



Evaluation of exposure of metro passengers to whole-body vibration and recurrent shocks according to ISO 2631- 1 standard

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Abstract

Nowadays, using rail vehicles like metro is necessary for transportation in megacities and metropolises. In this descriptive-analytical study, whole body vibration was evaluated by two methods including basic evaluation and the recommended dose of vibration proposed based on ISO 2631-1 standard. In the present study measurements were performed over 13000 seconds in usual daily working hours by using SVAN 958 apparatus manufactured by Svantek Company, while the wagons were in motion at average speed. Tri-axial effective acceleration values were determined on the passengers contact surfaces and on the wagon seats in the different lines of Tehran metro. The results of evaluation based on the basic method showed that evaluated levels for 60 and 150 minutes of exposure calculated by an equation with higher safety according to ISO standard showed that all of samples except one were in the Health Guide Critical Zone (HGCZ). Based on Vibration Dose Value (VDV) method, except for two cases in each group of the exposure periods which were in the HGCZ of ISO, all the other cases had low risk levels of exposure. The findings of both the methods indicated that, different evaluation methods may gain different outcomes. It seems that the recommended safety levels in VDV method seriously need to be corrected. In addition, considering average exposure levels gained in this study, it is recommended to apply appropriate control measures for declining exposure amount of passengers.

Keywords: Passenger, Standard, Vibration, Whole body

Introduction

Human vibration is referred to those kinds of vibrations which are transmitted from various mechanical structures to human body, mostly through the organs in contact to the vibrating surfaces. Whole-body vibration is one of the two types of human vibrations in which, vibration energy is mainly transmitted through

seat cushion, person's feet, and seat back to the person's body [1]. It is estimated that one worker out of four workers in Europe is exposed to one of the whole-body and/or hand-arm vibrations [2]. There is a similar estimation for exposure amount of Iranian workers, although a few studies have been conducted on the subject of vibration

exposure.

Long term exposure to whole body vibration adversely affects the human health, creating a wide range of health problems particularly in the waist including Intervertebral Disc Herniation and other spinal cord diseases. Whole body vibration could cause blurred vision, lack of balance, and low concentration. In some cases, specific vibration frequencies and levels could cause serious damages to the internal body organs. After prolonged daily exposure, variant health problems may occur on the whole body, like permanent damages to the internal organs, muscles, joints, and skeleton structures [3-6].

Backache symptoms are mainly observed among the workers confronted with whole body vibration in comparison to other workers [7,8]. In this regard, a study by Johanning et al. in 2006 showed that backache rate in the rail engineers confronted with whole body vibration was meaningfully higher than the control group; shoulder pains were also more observed in the studied case group rather than the control group [9].

As a matter of fact, numerous studies have been conducted worldwide to evaluate whole-body vibration in different Machineries such as farming tractors, construction machineries and transportation vehicles. In some studies, for example a study conducted by Manal El Sayed et al. in Cairo on passengers of trains, buses and cars, and a study by Funakoshi et al. in Japan on the taxi drivers, the amount of exposure to whole-body vibration was determined on the basis of the recommended methods of ISO standard [6,8,10-13]. Besides, in the studies of Khavanin et al. the exposure amount of metro drivers was determined according to ISO 2631-1 method and then compared to BS 6841 standard [14-15]. In another study by this team, the exposure amount of transit bus drivers to whole-body vibration was investigated in ISO method [16].

Trains have traditionally been one of the most popular transportation vehicles. Passengers choose metro for different reasons; avoiding urban traffics, its low cost, and its fastness.

Metro passengers are unintentionally exposed to whole-body vibration transmitted to their bodies mostly from the seat due to its large contact area [6,17].

Confronting with transient acceleration on lateral axes is a common feature of traveling with rail transportation systems. According to ISO 2631-4, the influences of vertical and horizontal movements could be much influential to the passengers and the crew of rail transportation systems when they are sitting on the seats. In addition, some of the acceleration signals are perhaps related to geometric design of the rails. A wide range of acceleration in some cases could be resulted from high speed of the train, its age, and its repairmen frequency [6,18,19].

ISO 2631-1 have generally introduced two methods for evaluating the influences of periodic, accidental and transient whole-body vibration on human's health; one is RMS on the basis of acceleration magnitude, and the other one is Vibration Dose Value (VDV) on the basis of Vibration dose value. ISO 2631-1 has explained the measurement method of root mean squares (RMS) of acceleration or Maximum transient vibration value (MTVV) and Vibration Dose Value, VDV (biquadratic of vibration dose) and expresses that when the degree of the crest factor is higher than 9, VDV gives a more reliable evaluation; because high degrees of crest factor is an indication of vibration and recurrent shocks [20].

Since many studies on this subject has been carried out on the workers of transportation lines, and the number of studies concerning the exposure amount of the passengers to whole-body vibration is limit, this study was conducted with the aim of evaluating the exposure amount of Tehran city metro passengers to whole-body vibration and recurrent shocks. Determination of the exposure amount especially in metropolises like Tehran is important because they have the mean travel time of more than 1.5 hours in a day. This is specifically important for those passengers who experience occupational exposure to vibration as well.

Method

Today, various national and international standards have recommended frequency range of 0.5 to 80 for evaluating whole-body vibration based on various researches. In the present descriptive-analytical study, ISO 2631-1 and ISO 2631-4 standards were used in order to evaluate the daily exposure amount of metro passengers. Considering the whole circumstances, ISO 2631-1 has proposed a general method for measuring the vibration on seat surface for evaluating the vibration in sitting persons. Accelerometers were installed according to the guidelines of the two ISO 2631-1 and ISO 10326-1 standards [19-22]. Moreover, measurements were performed using a tri-axial accelerometer at the same time on all the three axes on the sitting passenger's seat.

During the measurements, a person with the weight of 78 kg and the height of 175 cm was sitting on seats in all trains and lines in order to remove the interference of passenger individual characteristics. Accelerations of the triple axes were measured on the seat surface based on the tips of ISO 2631-1. In order to avoid the influence of the initial movement of passengers on vibration signals, the measurement device was activated after the complete installation of the accelerometer.

Vibration was measured by using SVAN 958 analyzer of Svantek Company with SV39A/L tri-axial accelerometer (within the frequency range of 0.5 to 3 KHz), which was designed based on ISO 2631-1 and SAE j1013 and was installed in a 12-mm-thick plastic pad. The device was calibrated before and after the measurements by the calibrator made by the above-mentioned company.

During the measurements, the detection time was set on 100 mille seconds, and the utilized frequency weighting filter bands were wk, wd, wd, respectively for measuring on the x, y, and z axes. This device was capable to separate simultaneous acceleration measurements in 3 different directions. Since the number of the wagons in the studied trains was 7, and the length of these wagons in AC and DC trains was 19000 and 19520 mm, and the width of them was 2600 and 2460 mm, the participants were analyzed in

the middle wagon of the all explored trains on a center-located fixed seat.

Electric railway is a modern type of transportation vehicle using the electricity as a traction force. In electric traction, the source of energy is external and is provided from outside of the locomotive. Electronic power system may be either Alternative Current (AC) type or Direct Current (DC) type. DC has been the simple power system of the trains for many years, but AC is a quite newer system with a more complicated structure appropriate for long distances.

The weight of each investigated AC train in all lines was 257 ton, while the weight of the DC trains was 240 ton. The weight of active DC trains in line 1 was as same as the weight of AC trains. Each wagon had a four-point suspension system for controlling wagon's height under all loading conditions. This system adjusts the wagon's height in a predetermined value by controlling air pressure in two cushions which have been installed between the wagon's body and each bogie (Bogie is a chariot with 4 or 6 wheels that is located under the wagon and makes it to move. Each wagon usually has two bogies having some parts like chassis, force transmission system, suspension system, and other moving parts.). When the wagon's height changes due to the varied loadings, air suspension valves let the compressed air flow in or get out of the cushion to increase or decrease the height of the wagon [23].

This study was conducted on 11 different trains of 3 lines with similar rail infrastructure in Tehran city metro. The measurements were performed during a fixed period of 20 minutes from 9 a.m. to 16 p.m. in which, the metro traffic was almost uniform. The sample size was determined by considering the similarity of railway systems in the studied three lines and by considering the Standard Deviation (SD) obtained in a preliminary study. As a result, at least 4 trains in each line and 5 trains of each type of AC and DC were studied. It is worth noting that there were only three active trains in line 4 during the study while all of them were of AC type.

The trains were randomly chosen from different lines under the permission of Tehran Urban & Suburban Railway Operation Co. The whole-body vibration was measured by considering convenience criteria on the passenger’s seat and on the cabin’s floor along the 3 directions mentioned in ISO 2631-1 standard. The studied trains of the lines 1, 2, and 4 were of the two types of AC and DC, and the average speed of the trains was 67 Km/h with the SD of 5.3 in all the lines. According to the field studies by Tehran Railway Operation Co, the travel time of passengers in the line 4 normally ranged from 1 hour to 2-2.5 hours in a round trip per day.

It is recommended from the most standard procedures that measurement of whole body vibration along each axis should be performed in duration of at least 20 minutes whenever it is possible, and at least 3 minutes if it is not possible. However, it is possible to perform the measurements during the long-term and sometimes during the mid-term exposures. The least measurement period in this study was 20 minutes [18,20,24,25]. Analysis and calculation of whole-body vibration in the present research was conducted by Excel and SPSS programs based on the instructions of ISO 2631-1.

Normally, the primary index for examination

of human vibration is r.m.s acceleration, although under some conditions, evaluation of a person’s response to vibration using weighed frequency r.m.s acceleration is not adequate, because human’s health could be influenced remarkably by pick amounts. Hence, evaluation with r.m.s method might neglect the risk level; in such cases, the mean standard VDV index is recommended [18,20,26].

Health effects of exposure limits introduced by ISO 2631-1 have undefined health cautious critical zones, “Probable health risk zone”, and health effects zone. In the critical zone, potential health risks have been observed. Low and high limits of r.m.s-based evaluation method are almost similar to each other in range of 4 to 8 hours exposure. The limits for 8 hours exposure are 0.45 m/s² and 0.9 m/s², respectively. According to the VDV method the limits are 8.5 m/s^{1.75} and 17 m/s^{1.75}, respectively, for a usual daily work shift. In addition to the limit values for 4 and 8 hours exposure, the estimated limit values for 0.5 and 2.5 hours of exposure which were employed in this study are listed in table 2 respectively for r.m.s acceleration method and VDV method based on the ISO 2631-1 standard.

In the case of 8 hours exposure of the r.m.s

Table 1 Low and high limits based on the HGCZ in different time durations- from ISO 2631-1

Time period (hour)	r.m.s							
	1		2.5		4		8	
Limits	Low limit	High limit	Low limit	High limit	Low limit	High limit	Low limit	High limit
From the B.1 equation	1.40	2.30	0.85	1.60	0.65	1.20	0.45	0.85
From the B.2 equation	0.90	1.60	0.70	1.30	0.60	1.10	0.50	0.90
Time duration (hour)	V.D.V							
	1		2.5		4		8	
Limits	Low limit	High limit	Low limit	High limit	Low limit	High limit	Low limit	High limit
From the B.1 equation	15.20	25.00	11.60	21.80	10.00	18.4	8.20	15.50
From the B.2 equation	9.75	17.35	9.54	17.72	9.20	16.85	9.10	16.40

B.1 equation: $a_{w1} \cdot T_1^{1/2} = a_{w2} \cdot T_2^{1/2}$

B.2 equation: $a_{w1} \cdot T_1^{1/4} = a_{w2} \cdot T_2^{1/4}$

method, due to the high similarity of the two equations in this region, low limit of B.1 equation and high limit of B.2 equation have been reported in literature. It is worth noting that, general values mentioned in literature for conducting the evaluation by VDV are 8.5 and 17 m/s^{1.75} respectively for low and high limits in the usual work shift which have been obtained on the basis of these graphs .

High and low limits of VDV for 30 and 150 minutes were calculated after determining the r.m.s values from HGCZ. It should be noted that, defined VDV values shall be used for examination of health effects of whole-body vibration in the mentioned time periods, and they cannot be used for evaluating the convenience factor.

Results

Determination of appropriate method for quantitative evaluation:

Normally, r.m.s weighed frequency is utilized for evaluating the health effects of vibration according to ISO 2631-1. However, in some especial cases such as the crest factor over 9, $\frac{MTVV}{a_{wrms}}$ more than 1.5, or $\frac{MTVV}{a_{wrms}T^{1/4}}$ more than 1.75, the standard procedure recommends two alternative methods for evaluation called MTVV (Maximum Transient Vibration Value) and VDV (Vibration Dose Value). MTVV is the maximum current r.m.s value in the measurement period in which, current r.m.s means the largest acceleration in the previous second. Crest factors in this study have been used for judging on the adequacy of the RMS method.

However, it is mentioned by the standard that even if MTVV or VDV are used, it is a must to report the r.m.s values. In other words, when one of the three mentioned conditions exists, vibration shocks become important; and factors like MTVV and VDV should also be taken into account in addition to the basic vibration [4,14,17]. Considering that MTVV is the highest vibration acceleration in 1 second, in this study the effect of a one-second-vibration signal in long terms of measurement like 1200 seconds is not that much significant.

Mean crest factor varied from 5 on the x axis for the AC type trains to 8.9 on the y axis for the DC

type trains of the line 1. Besides, the lowest and highest crest factor values varied from 2.3 on the x axis of participant 7 to about 16 on the y axis of participant 8. Thus, both of the methods, VDV and RMS, were utilized for more accurate evaluations in this study.

As it has already been mentioned, ISO 2631 follows the idea that the whole-body vibration should only be evaluated on the basis of the results of a 3 directional measurements on the seat cushion. Although this standard suggests measuring the vibration of the seat back, in estimations it only considers the results of the three main axes vibration on the seat cushion. Also, it is recommended by the standard to use the highest values of WRMS acceleration and VDV for comparing the results with the allowable limits of daily 8 hours of exposure.

It is expressed by the standard to report the dominant axis when other axes are negligible, and to investigate the resultant of the 3 axes when the measured vibration amounts are comparable on two or three directions of x, y, and z, but it has not introduced any quantitative scale for comparability. In 2003, EN 1032 standard, which is in quite accordance with ISO 2631, introduced a quantitative scale for comparability of axes claiming that an axis can be considered as the dominant one when the amount of weighed frequency r.m.s acceleration in the two other directions is less than 0.66 of the dominant axis after applying coefficient of 1.4 to the horizontal (x) and vertical (y) axes [1, 18,19,21].

In the present study, the comparability examination of the measured axes was conducted on the basis of the latter guideline; indeed, the ratio of Median axes to max axes was utilized for this purpose. In this study, all participants had RMS acceleration values above or equal to 0.66 on the seat cushions, and based on VDV, except for one participant (No. 2) all other cases were in this range. These findings indicated that evaluation of the whole-body vibration effects on human's health ought to be carried out on the basis of Vector Sum Value.

It could be said that, exposure to whole-

body vibration does not happen for each passenger throughout a whole working day; to put it in a simple way, passengers' vibration exposure cannot be studied on the basis of the determined amounts of a usual daily working shift. According to the points stated earlier, in this study the resultant of the three axes in the confluence of seat and passenger was calculated and used to evaluate the effects of whole-body

vibration on human health-caused by traveling by metro. The values of axes resultants and the values of the three axes of RMS acceleration and VDV are observed in table 2. As the table and the calculations indicate, the mean r.m.s acceleration during the measurement time was 1.1 with the SD of 0.14, and average VDV in all the participants was 6.72 with the SD of 1.26. As it is obvious in Table 2, the values of

Table 2 Results of the measured and estimated vibration in the passengers of the studied trains

Code	Line	Car type	Time measurement	r.m.s				CF			VDV			VDV total		
				X	y	Z	VSV	X	y	Z	X	y	Z	VSV	60	150
1	1	AC*	20	0.27	0.46	0.59	0.95	3.32	8.13	4.80	2.45	3.23	5.32	6.07	7.98	10.03
2	1	AC*	20	0.36	0.48	0.69	1.09	8.14	13.02	14.03	1.86	3.18	8.34	8.52	11.20	14.12
3	1	DC**	20	0.28	0.47	0.86	1.15	14.03	11.00	4.02	3.01	3.65	6.05	6.96	9.16	11.50
4	1	DC**	20	0.51	0.33	0.85	1.20	8.31	4.32	13.00	4.71	2.07	6.21	7.66	10.11	12.71
5	2	AC*	20	0.28	0.53	0.49	0.97	4.03	7.51	5.51	2.50	3.52	3.03	5.34	7.02	8.83
6	2	DC**	20	0.51	0.72	0.251	1.25	3.70	15.01	11.02	2.63	3.86	1.08	5.67	7.47	9.39
7	2	DC**	20	0.57	0.77	0.205	1.35	2.33	5.50	7.21	4.40	5.79	0.70	8.71	11.51	14.40
8	2	AC*	20	0.35	0.46	0.67	1.05	3.42	16.04	4.13	2.84	3.85	5.47	6.68	8.79	11.13
9	4	AC*	20	0.39	0.39	0.48	0.91	5.53	3.71	1.62	3.07	2.51	2.43	4.79	6.32	7.92
10	4	AC*	20	0.52	0.35	0.514	1.02	3.10	4.30	15.03	3.74	2.21	5.17	6.28	8.27	10.41
11	4	AC*	20	0.41	0.57	0.64	1.17	7.91	4.81	11.00	3.67	4.22	5.54	7.31	9.61	12.12
		average		0.40	0.50	0.57	1.10	5.80	8.49	8.31	3.17	3.46	4.49	6.73	8.86	11.14
		STDEV		0.11	0.14	0.21	0.14	3.50	4.56	4.65	0.87	1.04	2.36	1.26	1.66	2.09

*AC: Alternative Current

**DC: Direct Current

calculated resultant of axes in RMS method for all the 11 studied cases were above the low limits of both B.1 and B.2 equations (Table 1) during the supposed 2.5 hours exposure, and except for the participant 7 which was higher than the high limit of B.2 equation during the same supposed exposure time, all the other participants were lower than the low limit of the two equations.

Furthermore, the calculated RMS vector sum values in all the 11 studies cases were more than the low limit of B.2 equation in the supposed exposure time of 1 hour, and of course all the values were lower than the high limit of B.2 equation. That is, based on this equation, all the cases are in the HGCZ range and have the potential of health risk in this situation. In the same exposure period all the cases were higher than the low limit and lower than the defined high limit in equation. However, the range

of results obtained from the B.2 equation is closer to the high limit of exposure; therefore, this equation estimates the potential of health risk due to the vibration higher than B.1 equation.

VDV-based evaluations calculated during 1 hour exposure demonstrated that, all the 11 investigated cases on the basis of B.1 equation were under the low limit of HGCZ, and on the basis of B.2 equation, i.e. the safer equation, except for the cases 2, 4 and 7 which were in the HGCZ range; the rest of the 8 cases were below the low limit of HGCZ. Two of the three cases that were higher than the low limit of HGCZ were of DC type trains and the remained one was in type of AC trains.

With assumption of 2.5 hours exposure of Tehran metro passengers, 4 cases out of the 11 studied cases were in the HGCZ range based on the B.1 equation indicating a potential health

risk, and the remaining 7 cases were below the determined low limit. In these cases, two DC type trains and two AC type trains had higher risk levels according to VDV method. Based on the safer equation, in 2.5 hours of exposure, except for the cases 5, 6, and 9 that were below the low limit of ISO 2631-1, the rest of the 8 cases were in the

HGCZ. As it is shown in Table 2, based on the both equations, none of the cases in the VDV scale exceeded the high limit of HGCZ in the assumed exposure times. Results of all the estimated exposures based on the high and low limits of ISO 2631-1 in 1 and 2.5 hours durations are observed in Figure 1.

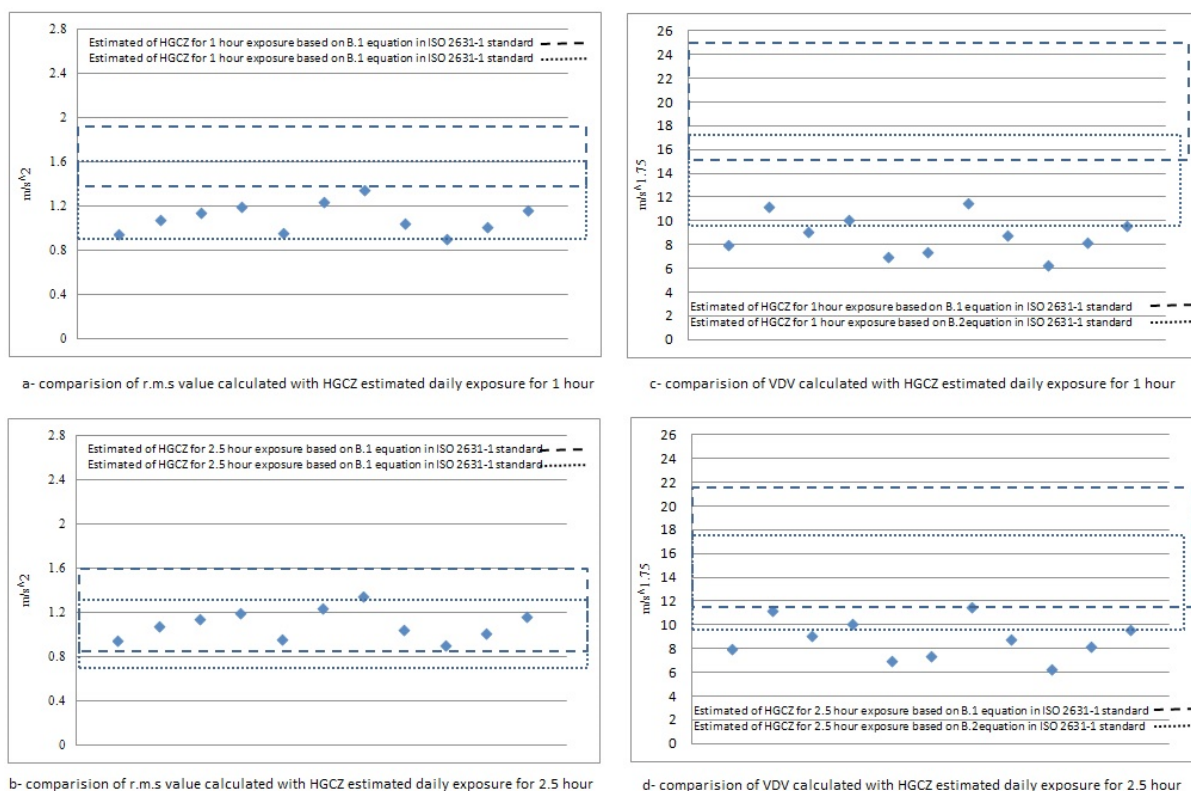


Figure 1 Comparison of the calculated RMS and VDV amount in the considered exposure times with HGCZ limits of ISO 2631-1

Discussion

The findings of the present study indicated that, at the measurement time, average r.m.s acceleration was equal to 1.1 with the SD of 0.14, and average VDV in all the participants was 6.72 with the SD of 1.26. Moreover, average VDV values in 60 and 150 minutes were 8.86 and 11.14 m/s^{1.75}, respectively.

In this study, the value of crest factor at least along one axis observed more than 9 for 7 participants. This is why we used the secondary evaluation method; this critical value has been mentioned as 6 in BS 6841 standard. As far as this value is used for determining an appropriate evaluation method, except for the case 9, the crest factor of other cases was higher than 6, at least along one

axis. In a recent study by Zhao and Schindler, this critical value for crest factor has been recommended as 4.5. If we take this value into account, all the 11 studied participants have a high value of crest factor at least along one axis [20,24,26].

In evaluations by VDV method, the value of VDV as the resultant of axes in the measurement period was 6.72 m/s^{1.75}. This value was 8.85 m/s^{1.75} in the shortest line of Tehran metro for 1 hour exposure. It should be noted that the evaluated values in the sitting position on x and y axes have been multiplied by 1.4. These recent values are more than the calculated values in a study by Narayanamoorthy et al. on Tehran

trains, and are less than the evaluated values in a study by Manal El Sayed et al. on the Cairo metro trains [6,10,27].

Vibration dose is only used for measuring human vibrations. This concept was gained through experimental researches showing that, there is a biquadratic relationship between vibration magnitude and inconvenience and health impacts; so this value has been paid more attention rather than the effective acceleration on the shocks. Due to its cumulative feature, the value of vibration dose does not decrease by decreasing vibration magnitude along time, while the effective acceleration remains stable under such conditions. Lewis and Griffin have reported that, using VDV method for evaluating the health effects caused by a kind of vibration containing important shocks, gives a more cautious and safer evaluation in comparison to the basic method of evaluation [4,15,28].

Comparing the results of the VDV and RMS methods shows that, RMS in this study is a better method for examination the effects of whole-body vibration on the passengers' health, maybe due to vibration signals containing the short-range picks. It should be mentioned that, in VDV evaluation, the values were gained by equation 7, and unfortunately the high and low limits in ISO 2631-1 standard were determined only in 8 hours exposure. Future studies may suggest another method for evaluating the vibration dose values in the exposure periods less and/or more than 8 hours. Anyways, based on the present study, RMS method seems to be the prior method. However, study of vibration in other types of transportation vehicles has shown that, VDV method is generally a safer evaluation method in comparison to RMS method [7,25].

In the recent studies, in which the two ISO 2631-1 and ISO 2631-5 standards have been compared to each other, it has been shown that, VDV limits in different standards may not provide adequate and necessary safety for human health in some occupations. Thus, more studies should be conducted especially for determining safe limits of vibration exposure on the basis of VDV index. Vibration exposure in each environment or in each kind of machinery

creating human vibration has special features of its own, and hence, no general rule or method can be prescribed for all the conditions and machineries.

In 2005, Alem suggested some alterations for HGCZ limits related to VDV in order to predict health risks caused by confrontation with whole-body vibration. He believed that, the ISO 2631-1 limits are high. He suggested that, the low limit of HGCZ (submitted by ISO 2631-1, Annex B) should be 3.5 and its high limit should be 4.8 (23). If these values are used in this study, all the explored cases in both 1 and 2.5-hour exposures would be above the defined high limit.

Although the recent values have been recommended for 8 hours of exposure, when their equivalent shorter times were calculated, considering the nature of the biquadratic root of vibration dose values, 4 cases of the evaluated VDV amounts in 60 minutes were in the new HGCZ and the other cases were higher than the high limit of 8 m/s^{1.75}. In 150 minutes of exposure, all the cases had higher values than the high limit (= 6.4 m/s^{1.75}) obtained by a B.2-like equation, and they were in the possible health risk zone. Since VDV gives a safer criterion because of its inherent features, such as considering biquadratic root of vibration acceleration signal, it could be concluded from the obtained results of the present study that, ISO-based VDV values are not in the safe limits, especially in short-term and permanent exposures, so further studies should be conducted to revise the defined limits of this index.

In BS 6841 standard, VDV equal to 15 has been defined as the health risk limit. However, this standard even at threshold VDV value of 15 has been very cautious as a safe limit and has called it just a general index [10]. EU has also submitted two criteria of daily action level and limit level of whole-body vibration for r.m.s and VDV through an instruction entitled "Physical Factors Instruction (vibration)"; these newly introduced criteria are very similar to the low and high limits of HGCZ [1,20,24]. Eventually, in evaluating r.m.s values with submitted health criteria in ISO 2631 standard, it should be said that, generally the evaluation

should be conducted when it is supposed to estimate health effects risk, and it is correct when the passengers' exposure is permanent and always happens during the week. Thus, if the vibration exposure of the passengers is not permanent, using this criterion is basically wrong. Anyways, when the exposure time reduces, the defined low and high limits change as well, and their values are shown in table 2 for the exposure periods of 30 and 150 minutes. In order to determine the level of health effects risk in the passengers, the values have been proposed according to graph 1 in case of recurrent and permanent exposures for the daily exposure periods of 1 and 2.5 hours.

The HGCZ limits for each exposure period highlights a risk level on the graphs for all the different studied samples and trains, both in the r.m.s method and in the VDV method. The results of the vibration exposure in this study show lower exposure values in comparison to the findings of Manal El Sayed et al [6]. Also, it is suggested for the future researches to study the first and the last wagons of trains and evaluate different parts of the wagons to determine an exact exposure amount. It is also suggested to use Sed index, recommended by ISO 2631-5, for determining the passengers' exposure amount, and to compare the results of those studies with the results of this research.

Conclusion

As figure 1 indicates, total r.m.s acceleration for the passengers with 1 hour of daily exposure was equal to 1.1 m/s². This value was between the low and high limits determined by an equation which shows safer limits in shorter exposure periods. Based on the standard calculations, the passengers with the average daily exposure of 150 minutes were in the limits of HGCZ, too. It is of worth to mention that, this amount of exposure is of importance especially for the passengers who are exposed to whole body vibration in their occupations. Hence, these exposure amounts can be used in evaluating their occupational exposure. The VDV values in 60 and 150 minutes – based on the equation which creates more safety – were under and in range of the HGCZ limits, respectively.

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Contribution

Study design: KA, RM, AKH

Data collection: KA, ZS

Data analysis: KA, ZS, RM

Manuscript preparation: KA, RM, AKH

Conflict of interest

"The authors declare that they have no competing interests."

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