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Assessment of Metro Passengers' Convenience While Sitting and Standing in Confrontation with Whole-Body Vibration

KEYKAOUS AZRAH[1], ALI KHAVANIN[2], ALIREZA SHARIFI [3]; ZAHRA SAFARI[2]; RAMAZAN MIRZAEI[4]*

[1]Department of Occupational Health Engineering, School of Public Health, Gonabad University of Medical Sciences, Gonabad, Iran; [2]Department of Occupational Health Engineering, School of Medical Sciences, Tarbiat Modares University, Tehran, Iran; [3] Labor Inspector of Tehran Labor Office, Tehran, Iran; [4] Department of Occupational Health Engineering, Health Promotion Research Center, Zahedan University of Medical Sciences, Zahedan, Iran

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ABSTRACT

Nowadays, using public transportation vehicles like metro in large cities are of significance, and exposure to whole-body vibration for the metro passengers is one of the physical contaminations. This paper is conducted with the aim of evaluating the passengers' convenience and health both in sitting and standing conditions. The present study was done on the passengers of lines 1, 2, and 4 of Tehran metro with the use of an oscillator and a SVAN958 analyzer of SVSNTEK Co., based on the measurement methods and guidelines of ISO 2631-1, 4. The average amounts of RMS acceleration while sitting was 1.1 m/s^2 with the standard deviation of 0.14 and while standing was 0.91 m/s^2 with the standard deviation of 0.05; estimated VDV amount while sitting and standing equaled 6.72 m/s^2 with the standard deviation of 1.26 and 6.48 $m/s^{1.75}$ with the standard deviation of 0.96. Calculated RMS amounts generally fluctuated between level 3 (fairly unpleasant) and level 4 (unpleasant) of convenience evaluation scale, and total calculated VDV amounts for the sitting passengers was 1.1 $m/s^{1.75}$, being more than the perceived dose of standing passengers.

KEYWORDS: *Vibration, Vehicles, Acceleration, Passengers*

INTRODUCTION

Buses, cars, and trains are important public transportation vehicles that nowadays are extensively used in all over the world (in villages, small town, large cities, etc.) for passengers' transportation. Trains are the commonest and the most convenient urban and suburb public transportation vehicles. Different passengers with different personalities state various reasons for choosing the above-mentioned vehicles of transportation [1, 2].

One of the important matters that people do care for is the convenience of travelling; especially, when travelling duration is more than 1 or 2 hours. Besides, saving money, saving time, and troublesome and nerve-raking urban traffics are of importance in the choice of transportation vehicles. Thus, travelling with train is more advantageous than travelling with bus and taxi, especially in metropolises like Tehran [1-3].

Bothering and noticeable whole-body vibration is considered as a health problem at many occupational and non-occupational places [3]. Almost all the passengers of different vehicles – no matter what the vehicle type is – are exposed to whole-body vibration while travelling, in which the vibration is transmitted through different parts of the body

**** Corresponding Author: Ramazan Mirzaei, Email: rammir277@yahoo.com***

that are in contact with vibrating surfaces, such as seat cushion, seatback, cabin floor, and sometimes the headrest [3, 4].

This energy is entered to one's body through his/ her legs, backside, waist and back, and sometimes head and neck, and eventually influences on the convenience of the individual and the efficiency of his/her activities during the trip. In addition, it effects on the health of some people when they should use transportation vehicles, consistently [2, 5, 6]. Only one hour of whole-body vibration while sitting is enough to cause muscular exhaustion and to prepare the ground for waist damages [1]. Vibration is the main cause for many of the musculoskeletal disorders in different parts of the body like shoulders, neck and waist. Moreover, exposure to whole-body vibration brings about other problems such as health risks in the functions of psycho-motional, physiological, and psychological systems.

Vibration could cause blurred vision, balance loss, and poor concentration. Sometimes, frequencies and vibrating surfaces might cause permanent damages to internal organs. Permanent exposure to whole-body vibration in prolonged working years might cause many health problems, including fixed damages to internal organs, muscles, joints, and bone structure, influencing on body and its different organs. Studies show that, those that are exposed to whole-body vibration have more severe waist problems than those who are not exposed to vibration at all [2, 5, 7].

Convenience and comfort of the passengers during the trip vary due to some factors such as waiting of the passengers and trip duration. Noticeably, convenience is usually reduced with the increase of trip duration. Waiting of the passengers also varies on the basis of some factors like ticket cost, train class, and doing various activities like reading, writing, typing, eating, drinking, etc. that might be influenced by vibration; they are under the influence of environmental conditions like temperature and moisture, cabin design, the noise amount that the passengers are exposed to, visional stimuli, rail infrastructure, physical building of cabin, and so on [5, 7-10].

The objective of this study was evaluation of comfort in metro passengers exposed to whole body vibration due to the very limited information in this relevant.

MATERIALS AND METHODS

Research environment and measurement method: Numerous studies in long years have indicated that, vital frequency range of whole-body vibration is from 0.5 to 80 Hz. Today, different national and international standards suggest the same frequency range in studying the issue of whole-body vibration [5,7,11,12].

Because, the effect of longitudinal and transverse movements in the passengers and staff could vary in sitting and standing conditions (sitting condition is more important), both sitting and standing passengers were investigated.

By considering the overall condition, ISO 2631-1 has already suggested a general assessment method for evaluating seat vibration in order to evaluate the vibration in the sitting people's bodies; but this method is not always an appropriate method for assessing and evaluating the transmitted vibration from vehicles on rail routes. Thus, for a correct and suitable evaluation, in addition to using the guidelines of the 1st section of ISO 2631, the guidelines and considerations of the 4th section of ISO 2631 should be used that have specifically been prepared for evaluating the vibration effects on the convenience of the passengers and staff of the rail transportation systems. They were all used in this study. Besides, the installation of oscillators and measurements were done based on the guidelines of ISO 2631-1, 4 and 10326-1 for whole-body vibration [8, 11, 12].

The measurements were done with the use of an oscillator and a SVAN958 analyzer of Svantek Company with SV39A/L Three axial accelerator (in the frequency range of 0.5 to 3 Hz), that have been designed based on ISO 2631-1 and SAE j1013, and were installed in a plastic pad with the thickness 12 mm.

Device calibration was done before and after measurements with a calibrator of the aforementioned company. While measuring, detection time of the devise was set on 100 milliseconds, and frequency-weighing filter band, which was used for measurements on x, y, and z axes, was wd, wd, and wb, respectively, while a passenger, who was willing to cooperate in this study, was sitting on a seat, and while the same passenger was standing in the wagon throughout the whole time of his/ her trip.

This devise is capable of separate and simultaneous acceleration measurement along 3 different directions. Considering that the investigated trains had 7 wagons, and the length of AC and DC trains' wagons was 19000 and 19520 mm, and the width of them was 2600 and 2460 mm, all the participants of this study were chosen from the middle wagon of a train, who were sitting somehow in the center of the wagon on a single seat; standing passengers were chosen from somewhere near to the selected sitting passengers.

This study was done in 11 trains of 3 lines of Tehran metro with similar infrastructures and rail systems in fixed time of 20 minutes in 2013. These trains were randomly chosen from different lines with a decree from Tehran metro's management office, and whole-body vibration measurements were done on the passenger's seat and on the cabin floor in 3 different directions mentioned by ISO 2631-1, by taking into account convenience criteria.

All the measurements were done from 10 a.m. to 5 p.m. that the trains are usually crowded. In order to avoid the influence of individualistic features of passengers on the measurements, one single person from each train was investigated for both sitting and standing conditions, who was 78 kg and 175 cm tall.

The trains in the lines 1, 2 and 4 of Tehran metro are of AC and DC types; both types were used in the present study. The number of active stations in the lines 1, 2 and 4 was 5, 18, and 27 stations; average speed of the trains was 67 km/h with standard deviation of 5.3 km in all the lines. The one-way routes of the lines 1, 2 and 4 were 5.6, 20.4, and 34.26 km long. This is possible for every passenger to get on either one, or several metro lines. Travelling duration may take some minutes (about 30 minutes in the one-way road of the line 4 of metro) to 2 or 2.5 hours per day in a two-way road with the use of different trains of Tehran metro.

In the case of measurement duration, the standards suggest at least 20 minutes for whole-body vibration measurements on each axis where possible, and at least 3 minutes where impossible. However, investigation is possible in long measurement durations and sometimes in half of the exposure time [12, 13]. Therefore, the minimum measurement time of the current study was 20 minutes.

Accelerations on all the three axes were measured on the cabin floor for standing passengers, and on the cushion of the seat for sitting ones based on the guidelines of ISO 2631-1, 4. For avoiding the influence of initial movements of passengers on vibratory signal, the measurer devise was activated after the complete installation of the oscillator in the considered location.

Analyzing and calculating whole-body vibration in this study was done based on the executive instructions of ISO 2631-1. The amounts of RMS acceleration, VDV, and crest factor were based on 1-3 equations, accordingly. In a way that weighed frequency of RMS acceleration was calculated based on equation 1 (in which a_(w RMS)is the weighed frequency RMS acceleration, T is the measurement duration, and aw (t) is considered as weighed-frequency acceleration in t time.)

Eq. (1): $$a_{w\,r.m.s} = \sqrt{\frac{1}{T}\int_0^T a_w^2(t)\,dt}$$

VDV, which is the fourth root of fourth squares of vibratory acceleration signal, was determined based on equation 2 in which T is the measurement time, and $a_w(t)$ is the weighed frequency acceleration of t time.

Eq. (2): $$VDV({m}/{s^{1.75}}) = \sqrt[4]{\int_0^T [a_w(t)]^4\,dt}$$

And crest factor (CF) was calculated based on equation 3 (16, 21).

Eq. (3): $$CF = \frac{a_{w\,(t)max}}{a_{w\,r.m.s}}$$

Evaluation method: Since the accepted amounts for convenience investigation relies on numerous factors, which may vary in each function, general limits of whole-body vibration have not been absolutely defined with considering convenience and comfort. In Table 1, the determined limits of convenience by ISO 2631-1, expressing probable reactions to the whole vibration's different magnitudes are shown [12, 14].

On the other hand, reaction to different magnitudes varies based on the passengers' experience considering the trip duration, passenger's activity type, his or her expecting to do a special activity (like reading, drinking tea, writing, etc.) and many other different factors (noise disorder, temperature, and so on.).

Table 1. Probable mental reaction of a person in the face of different amounts of whole-body vibration

RMS acceleration (m/s2)	Mental reaction of a person	No convenience level in this paper
< 0.315	Not uncomfortable	1
0.315 to 0.63	A little uncomfortable	2
0.5 -1	Fairly uncomfortable	3
0.8-1.6	Uncomfortable	4
1.25-2.5	Very uncomfortable	5
>2	Extremely uncomfortable	6

Usually, permanent initial index for investigating human vibration is RMS acceleration, but sometimes, for example when the amount of crest factor is more than 9, evaluating human's reaction to vibration with the use of weighed frequency RMS acceleration is not enough. One's convenience might meaningfully be influenced by different amount of pick. Hence, evaluations with RMS averaging method might consider the risk level as something trivial. In such cases, VDV index is suggested, and since there is no limits for VDV index based on the convenience criterion, calculated vibration amounts in an environment may be compared to such amounts in another environment for assessing the lack of convenience.

In most of the vibration assessment methods, those measurements done on the three coordinate axes should be mixed together. However, unfortunately most of the standards concern with the dominant axis, and 2 of the axes are neglected questioning the accuracy of the work. ISO 2631-1:1997 suggest the measurement of cushion vibration on translational axes, and advises the most severe direction (dominant axis) for vibration assessment. However, in this study, the axes combination method was used based on the recent standards and studies [1, 15, 16].

Transverse vibrations in the seatback of the vehicles are significantly influential on the people's convenience, so ISO 2631-1 suggests that if the vibration amount of the seatback was not measured, 1.4 should replace 1 as a coefficient figure for x and y axes to assess the convenience amount on the seat cushion. As it is suggested, the data of horizontal axes that are indicated in the table related to the sitting condition for RMS and VDV have been multiplied by 1.4 for measuring the general exposure.

RESULTS

As ISO 2631 suggests, the results of similar researches could be used for normal healthy people. WRMS, CF, and VDV data in the three directions of x, y, and z of train seats of different lines for sitting passengers are demonstrated in Table 2, and for standing passengers in Table 3 based on the suggestions of ISO 2631-1, 4. In addition, assessed amounts with the consideration of probable minimum and maximum exposure duration of a day are illustrated in the same two tables for the passengers both in sitting and in standing conditions.

In RMS acceleration assessment showing average acceleration during assessment period, the triple axes were mixed/ combined to one another with calculating the second root of total acceleration squares. This combination is calculated with the equation below for RMS acceleration amounts with the use of ISO 2631 method;

Eq. (4) :

$$a_{xyz} = \sqrt{{k_x}^2 a_{wx}^2 + {k_y}^2 a_{wy}^2 + {k_z}^2 a_{wz}^2}$$

In this equation: a_{xyz}: is the root of total weighed-frequency squares, and a_{wx}, a_{wy}, and a_{wz} show the weighed accelerations in x, y, and z axes, respectively; k_x, k_y, and k_z, also show the relevant coefficient of x and y axes, which is 1.4, and the relevant coefficient of z axis which is 1. For combining the coordinate VDV axes, the following equation is used:

Eq. (5):

$$VDV_{xyz} = \sqrt[4]{{k_z}^4 VDV_x^4 + {k_z}^4 VDV_y^4 + {k_z}^4 VDV_z^4}$$

In this equation, VDV_{xyz} is the combined vibration dose, and VDV_x, VDV_y, and VDV_z are vibration doses on x, y, and z axes; k_x, k_y, and k_z also show the relevant coefficient of x and y axes, which is 1.4, and the relevant coefficient of z axis which is 1.

VDV amounts are based on the fourth square of average weighed exposure acceleration, emphasizing that larger acceleration amounts are more valuable than average second squares of RMS acceleration. Equivalent VDV has been defined according to the equation 6 in some periods other than measurement period, in which VDV_n is the total VDV in n time, t_n is the total vibration exposure time for n duty, $t_{\text{n measured}}$ is the time period in which VDV has been measured for the time n, and $\text{VDV}_{\text{n measured}}$ is the asseseed VDV for n duty

Eq. (6):

$$VDV_n = \sqrt[4]{\frac{t_n}{t_{n\ measured}} \times VDV_{n\ measured}^4}$$

As Table 3 and 4 show, average RMS amounts in sitting condition equals 1.1 m/s^2 with the standard deviation of 0.14, and VDV is 6.72 $m/s^{1.75}$ with the standard deviation of 1.26. These amounts are calculated when the coefficient of x and y axes is 1.4. When the combination of axes was calculated on the two horizontal axes without considering the mentioned factors, mean amount of RMS acceleration equaled 0.89 m/s^2 with the standard deviation of 0.1; VDV average in all the participants equaled 5.67 $m/s^{1.75}$ with the standard deviation of 1.38.

During the assessment time, mean amounts of RMS and VDV in standing condition were 0.91 m/s^2 with the standard deviation of 0.05, and 6.48 $m/s^{1.75}$ with the standard deviation of 0.96. Mean amounts of RMS acceleration on x, y, and z axes while sitting is 0.57, 0.5 and 0.4, and while standing 0.64, o.48, and 0.39 m/s^2. The dominant axis in 7 trains out of the 11 investigated trains was axis z; all the seven trains but two of them, belonging to line 1, were of AC type. In addition, in the two DC trains of line 2 and one of AC trains of the same line, the dominant axis was y. It is worth to note that, axis x was the dominant axis in 3 investigated trains of the line 1.

The numbers of dominant axes in sitting condition for VDV index is similar to the condition of RMS; that is, 7 trains on z axis, 3 trains on y axis, and 1 train on x axis.

Table 2. Results of calculated vibration in sitting condition of studied metro passengers

Code	line	Car type	Time measurement	RMS X	RMS y	RMS Z	RMS VSV*	CF X	CF y	CF Z	VDV X	VDV y	VDV Z	VDV total VSV	VDV total 30	VDV total 150
1	1	AC	20	0.27	0.46	**0.59**	**0.95**	3.3	8.1	4.8	2.45	3.23	**5.32**	6.07	6.71	10.0
2	1	AC	20	0.36	0.48	**0.69**	**1.09**	8.1	13	14	1.858	3.18	**8.34**	8.52	9.43	14.1
3	1	DC	20	0.28	0.47	**0.86**	**1.15**	14	11	4	3.015	3.65	**6.05**	6.96	7.7	11.5
4	1	DC	20	0.51	0.33	**0.85**	**1.20**	8.3	4.3	13	4.709	2.07	**6.21**	7.66	8.48	12.7
5	2	AC	20	0.28	**0.53**	0.49	**0.97**	4	7.5	5.5	2.502	**3.5**	3.032	5.34	5.91	8.83
6	2	DC	20	0.51	**0.72**	0.251	**1.25**	3.7	15	11	2.632	**3.86**	1.08	5.67	6.28	9.39
7	2	DC	20	0.57	**0.77**	0.205	**1.35**	2.3	5.5	7.2	4.403	**5.79**	0.704	8.71	9.64	14.4
8	2	AC	20	0.35	0.46	**0.67**	**1.05**	3.4	16	4.1	2.842	3.85	**5.47**	6.68	7.39	11.1

9	4	AC	20	0.39	0.39	**0.48**	**0.91**	5.5	3.7	1.6	**3.07**	2.5	2.431	4.79	5.3	7.92
10	4	AC	20	**0.52**	0.35	0.514	**1.02**	3.1	4.3	15	3.74	2.21	**5.17**	6.28	6.95	10.4
11	4	AC	20	0.41	0.57	**0.64**	**1.17**	7.9	4.8	11	3.67	4.2	**5.54**	7.3	8.08	12.1
		Average		0.4	0.5	0.57	1.1	5.8	8.4	8.2	3.172	3.46	4.486	6.72	7.44	11.1
		STDEV		0.11	0.14	0.21	0.14	3.6	4.5	4.6	0.87	1.04	2.36	1.26	1.39	2.08

*Vector Sum Value of three directions

CF average amounts of sitting condition on x, y, and z axes were 5.8, 8.4, and 8.2, and of standing condition were 11, 8.76, and 10.6, respectively; these amounts are average amounts relevant to this index, illustrating that it is better to use VDV index for vibration assessments.

Average amounts of RMS acceleration of sitting condition on the lines 1, 2 and 4 of Tehran metro were 1.1, 1.16, and 1.03; the highest and lowest mean amounts on all the axes belonged to the line 1, and on z and x axes equaled 0.75 and 0.33, respectively. The RMS mean amounts of standing condition on the lines 1, 2 and 4 were 0.91, 0.9 and 0.93 m/s^2. The highest mean amount also went to the z axis of the line 1, and the lowest mean amount belonged to this very same line equaled 0.33 m/s^2.

The highest amount of crest factor of standing condition on x, and z axes of the line 1 and the x axis of the line 4 equaled 12, and the lowest amount of the y axis on the line 4 equaled 5.3.

The mean amount of combined VDV on x, y, and z axes of sitting condition of the lines 1, 2, and 4 were 7.3, and 6.6, and 6.12, and of standing condition were calculated as 6.48, 6.24, and 6.79. The highest amount of VDV average in sitting condition is related to the z axis on the line 1 equaling 6.48, and the lowest amount of VDV average is related to the same line and the axis x, equaling 2.59.

Table 3. Results of calculated vibration of standing condition for the studied metro passengers

				RMS				CF			VDV					
Code	**Car type**	**line**	**Duration**	**X**	**y**	**Z**	**VSV**	**X**	**Y**	**Z**	**X**	**y**	**Z**	**VSV**	**30min**	**150min**
1	AC	1	20	0.37	0.37	**0.71**	0.88	8.8	12.6	7.1	1.97	3.94	**5.69**	6.71	7.42	11.1
2	AC	1	20	0.35	**0.63**	0.42	0.83	13	14.9	28.8	2.86	4.3	**4.74**	6.75	7.47	11.17
3	DC	1	20	0.33	0.39	**0.88**	1.02	17	8.7	2.35	3.09	2.5	**6.22**	6.68	7.4	11.06
4	DC	1	20	0.27	0.43	**0.76**	0.91	7.6	5.9	10.2	2.42	2.78	**5.24**	5.78	6.4	9.56
5	AC	2	20	0.48	**0.55**	0.48	0.87	9.2	4.55	2.11	2.53	**3.64**	1.51	5.38	5.96	8.909
6	DC	2	20	0.39	0.41	**0.73**	0.93	13	11.5	17.5	3.07	2.27	**7.93**	8.15	9.01	13.48
7	DC	2	20	0.46	0.36	**0.65**	0.87	11	7.45	12.6	3.43	2.41	**4.34**	5.65	6.25	9.34
8	AC	2	20	0.41	0.39	**0.72**	0.92	6.3	14.9	7.4	3.16	2.54	**4.91**	5.79	6.41	9.58
9	AC	4	20	0.41	0.46	**0.75**	0.97	26	8.16	9.2	3.17	3	**7.1**	7.54	8.35	12.48
10	AC	4	20	0.34	**0.67**	0.53	0.92	7.5	3.3	5.56	2.81	3.31	**3.36**	5.36	5.94	8.88
11	AC	4	20	0.48	**0.66**	0.392	0.9	2.9	4.45	13.5	3.51	**5.02**	3.01	7.46	8.26	12.35
	Average			0.39	0.48	0.64	0.91	11	8.76	10.6	2.91	3.25	4.91	6.48	7.17	10.72
	SD			0.07	0.12	0.16	0.05	6.1	4.16	7.62	0.46	0.89	1.85	0.96	1.06	1.58

DISCUSSION

The mean amount of RMS acceleration of all the assessments of sitting condition was 1.1 m/s^2, when the suggested method, or extra coefficients on horizontal axes were used. This amount is categorized under the unpleasant group in the fourth level of convenience evaluation method of ISO 2631.

When axes combination method without extra coefficient of horizontal axes was used, this amount was 0.89 m/s^2; this latest amount is fluctuating between the third and the fourth levels; it means that, it can fall under the third level called unpleasant, and the fourth level, called the unpleasant level.

Falling under each of these levels might depend on many other factors mentioned in the previous sections of the present paper other than whole-body vibration, to which the studied person was exposed. Hence, when the conditions of environment are suitable, it can be put under the third group, and when in addition to vibration, the environment is littered with other influential factors on convenience, it can be put under the fourth level. Mean amounts of RMS of sitting condition on x, y, and z-axes were 0.57, 0.5 and 0.4, decreasing gradually. If based on ISO 2631 standard, the dominant axis was the criterion of assessment, and when there was no coefficient, the existing conditions of level 2 are accounted as somewhat little uncomfortable.

In some conditions, the calculated results of the seat-surface are more than that of the cabin floor, so it can be concluded that, the seat instead of being a decliner of vibration enforces the vibratory signal under the influence of some factors. EU Directive 2002/44/CE has already determined the allowed limits for transmitted hand-arm and whole-body vibrations based on the health risks, but it does not cover the passengers' convenience. It is possible in some special conditions and due to unaccepted inconvenience, that only one vibratory condition is considered. However, this is possible to classify the same vibration as a pleasant or exhilarating vibration in another condition [7, 17, 18].

Average amounts of RMS acceleration of sitting passengers in DC trains was 1.24, and in AC trains was 1.02 m/s^2; in this condition, both of the groups are placed in the fourth level, though, AC trains could be placed in the third level. Mean amounts of RMS in the lines 1, 2, and 4 own the highest amounts; however, the amounts of all these three lines fell into the fourth level, the unpleasant/ uncomfortable level. The resulted data of each of the studied participants in the determined limits of ISO 2631-1 are shown in Fig. 1.

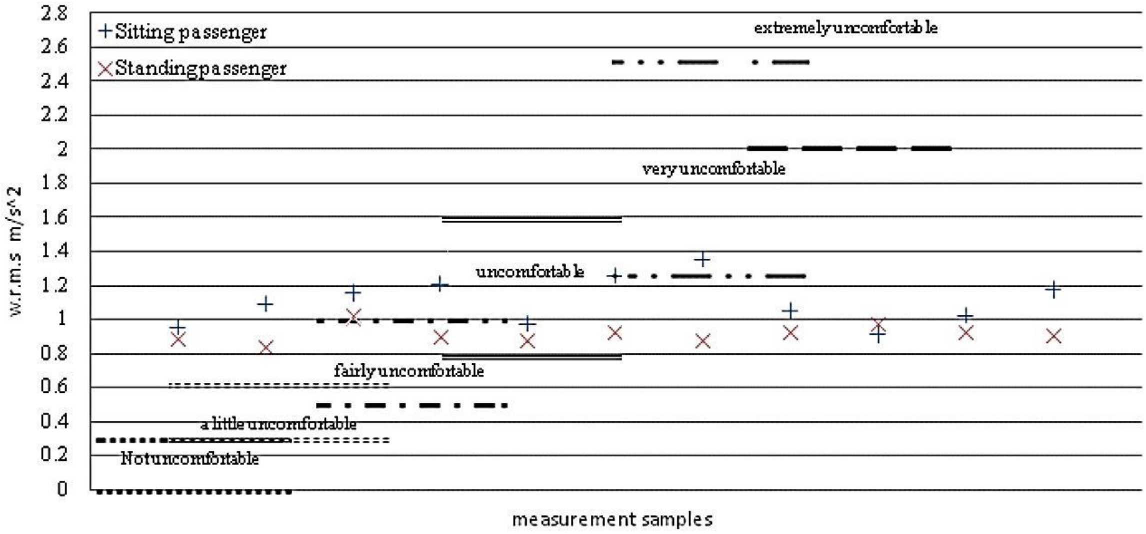

Fig1. Assessed amounts of participants in sitting and standing conditions, and in the convenience limits of ISO 2631-1

Average calculated amounts of the axes for sitting and standing conditions on the dominant z-axis was 0.57 and 0.64. When these amounts were taken into account as assessment criteria, they would fall into the unpleasant level in the standing condition, and in to the little unpleasant condition in the sitting condition. In other studies [17, 20], on Tehran metro drivers, the dominant axes of the studied trains, some of which were common in this study, were z, and then y-axes; that study's results are confirmed in the present study both in sitting and in standing conditions. The dominance of axis z has already been reported in other studies done on the rail vehicles [19, 20].

The mean amount of RMS acceleration of passengers' exposure in standing condition is 0.91 m/s^2 located in the third level. Calculated data of AC and DC trains in standing condition were similar to one another and in the third level. The average RMS amounts of the metro lines were like that of the train types (0.9 m/s^2).Therefore, exposure in all the three metro lines falls under the "fairly" group/ level. The mean CF amounts in sitting condition varied from 5 on x axis for AC trains to 8.9 on y axis for DC trains of the line 1. The highest and the lowest amounts of CF also varied from axis x in sitting condition of sample 7 to 29 on axis z of sample 2 in standing condition. One of the criteria of ISO 2631 that has introduced VDV method as a secondary method accompanied with RMS method for vibration assessment is when the crest factor is more than 9; in the present study, crest factor is more than 9 at least on one of the axes in 7 cases in sitting condition and 10 cases of standing condition.

Since no criterion has been submitted for convenience assessment in VDV method, the results can be used in similar environments in comparison to VDV findings, only. The VDV amounts of axes resultant in measurement duration in standing and sitting conditions equaling 6.48 and 6.72 $m/s^{1.75}$. These amounts in the measurement duration for a one-way road in the shortest line of Tehran metro in the sitting and standing passengers were 7.44 and 7.17 $m/s^{1.75}$. It should be noted that the assessed amounts on x and y axes in siting condition have been multiplied by 1.4, so final mean amounts in sitting condition were more than those in standing condition. In general, the assessed amounts of standing conditions are more than those of sitting conditions.

VDV mean amounts during a two-way road of the line 1 of Tehran metro, about 150 minutes, were accordingly calculated in sitting and standing passengers as 11.1 and 10.72 per day. Recent amounts are more than the calculated amounts of the research of Narayanamoorthy et al. [21], in the studied trains of Tehran, and were less than the calculated data from the study of El Sayed et al. [2,19] in Cairo metro. The study of El Sayed et al. [19] on bus passengers showed lower amounts of exposure.

CONCLUSION

The condition of the passengers of Tehran metro in sitting and standing conditions can be placed somewhere between the third (unpleasant) and the fourth (unpleasant) levels. It is suggested to conduct future related researches under the light of the present studies to determine another index like VDV, which is sensitive to vibratory signal shocks, in order to gather necessary, beneficial, and constructive data. Furthermore, if VDV amounts considering convenience are apparently submitted, incorrect judgments with the use of this index are avoided.

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