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Noise pollution survey of a two-storey intersection station in Tehran metropolitan subway system

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Abstract According to the world population increase and demand on transportation in mega cities, modern and low-cost technologies are remarkably considered. Meanwhile, subway system, as a means to transfer a large population of people, is extremely welcomed due to its particular advantages including time and cost savings, traffic jam avoidance, and unaffected by weather. Nevertheless, despite the benefits of these technologies, such devices also have been associated with disadvantages for human. In many subway systems, noisy environments are clearly observed; therefore, workers and even the passengers are exposed to higher noise levels than permissible limit. In this research, noise measurements were performed at Imam Khomeini Station as the most crowded intersection subway station in Tehran. In this descriptive–sectional survey, the amount of noise pollution was investigated at both stories of Imam Khomeini Intersection Station. A variety of noise pollution indicators such as L_{eq} 10 min were separately measured at each storey through five measurement points from 7 A.M. to 10 P.M. It was shown that the equivalent sound level range at Imam Khomeini station towards Elmo Sanat and Imam Khomeini towards Mirdamad were between 70.56–79.54 and 68.35–79.12 dB (A), respectively. It was indicated that except for the entrance stairs to the subway waiting platform and the first section of the platform on both stories, other measurement stations have the same equivalent sound levels.

Keywords Noise pollution · Subway · Equivalent sound level · Intersection station

Introduction

Nowadays, noise pollution is considered among serious environmental risks. Exposure to noise levels higher than permissible limits results in a

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decrease in worker's quality, wasting time, job stress, and dissatisfaction (Gershon et al. 2005). Hearing impairment, annoyance, sleep disturbance, and hypertension are considered among the other adverse effects of noise exposure. Stress hormones such as adrenalin and noradrenalin associated with noise have the potential to enhance the incidence risk of diseases, e.g., cardiovascular diseases (Ko et al. 2011). Some epidemiological studies have shown an increase in the blood pressure as a result of exposure to chronic noise (Ni et al. 2007; Stansfeld and Matheson 2003). Most evidence suggests that the blue-collar workers exposed to sound level equal to (L_{eq} 8 h $\geq$ 80 dB (A)), have a greater risk for accidents (Picard et al. 2008). Also, according to statistics published in the USA, 11 million Americans are exposed to sound levels with damaging potential. In this country in 1990, 200 million dollars indemnity was paid in this case (Rachiotis et al. 2006), and it was estimated that 600 million workers were exposed to noise pollution (Ferrite and Santana 2005).

According to the world population increase and demand on transportation in mega cities, modern and low-cost technologies are remarkably considered. Meanwhile, subway systems as a means of transporting people are extremely accepted considering its special condition such as time and cost saving, traffic jam avoidance, and unaffected by

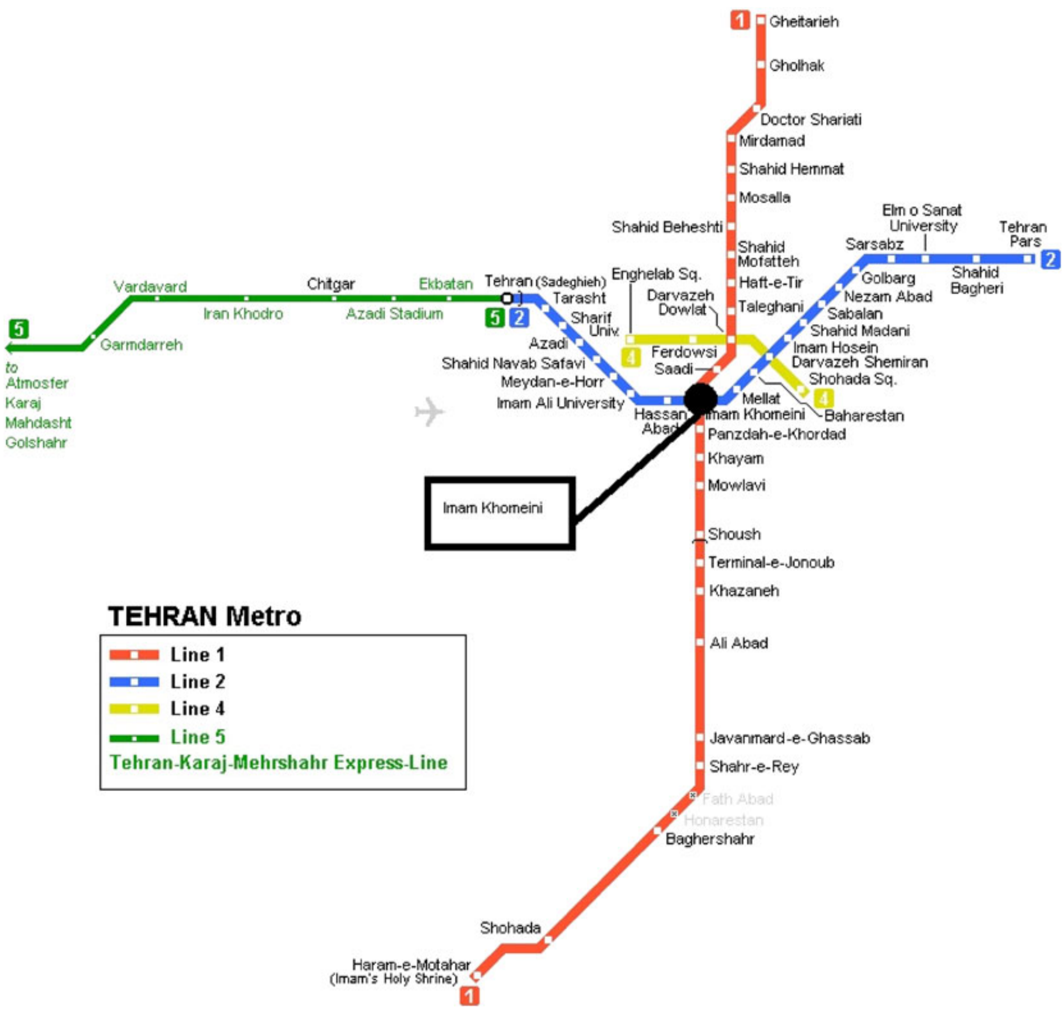

Fig. 1 The map of Tehran subway stations and lines (Imam Khomeini Intersection Station is displayed using a *black point*)

weather. In spite of advantages of this technology, it has some negative points as well. This means might be associated with great risks including physical risks (noise, vibration, electromagnetic radiation, electric sources hazard, and high temperature), biological risks (contagious disease transmission through person to person), chemical risks (exposure to toxic chemicals or allergens, metals, gas emissions, and fumes), and physiological risks (violence and psychological stress caused by work; Gershon et al. 2005).

In most subway systems, especially the older ones, noisy environments can be observed distinctively. It is not only because of the noise caused by rail transportation systems but also as a result of the sound reflection in an indoor environment. Thus, workers and even passengers exposed to noise at higher levels than standard limits are faced with more risks owing to the extra time they spend in such noisy environment. Hence, problem assessment and applicable action plans to control the harmful effects have become issues of immediate concern for community as it was evidenced by the large number of anti-noise laws, ordinances, and regulations decreed by many governments (Piccolo et al. 2005). Thus, awareness of equivalent sound level in the subway environment is the first stage to present new remedy for this dilemma and then to have a precise judgment for the case study using scientific principles.

Material and method

Tehran is the capital of Iran with a population of approximately nine million people during days and seven million inhabitants at night. The subway system of Tehran with five lines is the busiest means of public transportation wherein four lines are opened and one line is currently under construction. Figure 1 shows the map of lines and stations of the subway in Tehran. Line 1 connects the north of Tehran (Tajrish Square Station) to the south (Imam Khomeini Shrine Station) and has a length of 29.3 Km. Line 2, with 26.4 Km length, connects eastern part of Tehran (East Terminal Station) to the west (Sadeghieh Station). Both lines included the main part of Tehran subway system pass similarly from a two-storey station called Imam Khomeini Intersection Station, the most crowded station in Tehran.

This descriptive–sectional survey was conducted at a two-storey intersection station, Imam Khomeini Station, in winter 2010. Noise measurements were individually performed at each storey of the station. This interchange station is totally considered as a group and each storey is referred to a separate sub group. In other words, Imam Khomeini Station toward Mirdamad Station is referred to subgroup 2 (the first storey) and Imam Khomeini Station toward Elmo Sanat Station is referred to subgroup 1 (the second storey). Each

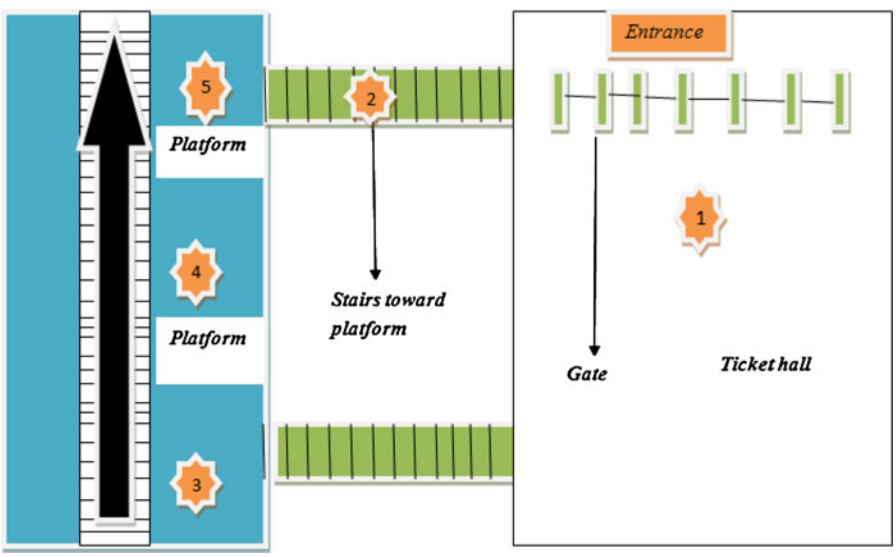

Fig. 2 Noise measurement points map at Imam Khomeini Intersection Station

Table 1 The equivalent sound level (L_{eq} 10 min) of subgroup 1 over 15 measurement intervals during day

Points	1	2	3	4	5[a]
$L_{Aeq(10\,min)}$ (dB (A))					
Mean	70.56809	70.85426	78.88335	78.73164	79.54379
SD	2.794433	2.506695	1.410107	1.295787	1.520637
Higher limit	76.15696	75.86765	81.70357	81.32322	82.58506
Lower limit	64.97923	65.84087	76.06314	76.14007	76.50251

[a]Points of each subgroup are clarified in Fig. 2

storey has the same parts including ticket hall, entrance stairs, and waiting platforms.

Tehran subway system has two types of trains including AC (new trains) and DC (older trains). These two types of train pass through the Imam Khomeini Intersection Station regularly. The under-investigated station, with an enclosed area of approximately 10,223 m^2, has five entrances including: (1) Bab Homayoon, (2) Sepah, (3) Lalezar, (4) Ferdowsi, and (5) Khayam Entrances in which all entrances have typically the same constructions.

Each storey was divided into three different measurement areas: first area (point number 1) refers to the ticket hall where the passengers pass through the gates to enter into the platform. Second area (point number 2) indicates the stairs that join the ticket hall area with station platform and the third area includes the waiting platform (point numbers 3, 4, and 5). Note that in this station, the second storey has fewer stairs than the first one. In each waiting platform of each storey, measurements were conducted at three different points. These points include the front end (point number 3), the middle section of the platform (point number 4), and the rear end (point number 5). Hence, five distinct measurement points were considered at each storey. Figure 2 presents the noise measurement points at Imam Khomeini Intersection Station briefly. Note that as the measurement points were the same in both subgroups of Imam Khomeini Intersection Station, only one subgroup was illustrated in Fig. 2.

In this survey, the CELL 450 meter, a digital sound level meter (SLM) accompanied by an analyzer, was used to measure the noise levels. At the beginning and at the end of each data collection day, the SLM was calibrated according to the instructions of meter manufacturer (Cell-101/1). Also, a windscreen was used in all stages of data collection and measurements.

Based on the previous studies, an equivalent sound level of 10 min/h was considered for the noise measurement period (Golmohammadi 2006). Measurements were hourly performed in each subgroup from 7 A.M. to 22 P.M. (Aly 2005). In other words, every point of each subgroup was measured 15 times during day. In case of waiting platform noise measurements, the SLM was approximately placed at 1 m away from the ground (3 ft) and about 0.5 m (1.5 feet) far from the edge of platforms (Gershon et al. 2006). The statistics analysis (SPSS Version 16) was used to compare all of the measurement values. The ANOVA test (one-way) and Independent Samples Test were, respectively, applied to compare the measured areas within one storey (between the five points existed in one storey) and two stories (between measurements in both stories).

Results

In this survey, the equivalent continuous sound pressure level (L_{eq}) is the most remarkable

Table 2 The equivalent sound level (L_{eq} 10 min) of subgroup 2 over 15 measurement intervals during day

Points	1	2	3	4	5
$L_{Aeq(10\,min)}$ (dB (A))					
Mean	70.62904	68.35502	77.46588	78.37561	79.12967
SD	1.649782	0.511398	2.448187	3.883186	1.784018
Higher limit	73.9286	69.37781	82.36226	86.14198	82.69771
Lower limit	67.32947	67.33222	72.56951	70.60924	75.56164

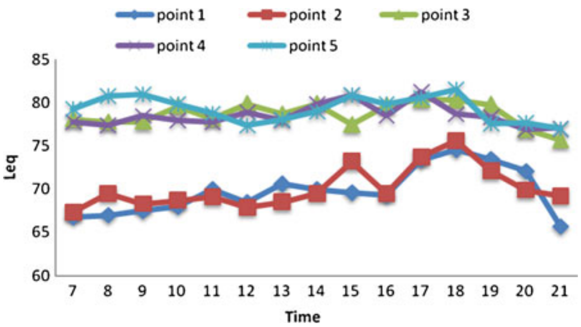

Fig. 3 The equivalent sound level (L_{eq} 10 min) at different hours in subgroup 1

parameter that would be discussed. However, the following factors related to noise pollution were also measured at which the results are shown in detail in Table 3.

LAS $_{min}$	Minimum value of SPL
LAS $_{max}$	Maximum value of SPL
LZpk	Peak sound level
LEP	The normalized equivalent sound level for an exact period of hour or minute
LAE	Noise exposure level
LTm3	The maximum sound level over 3 seconds
LTm5	The maximum sound level over 5 seconds
HML	C-weighting sound level - A-weighting sound level (harmonic level)

For each area, the L_{eq} of 10 min (L_{eq} 10 min) was assessed during day. As it was stated before, in each point, 15 measurements were carried out separately over a period of 15 h from 7:00 A.M. to

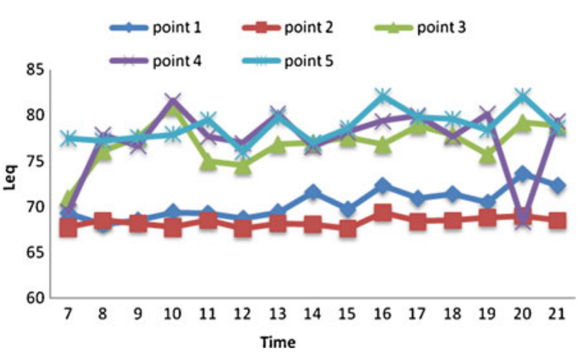

Fig. 4 The equivalent sound level (L_{eq} 10 min) at different hours in subgroup 2

Table 3 Measurement of various noise pollution indices in Imam Khomeini Intersection Station

	Measured factors	L_{eq}		LASmax		LASmin		LZpk		LAE		LEP		LTm3		LTm5		HML	
	Zones	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Subgroup 1	Mean	70.7	79	85.1	94.4	62.3	63.3	104	110.9	97.1	106.8	52.9	62.1	72.8	80.7	73.4	81.5	10.5	9.3
	SD	2.5	1.1	5.3	2.7	1.9	2.2	3.8	2.9	1.5	1.1	2	2.4	3	1.4	3.1	1.6	3.7	5.1
	Higher limit	75.6	81.3	95.9	99.8	66.2	67.8	111.4	116.7	100.2	109	57.1	67	78.7	83.6	79.7	84.7	17.8	19.6
	Lower limit	65.8	76.8	74.5	89.1	58.5	58.8	96.7	105.1	94.1	104.6	48.8	57.2	66.8	77.9	67.2	78.3	3.1	−0.9
Subgroup 2	Mean	69.6	78.4	79.6	96	64.3	67.7	100.5	110.9	97.2	106.1	58.8	61.5	71.1	80.3	71.7	81.2	10.9	9.3
	SD	1.1	1.7	3.2	5.1	0.7	5	1.8	4.5	1.2	1.8	6.7	1.8	1.3	2	1.4	2.3	3	5.3
	Higher limit	71.9	81.7	86	106.2	65.7	77.8	104.2	120	99.7	109.6	72.3	65	73.8	84.4	74.5	85.8	17	19.9
	Lower limit	67.3	75	73.2	85.8	63	57.6	96.9	101.8	94.8	102.5	45.3	57.9	68.5	76.1	68.8	76.7	4.8	−1.2

Table 4 The statistic analysis at different points of subgroup 1 during day

Multiple comparisons (Scheffel)				
Measurement points	Measurement points	Sig. (2-tailed)	95% Confidence interval	
			Upper bound	Lower bound
1	2	.992	1.8741	−2.5941
1	3	.000	−6.6792	−11.1475
1	4	.000	−6.5325	−11.0008
1	5	.000	−7.2992	−11.7675
2	3	.000	−6.3192	−10.7875
2	4	.000	−6.1725	−10.6408
2	5	.000	−6.9392	−11.4075
3	4	1.000	2.3808	−2.0875
3	5	.941	1.6141	−2.8541
4	5	.880	1.4675	−3.0008

10:00 P.M. (150 measurements in each day). The results of these measurements in subgroups 1 and 2 are shown, respectively, in Tables 1 and 2.

For each area, results of the equivalent sound level (L_{eq} 10 min) in different hours of a day from 7:00 A.M. to 10:00 P.M. for various points of subgroups 1 and 2 are illustrated in Figs. 3 and 4, respectively.

As shown in Table 3, in addition to L_{eq} 10 min, the other noise pollution criterion such as LAE, LEP, etc. were also measured on both subgroups separately. These measurements were conducted in same areas during 7:00 A.M. and 10:00 P.M. within 1-h intervals. In Table 3, “A” zone means the total measurement values of ticket hall area and the entrance stairs to the subway platform while “B” zone presents the total measurement values of the front section, the middle section, and the rear section of the waiting platform. The values of “A” zone indicate the public sound (community noise) and values of “B” zone shows the equivalent train noise at platforms.

Table 4 shows the statistic analysis at different areas of Imam Khomeini to ElmoSanat station (subgroup 1) during day. There was no significant difference between the equivalent sound level values of the first and second point ($P > 0.05$) the same relation was observed at points 3, 4, and 5 as well. However, the equivalent sound level values (P value) between point 1 and points 3, 4, and 5 similar to the values between point 2 and points 3, 4, and 5 were less than 0.05 which means there was a significant difference between these points statistically.

The statistic analysis of Imam Khomeini to Mirdamad Station (subgroup 2) has shown identical results during day. As shown in Table 5, there was no significant difference between the values of points 1 and 2 and also between points 3, 4, and 5 ($P > 0.05$). However, the values between point 1

Table 5 The statistic analysis at different points of subgroup 2 during day

Multiple comparisons (Scheffel)				
Measurement points	Measurement points	[a]Sig. (2-tailed)	95% Confidence interval	
			Upper bound	Lower bound
1	2	.698	4.2709	−1.5417
1	3	.000	−3.6405	−9.5461
1	4	.000	−4.0739	−9.9795
1	5	.000	−5.4545	−11.4646
2	3	.000	−5.0516	−10.8642
2	4	.000	−5.4850	−11.2975
2	5	.000	−6.8647	−12.7835
3	4	.994	2.5195	−3.3861
3	5	.432	1.1389	−4.8713
4	5	.686	1.5722	−4.4379

[a]The mean difference is significant at the 0.05 level

Table 6 Statistic analysis between similar measurement points of two subgroups at Imam Khomeini Intersection Station

Independent samples test			
95% confidence interval of the difference			
Points	Sig. (2-tailed)	Lower	Upper
Ticket hall	0.493	−2.21234	1.09234
Entrance stairs to the subway platform	0.008	.51251	3.10082
Front section	0.020	.29915	3.22085
Middle section	0.257	−.90989	3.26989
Rear section	0.383	−.69138	1.74472

with points 3, 4, and 5 as well as point 2 with point 3, 4, and 5 present a significant difference ($P < 0.05$).

Table 6 shows the statistic analysis between similar measurement points of two subgroups in the investigated station. It was found that, only the entrance stairs to the subway waiting platform and the front section of the platform on both stories have significant differences in equivalent sound level ($P < 0.05$) while the P value of other areas were above 0.05 which means there was no significant difference in equivalent sound level.

Discussion and conclusion

In this descriptive–sectional research, several noise pollution factors such as equivalent sound level ($L_{\mathrm{Aeq(10)}}$) were measured in the two-storey of Imam Khomeini Intersection Station.

The average equivalent sound level ($L_{\mathrm{Aeq(10)}}$) in five different points of the second storey of Imam Khomeini Station (Imam Khomeini to ElmoSanat) were, respectively, equal to 70.56, 70.85, 78.88, 78.73, and 79.54 dB (A). The acoustic difference between the first two points including the ticket hall and the entrance stairs to the subway waiting platform, called "A" zone and the different points at the subway waiting platform (the front, middle, and the rear sections), called "B" zone was between 8 and 9 dB (A). This difference indicates that the main effect of the train noise was occurred on the waiting platform and the effects on the ticket hall and the entrance stairs is much lower than it. In Zone A, advertisement and the loudspeakers noise used to inform passengers were the main sources of the noise pollution.

To compare the subway noise with the community noise standards, the equivalent sound levels were investigated in each subgroup as well as both "A" and "B" zones separately. Table 7 shows the allowable noise exposure level for community noise equivalent level. According to NIOSH and OSHA recommendation, the 24-h allowable noise exposure level is equal to 75 dB (A) (Gershon et al. 2006).

The sound level of "A" zone including the Ticket Hall and the entrance stairs to the subway waiting platform was, respectively, equal to 70.56 and 70.85 dB (A). As the community noise standards over a period of 24 h was higher than the mentioned values in "A" zone ($P = 000$), it seems that no problem will happen to passengers and workers. However, the equivalent sound level of platform ranged from about 78 to 80 dB (A) was higher than the allowable limit of community noise ($P = 000$). In addition, the average equivalent sound level ($L_{\mathrm{Aeq(10)}}$) measurements of Imam Khomeini Station toward Mirdamad Station was tantamount to 70.62, 68.35, 77.46, 78.35, and 79.12. In this subgroup, similar to the second storey, the acoustic difference between zones "A" and "B" were ranged from 8 to 9 dB (A) which shows the train noise has negligible impact on "A" zone. The significant point here is that, the noise level of the entrance stairs to the subway waiting platform

Table 7 Allowable exposure durations for various exposure levels determined by different standards

	Exposure duration (min)					
	75 dBA	85 dBA	90 dBA	100 dBA	105 dBA	115 dBA
OSHA PEL	>24 h[a]	960	480	120	60	15
NIOSH REL	>24 h[a]	480	151	15	4.5	0.5
EPA/WHO	480	47.5	15	1.5	0.5	0

[a]Unlimited allowable exposure duration

is 2 dB (A) lower than the noise level in ticket hall and 9 dB (A) lower than the front section of the waiting platform. It can be explained by the distance between these points. This subgroup, located at the lower storey of the station, has extra stairs in which lead to more distances between the loudspeakers, the train platform and the mentioned point. In this subgroup, similarly, the equivalent sound level at the ticket hall and the entrance stairs , "A" zone, accounted respectively for 70.62 and 68.35 dB (A), were lower than the community noise standards ($P = 000$, $P = 0.007$). However, platform noise was ranged from 77 to 80 dB (A) which was exceeded the allowable limit of community noise ($P = 000, 000, 0.028$).

As it can be seen in Table 6, the comparison between similar points on both stories has shown that the equivalent sound level was not identical only at the entrance stairs to the subway platform and the front end of train ($P < 0.05$). In contrast, the other points such as the ticket hall, middle, and rear sections of the platform (with $P > 0.05$) indicate the same average equivalent sound level.

At Imam Khomeini Station toward Mirdamad Station, the P value of the ticket hall (first area) and the entrance stairs to the subway waiting platform (second area) was more than 0.05, the same result was perceived at third area (point numbers 3, 4, and 5). Nevertheless, the P value of the other areas was lower than 0.05 which indicates an inequality between the average equivalent sound levels of these areas. The same relation was observed in Imam Khomeini Station toward ElmoSanat Station due to similar structure and utilization of the same AC and DC trains. Based on noise measurements, the maximum noise levels was happened when the AC train is arrived at the station or started to pull out of the station and when the DC train is stopped at the platform owing to the output period and the applied brake caliper. The studied station with numerous passengers is the most crowded station in Tehran. The train drivers ride more carefully during their entrance and exit of the station, use the horn occasionally (a high impulsive noise), and decrease the train speed before arrival at the station to prevent any potential collision.

As it was shown in Table 3, the maximum measured noise level at "A" zone of the subgroup 1 was 85.1 dB (A) where this value for "B" zone of this subgroup was 94.4 dB (A), while the value of this index for the subgroup 2 was, respectively, 79.6 and 96 dB (A). The great difference in "A" zones for both sub groups is due to the location of the subgroup 2. As this platform is situated on the first storey, extra stairs lead to a decline in the sound level and, as a result, affects the average sound level. Nevertheless, there was no significant difference in "B" zones which could be explained by the similar physical structures and trains. The slight difference is related to the more DC trains passing through the subgroup 2 compared with the subgroup 1. Moreover, the minimum noise level was measured at both subgroups. The values of "A" and "B" zones in subgroup 2 were, respectively, tantamount to 64.3 and 67.7 dB (A) while in subgroup 1 were severally equal to 62.3 and 63.3 dB (A). It should be noted that the minimum noise level was mainly related to the advertisement system and loudspeakers. Since, in subgroup 2, advertisement system and the loudspeakers were used more than subgroup 1 the minimum noise levels were higher as well. Similar researches were carried out around the world focusing on the subway noise. Neitzel et al. (2009) measured noise levels of mass transit systems (subways, buses, ferries, tramway, and commuter railways) aboard transit vehicles and at vehicle boarding platforms or terminals in New York. They found that of the transit types evaluated, subway cars and platforms had the highest associated equivalent continuous average (L_{eq}) and maximum noise levels which the noise-induced hearing loss is considered possible (Neitzel et al. 2009). The results of another survey performed in New York, were in agreement with the present study (Gershon et al. 2005).

The noise evaluation of New York subways has shown that noise level has a range of 56 to 97 dB (A) at stations and inside the subway at which higher noise level was occurred when the train arrived and stopped at the platform or when an express train is passed. Also, another study, conducted in four New York boroughs with underground subways (Manhattan, Brooklyn, the Bronx, and Queens) showed that the average noise level measured on the subway platforms was 86 ± 4 dB (A). The maximum levels of 106 and 112 dB (A) were measured on subway platforms and inside subway cars, respectively (Gershon et al. 2006). In this research, the measured noise levels at subway platforms were between 78 and 80 dB (A) that indicates a lower value than the measurements in other researches. Using up to date and advanced technologies, as well as proper repairing and maintaining of equipment, results in lower noise level values. In this regard, applying appropriate tools and equipment according to the capabilities and variety of products can be considered as the effective factor in each industry and in any country. However, the higher noise level within arriving at the station or starting pulling out of the station or stopping at the platform is because of the applied brake caliper. In other words, it is necessary to not only use modern equipment but also maintain the equipment systematically. More recent researches have focused on the impact of subway noise level on the noise-induced hearing loss (NIHL; Gershon et al. 2005). The range of noise levels, which were in a broad scope from 70 to 110 dB (A), cause a decrease in hearing. It was shown that 10 million Americans are predicted to have NIHL (Gershon et al. 2005). Various elements such as length and speed of subway, quality of track "specially brake type (track edge)" are considered among the main effective factors in noise levels (Jones 1994; Hemsworth and Jones 2000; Hemsworth 2000; ETSU 2001; BS EN 1793). A number of solutions have been presented to decrease the subway noise level. For instance, (Liu and Liu 2009) pointed out that the vibration and noise level could be dwindled optimizing cross-sectional shape of subway wheels (Liu and Liu 2009). Implementing the other strategies and engineering controls like repair and improved maintenance of tracks using rubberized rails, acoustical tiles, rails without seam and weld, braking mechanisms, sound dampening, and sound absorption acoustical materials can also help to decrease the noise level (Gershon et al. 2005).

Finally, it is suggested to define the noise levels at DC and AC trains separately and also make a comparison at front, middle, and rear sections of the waiting platform.

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