, 3, 4, 6, 7) in Shenzhen, 5 (SP1, 2, 3, 6, 8) in Hong Kong and 6 (SP1, 3, 5, 6, 7, 8) in Guangzhou. To the metro commercial spaces in three metropolises, most of them are square type, which exist in commercial complex. Some of them are linear type, which are pedestrian streets as usual. Furthermore, there are lots of point type metro commercial spaces existing in Guangzhou, whereas less in Shenzhen and Hong Kong.

2.2. The Phase Ⅱ to extract physical factors of audio-visual environments

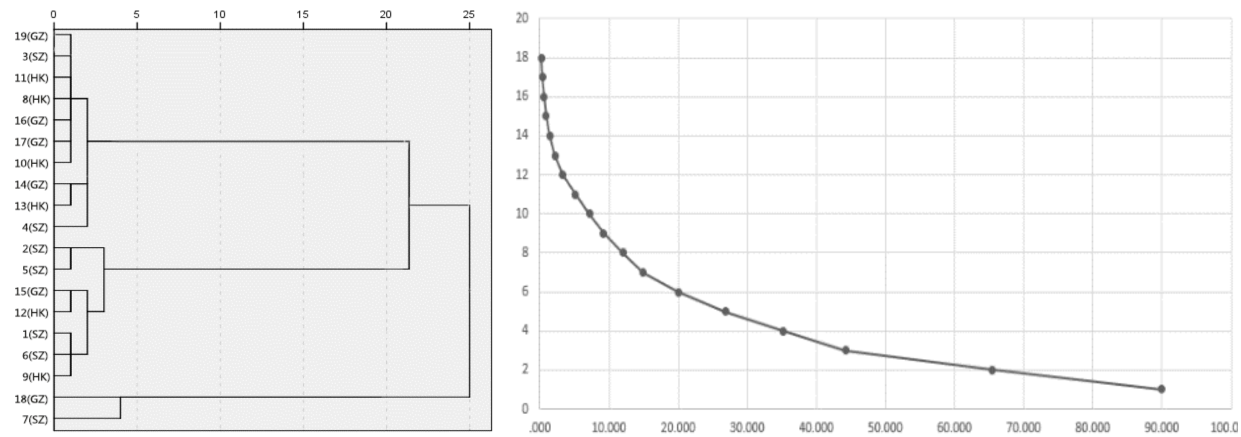
In spite of spatial form, other physical factors from visual and acoustic environment are also crucial in influencing aural and visual comfort in a metro commercial space. Based on the Phase I works, 19 typical spatial protypes of metro commercial spaces were chosen in the Phase II study. They were chosen according to the different spatial protypes existing in each city. The Phase II focused on collecting data of the acoustic and visual environment for further analyses. In the Shenzhen and Hong Kong, 7 and 6 typical metro commercial spaces due to spatial protypes were measured as illustrated in the previous study [14]. Using the same way, 6 typical metro commercial spaces reflecting spatial protypes in Guangzhou have been made in-situ measurements. In the Phase II, 5 visual environmental factors, V1-saturation, V2-brightness, V3-roughness, V4-aspect ratio and V5-illuminance have been measured, and 2 acoustic environmental factors, A1-sound level and A2-sound source have been measured. The V1and V2 were extracted from panoramic pictures by Color Impact software. The V3 was obtained by extracting the proportion of different materials of the facade. The V4 and V5 were collected through directly measurement. The A1 and A2 were got through in-situ recording [15]. Table 2 shows all values of the acoustic and visual environmental factors of the 19 typical cases extracted from the Phase I study in the Shenzhen, Hong Kong, and Guangzhou.

Table 2: Acoustic and visual environmental factors in the 19 typical metro commercial spaces

Case	City	Spatial Protype	V1	V2	V3 %	V4	V5 lx	A1 dB(A)	A2
1	Shenzhen	SP 1	7.74	44.03	44.80	0.67	283.80	75.40	2
2	Shenzhen	SP 3	9.03	41.13	64.40	0.50	357.80	75.90	3
3	Shenzhen	SP 4	10.37	41.08	29.00	0.67	187.40	69.50	2
4	Shenzhen	SP 4	7.54	41.99	49.10	1.67	680.40	67.60	2
5	Shenzhen	SP 4	19.15	46.07	57.10	0.83	277.00	71.90	3
6	Shenzhen	SP 6	6.38	43.01	49.20	0.25	661.60	77.60	2
7	Shenzhen	SP 7	8.86	49.61	43.40	0.33	17783.00	68.60	1
8	Hong Kong	SP 1	4.89	40.98	34.90	0.67	346.90	70.70	2
9	Hong Kong	SP 2	5.64	45.05	36.38	0.67	205.80	73.60	3
10	Hong Kong	SP 3	4.59	44.79	16.93	1.00	410.30	71.40	2
11	Hong Kong	SP 8	8.96	34.60	23.14	0.75	201.60	70.20	2
12	Hong Kong	SP 6	14.43	26.37	33.04	0.25	408.70	74.60	2
13	Hong Kong	SP 6	5.06	42.42	23.48	0.25	244.70	65.70	3
14	Guangzhou	SP 1	3.80	34.36	28.78	0.33	264.14	68.00	3
15	Guangzhou	SP 3	13.34	46.15	19.38	0.60	426.30	76.10	3
16	Guangzhou	SP 5	7.69	49.12	12.56	0.62	306.30	69.90	2
17	Guangzhou	SP 6	8.23	42.84	18.95	0.25	133.52	68.20	2
18	Guangzhou	SP 7	11.02	59.29	28.30	0.50	39600.00	61.00	1
19	Guangzhou	SP 8	7.75	47.09	17.89	0.33	255.46	65.30	2

From the Table 2, it is found that to the spatial protypes, the plan of point, the section of single floor, and the connection of inside the station, usually have a lower V1-saturation. To the other visual environmental factors, there is no regular variation in terms of the spatial protypes. To the acoustic environmental factors, Table 2 shows that the indirect connection spatial protypes usually have a lower A1-sound level.

Although there are 8 spatial protypes concluded to all the 103 metro commercial spaces, each one has its own acoustic and visual environmental characteristics. In order to extract typical models standing for various visual and acoustic environments, cluster analysis have been done to the all Phase II study cases as they reflected 8 spatial protypes. Figure 1 shows classification of various visual and acoustic environments due to the 8 typical spatial protypes of a metro commercial space. Three classifications could be got as the Figure 1 (b) shows that 3 is the rapid changing point in the whole distance variation chart. The result means that three visual and acoustic environment models could be concluded. The Figure 1 (a) describes the details of classification of the 19 metro commercial spaces. It can be seen that one acoustic and visual environmental model including 10 cases, one including 7, and one including 2.



(a) Rescaled distance cluster combine (b) Distance variation chart in classification stages

Figure 1: Classification of visual and acoustic environments to the 19 metro commercial spaces

2.3. The Phase Ⅲ to conduct social surveys

The Phase III is going to extract subjective evaluations of aural and visual comfort through social surveys. As the 19 study cases in the Phase II reflecting the various situations of the visual and acoustic environments to the 8 typical spatial protypes, the study cases for conducting social surveys are from the Phase II. According to the cluster analysis to the 19 Phase II cases, three typical audio-visual environment models could be got that reflects various situations of the acoustic and visual environments. The Table 3 shows the kinds of the spatial protypes (SP) and the acoustic and visual environmental models (EM) of the 19 study cases, and also the city which cases belong to. It can be seen that the EM 1 includes 10 cases, which belong to the SP1, 3, 4, 5, 6 and 8. EM2 includes 7 cases, which belong to the SP1, 2, 3, 4 and 6. EM3 includes 2 cases, which both belong to the SP7. In order to conduct social surveys in the metro commercial space, 12 of 19 study cases were selected in the Phase III as they standing for all situations of spatial protypes (SP) and the acoustic and visual environments (EM). Eventually, 4 cases have been selected in each city, which are the Case 1, 3, 6, 7, 8, 9, 10, 11, 15, 16, 17 and 18.

The way of conducting social surveys in the Guangzhou is the same as in the Shenzhen and Hong Kong [14], however, a slight difference has been made to the questionnaire in the Guangzhou survey. In the Guangzhou social survey, a question of mixing perception from both the aural and visual was asked that was not included in the Shenzhen and Hong Kong survey. Originally, 4 study cases have been chosen in each of the three cities, but the in-situ surveys were not permitted in 2 of the Hong Kong study sites. However, laboratory experiments to elicit subjective evaluations of aural and visual comfort to the 8 Shenzhen and Hong Kong study cases have also been made in the previous study [14]. And, the subjective evaluations of the laboratory and in-situ have already been compared in the previous study, which has been found that there is no significant difference between two. Therefore, the subjective evaluations of aural and visual comfort obtained in the laboratory will be used to the two Hong Kong cases without in-situ surveys. Totally, 540 responds of aural and visual comfort have been collected, 240 from the Shenzhen, 180 from the Hong Kong, and 120 from the Guangzhou.

Table 3: The spatial protypes, locations and environmental models of the 19 study cases

Case	Spatial protype	Study City	Selected case in the Phase III	Model of acoustic and visual environment		
				1	2	3
1	1	Shenzhen	√		√	
2	3	Shenzhen			√	
3	4	Shenzhen	√	√		
4	4	Shenzhen		√		
5	4	Shenzhen			√	
6	6	Shenzhen	√		√	
7	7	Shenzhen	√			√
8	1	Hong Kong	√	√		
9	2	Hong Kong	√		√	
10	3	Hong Kong	√	√		
11	8	Hong Kong	√	√		
12	6	Hong Kong			√	
13	6	Hong Kong		√		
14	1	Guangzhou		√		
15	3	Guangzhou	√		√	
16	5	Guangzhou	√	√		
17	6	Guangzhou	√	√		
18	7	Guangzhou	√			√
19	8	Guangzhou		√		
Total			12	10	7	2

3. RESULTS

Using data collected in the field study, correlation analyses of various factors of the acoustic and visual environments on aural and visual comfort were made using SPSS software [15]. To the all 12 study cases, using 540 samples to make the Pearson correlation analyses, the results of various physical factors of the acoustic and visual environments on the subjective comfort evaluations can be got as shown in the Table 4. It has to be noted that the evaluation of audio-visual comfort in the Table 4 means the mixing perception from both the aural and visual that is not asked in the Shenzhen and Hong Kong. In order to get the evaluation of audio-visual comfort to the Shenzhen and Hong Kong cases, a regression equation was developed using the Guangzhou data as shown in below,

$$y = 0.463x_1 + 0.134x_2 + 0.298x_3 + 0.165x_4 \tag{1}$$

where y is the evaluation of audio-visual comfort in a metro commercial space, x_1 is the evaluation of visual comfort, x_2 is the evaluation of lightness perception, x_3 is the evaluation of subjective quietness and x_4 is the evaluation of intelligibility. And then the audio-visual comfort evaluations of the Shenzhen and Hong Kong have been got and analyzed combined with that of the Guangzhou. From the Table 4, it is found that the correlation coefficient value of the acoustic and visual environmental factors on the aural and visual comfort is rather low although many reached a significance. A reason might be from differences of spatial protype as it is also an important visual environmental factor that was not taken as a physical factor in the Table 4.

Table 4: Pearson correlation between the acoustic and visual environmental factors and comfort in metro commercial spaces

Subjective evaluation	V1	V2	V3	V4	V5	A1	A2
Visual comfort	-0.17**	-0.06	-0.09*	0.05	0.18**	-0.14**	-0.11**
Aural comfort	-0.12**	0.10*	-0.08	-0.05	0.08	-0.10**	-0.06
Audio-visual comfort	-0.17**	0.05	-0.04	-0.01	0.17**	-0.12**	-0.13**

Note: 1. V1-Saturation; V2-Brightness; V3-Roughness; V4-Aspect ratio; V5-Illuminance; A1-Sound level; A2-Sound source.
2. **. Correlation is significant at the 0.01 level； *. Correlation is significant at the 0.05 level

3.1. Influencing factors on the visual comfort

The Table 4 shows that a positive significant correlation of the V5 on the visual comfort exists whereas other significant correlations of the V1, V3, A1 and A2 on the visual comfort are negative. As the correlation coefficient values were relatively low, further analyses taken spatial protype into account have been made as shown in Table 5. As the study samples for each spatial protype are not equal due to existing frequency in the study cities, correlation analysis of the V4 on visual comfort is not always available in terms of spatial protype due to the choosing limitation of the social surveys.

Table 5 ：Pearson correlation of the acoustic and visual factors on visual comfort in terms of SP

SP	Description	V1	V2	V3	V4	V5	A1	A2
1	P-SF-Inside the station	-0.48**	-0.49**	-0.48**	/	0.48**	-0.37**	0.03
2	L-SF-Inside the station	-0.33	-0.19	-0.15	/	0.35	-0.22	0.10
3	L-SF-Direct connection	-0.72**	-0.67**	-0.67**	0.73**	0.13	-0.40**	-0.49**
4	L-MF (no atrium)-Direct connection	-0.23	-0.27**	-0.25	-0.11	-0.11	0.10	-0.08
5	S-SF-Direct connection	-0.35	-0.42*	-0.44*	/	0.13	-0.19	-0.28
6	S-MF (no atrium)-Direct connection	0.06	0.12	-0.13	0.13	-0.12	-0.12	-0.01
7	S-SF-Indirect connection	-0.18	-0.17	0.14	-0.15	-0.06	-0.24*	0.04
8	S-MF-Indirect connection	-0.14	-0.01	-0.27	-0.06	0.18	-0.23	-0.01

Note: 1. SP-Spatial protype; P-Point; L-Linear; S-Square; SF-Single floor; MF-Multiple floors
2. V1-Saturation; V2-Brightness; V3-Roughness; V4- Aspect ratio; V5-Illuminance; A1-Sound level; A2-Sound source.

From the Table 5, it is found that the acoustic and visual environmental factors influencing the visual comfortable evaluation is quite different due to the different spatial protypes (SP) of metro commercial spaces. All the acoustic and visual environmental factors have no significant influence on the visual comfort to the SP2, 6, and 8. However, many factors significantly influence the visual comfort to the SP1 and 3. To the SP1, it can be seen that except A2-sound source, all other factors are significantly correlated with the visual comfortable evaluation most with a negative correlation, whereas to the SP3, that except V5-illuminance, all others are significantly correlated with the visual comfort also most are negative. To the other spatial protype SP4, 5 and 7, a few significant correlations exist between the acoustic and visual environmental factors and the visual comfort, in which only one exists in the SP4 and 7 while only two in the SP5. A reason of the significant difference exists for factor influencing visual comfort in terms of spatial protype might be related with the spatial protype itself. In terms of the plan variation of spatial protype, there are very less significant influencing factor existing in the plan of square, however, there are more in the point plan. To the same plan and connection of the spatial protype, the SP3 exists many significant influencing factors whereas the SP4 only has one. To the same plan and section of spatial protype, the SP2 exists none significant influencing factor whereas the SP3 has many. Above results present that the spatial protype is important in influencing the visual comfort.

Further analyses in the Table5, it is found that the V2-brightness, the V3-roughness, and the A1-sound level are the main factors influence on the visual comfortable evaluation, whereas the V4-aspect ratio, the V5-illuminance, and A2-sound source are less influence on the visual comfortable evaluation although there is not enough cases in the V4. To the SP1, there is positive correlation of the V5 to the visual comfort while negative of the V1, V2, V3 and A1. Similar as the SP1, the V1, V2, V3 and A1 also are negatively correlated with the visual comfort to the SP3. Besides, a more negative significant factor to the visual comfort is the A2. However, the positive significant correlation with visual comfort to the SP3 is the V4 different from that to the SP1. An interesting found is that V5 is the only significant factor that occurs in the SP1, which spatial protype is the point single floor inside the metro station. This might be related with rather smaller proportions of the shops in the whole space of the station hall, as higher illuminance would attract peoples notice to the shops that have function sparkling the station which is usually empty. Another interesting finding is that only in the SP3, the sound source (A2) is the significant influencing factor. In-situ observation found that except the SP3 metro commercial spaces, sound sources are rather less in others. To the metro commercial spaces with the spatial protype of the linear single floor direct connection, many eating shops exist bringing out various kinds of sounds.

Comparing all the spatial protypes of the Table 5, it is obvious that the plan variation is important related with the factors influencing the visual comfort. Hence, Table 6 analyzed the visual comfort in terms of the plan variation. It shows that the visual comfort of the square metro commercial spaces is the best with a 5.46 evaluation value, whereas that of the linear is the worst with a 4.93 evaluation value. It is assumed that the square form provides a broad wide vision that preferred by most people.

Table 6: Evaluation of the aural and visual comfort in terms of the plan variation

	Point	**Linear**	**Square**
Evaluations of visual comfort	5.08	4.93	5.46
Evaluations of aural comfort	4.01	4.16	4.69
Evaluations of audio-visual comfort	4.61	4.47	5.02

The significant influencing factors of the SP2 and 3 are still in difference although they are in the same plan form, it might be related with the different section forms and connection ways. Therefore, Figure 2 compared the visual comfort in terms of the variation of section and connection under the same plan form. It shows that, for the metro commercial space in the plan of square, the visual comfort of indirect connection is better than that of direct connection. This might be related with a much wider vision existing in the indirect connection metro commercial space, and a lower sound level in such a space which is far away from the station hall. For the metro commercial space in the plan of linear, the visual comfort evaluation of single floor is better than that of multiple floors. The phenomena may be caused by the existing narrow space in the multiple floors of linear metro commerce. All in all, when the vision of space is wide enough, the details such as saturation, brightness and other acoustic and visual environmental factors would be ignored, and the spatial protype becomes the most significant influence factor on the visual comfort in a metro commercial space.

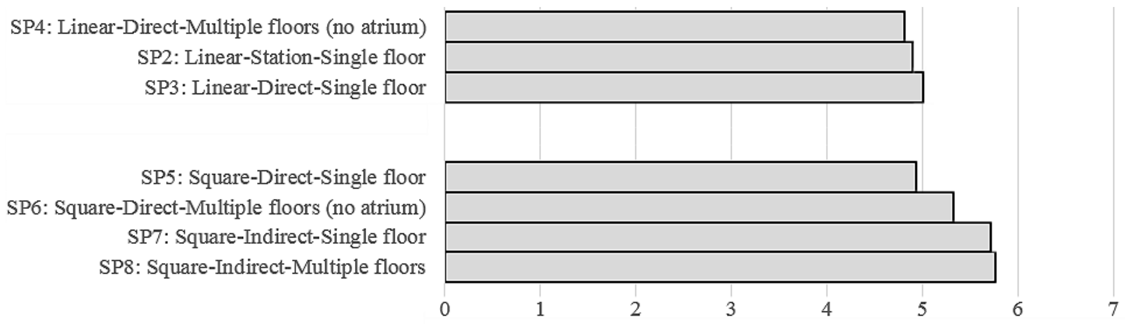


Figure 2: Comparison of the visual comfort in terms of the section and connection way

3.2. Influencing factors on the aural comfort

To factor influencing the aural comfort, there are also low coefficient value of all the factors on subjective evaluation as shown in the Table 4 although some significances exist of the V2-brightness, V1-saturation, and A1-sound level either positive or negative. This might be because the spatial protype (SP) has not be considered in the Table 4 which is the same as visual comfort analyses. In order to know the influence of SP, Table 7 presents analyses results of Pearson correlations of the acoustic and visual environmental factors on aural comfort in terms of spatial protypes.

Table 7：Pearson correlation of the acoustic and visual factors on aural comfort in terms of SP

SP	Description	V1	V2	V3	V4	V5	A1	A2
1	P-SF-Inside the station	-0.18	-0.20*	-0.18	/	0.17	-0.36**	-0.03
2	L-SF-Inside the station	0.18	-0.30	-0.32	/	0.15	-0.54**	-0.06
3	L-SF-Direct connection	-0.44**	-0.40**	-0.43**	0.45**	0.15	-0.26**	-0.44**
4	L-MF (no atrium)-Direct connection	-0.09	-0.07	-0.03	0.05	0.05	-0.05	-0.14
5	S-SF-Direct connection	-0.06	-0.04	-0.08	/	0.15	-0.08	-0.24
6	S-MF (no atrium)-Direct connection	-0.03	0.10	-0.06	0.07	-0.07	-0.04	-0.13
7	S-SF-Indirect connection	0.05	0.08	-0.10	0.09	-0.19	-0.19	0.15
8	S-MF-Indirect connection	-0.14	-0.02	-0.18	-0.08	0.20	-0.46**	0.14

Note: 1. SP-Spatial protype; P-Point; L-Linear; S-Square; SF-Single floor; MF-Multiple floors
2. V1-Saturation; V2-Brightness; V3-Roughness; V4- Aspect ratio; V5-Illuminance;
A1-Sound level; A2-Sound source.

From the Table 7, it is found that less significant factors existing comparing to the visual comfort. Similar as the visual comfort, significant influence of the acoustic and visual factors on aural comfort are rare to the metro commercial spaces of a square plan e.g. SP5, 6, 7 and 8. Although the significant influence of various factors on the aural comfort is less to the metro commercial spaces of point protype, it is still more than the square ones. In fact, factor influencing the aural comfort is not reaching significance to all the spatial protypes except the SP3 as can be seen in the Table 7. However, a slight difference between the point spatial protype and the square can be found. More significant influencing factors have been found in the point protype. Further calculation of mean value of the aural comfort shown in the Table 6 illustrates that the square protype metro commercial spaces have the highest evaluation value whereas the point has the lowest indicating that the square ones usually have better aural comfort than the point no matter variations of the other factors. To the metro commercial spaces with a linear plan, the situation is rather complicated. To them, the section and connection seem to play more roles. Figure 3 shows that the aural comfort evaluations of the linear protype metro commercial spaces, it is found that the multiple floor (SP4) has the lowest evaluation although the value is close to another single floor (SP2). Therefore, it assumed that the connection way of the station and commercial space also plays rather important role if comparing the aural comfort evaluation of the SP2 and SP3.

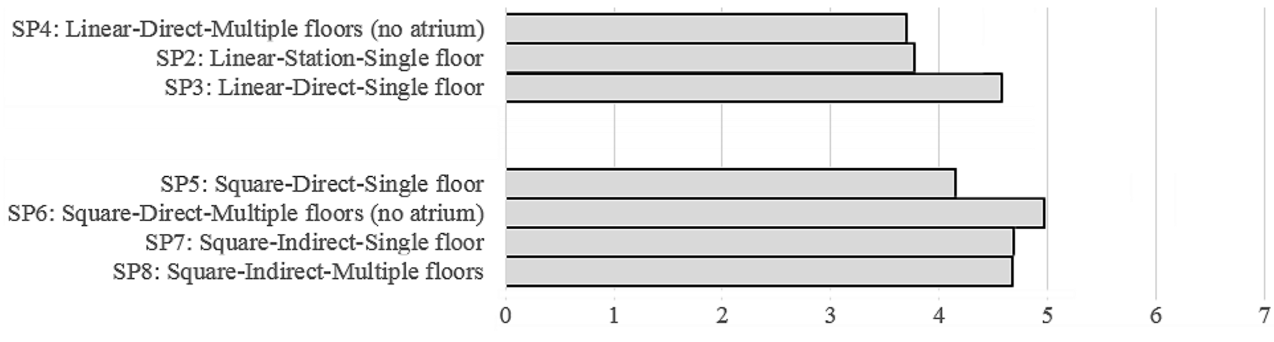


Figure 3: Comparison of the aural comfort in terms of the section and connection way

Given a consideration of each acoustic and visual environmental factor influence on the aural comfort, it is found that the factor of A1-sound level has relatively more influence on the aural comfort, which is usually negative indicating with a higher sound level, the aural comfort is lower. But the other factors have barely influence with only few significances as shown in the Table7, which generally means that physical factors of the acoustic and visual environments are less important to influence the aural comfort of a metro commercial space. However, if taking the spatial protype into account, many factors might significantly influence the aural comfort as shown in the SP3. To the SP3, negatively correlated with evaluation. To the metro commercial spaces with SP3, all factors except the V5-illuminance are significantly influence the aural comfort, and almost with a negative correlation. Only the V4-aspect ratio has a positive correlation.

3.3. Influencing factors on the audio-visual comfort

Many studies have pointed out that there is a close interaction of aural and visual comfortable perception [13, 15]. In order to investigate the comprehensive feeling of aural and visual together, a comparison of the factors influence on the aural and visual comfort has been made as in the Table 4. It can be seen that the acoustic environmental factor, sound level and source, have significant influence on the visual comfort, while the visual environmental factors, saturation and brightness, have significant influence on the aural comfort. The results proved close relationship of aural and visual again.

Therefore, this study furtherly explored subjective evaluation of the audio-visual comfort as shown in the Table 4. It is found that the acoustic environmental factor, sound level and source, and the visual environmental factor, saturation and illuminance, are significant influence on the audio-visual comfort although with a low correlation coefficient. Consistently, Pearson correlations are also made to the audio-visual comfort in terms of spatial protypes as shown in the Table 8. Generally speaking, there are less significant influence of the acoustic and visual environmental factors on the audio-visual comfort to the metro commercial spaces with a square plan except the SP5. On the opposite, there are many significant influence factors to the point plan ones. The result is quite similar as the visual comfort shown in the Table 5. To the metro commercial spaces with a linear plan, a similar result can also be got to the audio-visual comfort as the visual comfort.

Table 8 ∶ Pearson correlation of acoustic and visual factors on audio-aural comfort in terms of SP

SP	Description	V1	V2	V3	V4	V5	A1	A2
1	P-SF-Inside the station	-0.41**	-0.42**	-0.41**	/	0.41**	-0.38**	0.06
2	L-SF-Inside the station	-0.15	-0.13	-0.12	/	0.32	-0.17	0.21
3	L-SF-Direct connection	-0.58**	-0.53**	-0.57**	0.60**	0.02	-0.35**	-0.53**
4	L-MF (no atrium)-Direct connection	-0.21	-0.22	-0.18	-0.03	-0.04	0.02	-0.07
5	S-SF-Direct connection	-0.68**	-0.61**	-0.56**	/	0.08	-0.02	-0.12
6	S-MF (no atrium)-Direct connection	-0.02	0.08	-0.05	0.05	-0.06	-0.04	-0.12
7	S-SF-Indirect connection	0.04	0.07	-0.10	-0.15	0.09	-0.21	0.08
8	S-MF-Indirect connection	-0.16	0.02	-0.23	-0.08	0.23	-0.35	0.11

Note: 1. SP-Spatial protype; P-Point; L-Linear; S-Square; SF-Single floor; MF-Multiple floors
2. V1-Saturation; V2-Brightness; V3-Roughness; V4- Aspect ratio; V5-Illuminance; A1-Sound level; A2-Sound source.

Due to the plan influence on the audio-visual comfort evaluation as demonstrated above, the Table 6 also gave the mean evaluation values of audio-visual comfort according to the plan variation. It is found that to the audio-visual comfort, the metro commercial spaces with a square plan have the highest value but the linear ones have the lowest, which is the same as the visual comfort. In the Table 8, it is also found that differences can also be made due to variation of the section and the connection way. Figure 4 presents the audio-visual comfort in terms of the variation of section and connection way to the linear plan. It can be seen that in terms of the section variation, the single floor ones have slightly better audio-visual comfortable evaluation than the multi-floor ones, while in terms of the connection way, the direct connection ones have better evaluation than those inside the station ones.

Further analyses of each acoustic and visual environmental factor influence on the audio-visual comfort as shown in the Table 8, it is found that the V1-saturation, V2-brightness, V3-roughness and A1-sound level have relatively more influence on the audio-visual comfort, which are all negative indicating the audio-visual comfort would be worse if these factors have a higher value. To the other factors, only a few significances has been found. However, if taking the spatial protype into account, more significant influencing factors could be found in the SP1 and SP3. To the SP1, besides V1, 2, 3 and A1, the V5-illuminance significantly influences the audio-visual comfort with a positive correlation. To the SP3, besides V1, 2, 3 and A1, V4-aspect ratio and A2-sound source significantly influence the audio-visual comfort.

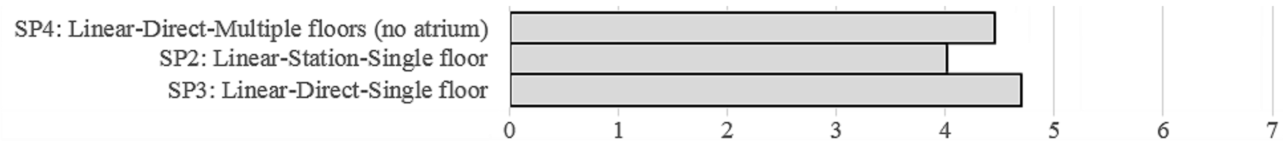


Figure 4: Comparison the audio-visual comfort of in terms of the section and connection way

4. DISCUSSION

From analyses of the section 3, the acoustic environmental factors have been found that could significantly influence the visual comfort evaluation while the visual environmental factors could significantly influence the aural comfort evaluation. The evaluation of audio-visual comfort could be significantly influenced by either the acoustic or the visual environmental factors. In order to clarify the correlation between aural and visual comfort and co-perception of both, the Table 9 presents Pearson correlations of the evaluations of visual, aural, and audio-visual comfort. Apparently, they are all closely correlated as the correlation coefficients are approx. above 0.5 and all significant. All of them has a positive correlation indicating better visual comfort enhancing aural comfort and vice versa. In the Table 9, it can also be seen that the audio-visual comfort is closer to the visual comfort than the aural comfort, however, the correlation coefficient of the audio-visual comfort and the aural comfort still reaches a high value of 0.64.

Table 9 ：Pearson correlation between visual comfort, aural comfort and audio-visual comfort

	Visual comfort	**Aural comfort**	**Audio-visual comfort**
Visual comfort	1	0.49**	0.75**
Aural comfort	0.49**	1	0.64**
Audio-visual comfort	0.75**	0.64**	1

**. Correlation is significant at the 0.01 level; *. Correlation is significant at the 0.05 level

As the field study has been carried out in three metropolises, subjective evaluations of the aural and visual comfort to these three cities are then compared as shown in the Figure 5. It can be seen that the Hong Kong has the highest visual comfort evaluation while the Guangzhou has the lowest although the value is close to the Shenzhen. To the aural comfort evaluation from the highest to the lowest is the Guangzhou, Hong Kong, and Shenzhen, however, the evaluation value is close of the three cities varied from 4.2 to 4.5. To the evaluation of audio-visual comfort, the Guangzhou has a higher value than the Shenzhen and Hong Kong with a slight difference. It is obvious that the differences of the aural and visual comfort in the three study cities are quite small except the Hong Kong has clearly better visual comfort evaluation. A reason of the Hong Kong has better visual comfortable evaluation might be related with having good acoustic and visual environmental factors due to the development principles of the metro commercial entities. In addition to visual comfort, there is no much difference of the aural and audio-visual comfort in the three study cities.

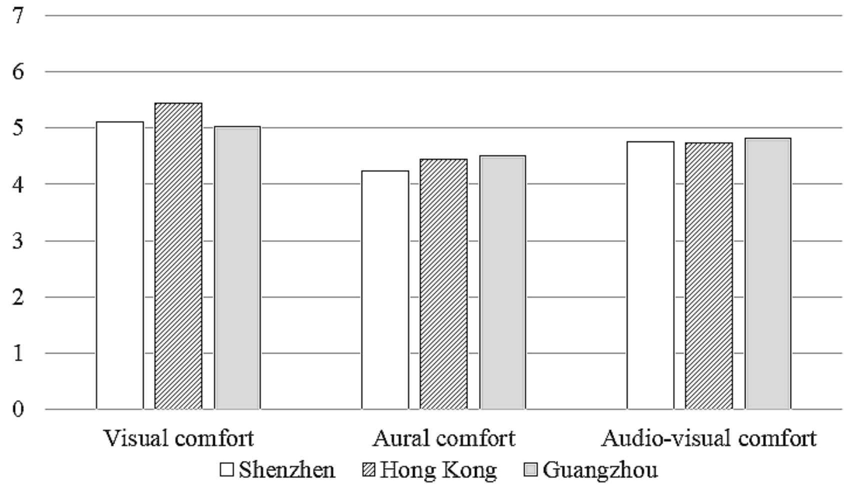


Figure 5: Evaluations of comfort in metro commercial spaces of three metropolises

5. CONCLUSION

In order to improve the aural and visual comfort of a Chinese metro commercial space, study of investigating the acoustic and visual environmental factors on the aural and visual comfort has been intensively made. Totally, 103 metro commercial spaces in the metropolises, Shenzhen, Hong Kong, and Guangzhou, have been explored, and 12 typical spaces reflecting variations of the plan, section, and connection way of the commercial space and the station, have been thoroughly studied. The results present that the subjective evaluation of aural, visual, and audio-visual are significantly correlated. A close positive correlation exists between them meaning that a good visual perception could improve aural perception and vice versa. The audio-visual perception is related with the visual perception more while the aural is still significant. A good audio-visual perception comes from good visual as well as good aural perception.

The result has found that the spatial protype has some influence on the aural and visual comfort. Usually, the metro commercial spaces with a square plan have better aural and visual comfort. To those with a point plan, the acoustic and visual environmental factors would play a role in determining the aural and visual comfort. To the section and connection way difference, the situation is complicated. To all the likely influence factors, it is noted that the visual environmental factors, saturation and roughness, have more negative influence on the visual and audio-visual comfort, whereas the illuminance has more positive influence. To the acoustic environmental factors, sound level and sound source have more negative influence on the visual comfort, aural comfort and audio-visual comfort. The results present that except the illuminance, all other acoustic and visual environmental factors are negatively correlated with the aural and visual comfort, indicating a low value of these factors is better to improve the aural and visual comfort of a metro commercial space.

6. ACKNOWLEDGEMENTS

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