

Preliminary assessment of vibration impacts generated by the public transport systems on pregnant women based on subjective reactions

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Purpose: Research efforts summarised in this study were a part of preliminary investigation to evaluate the impact of pregnant women's exposure to vibrations generated by public transport system when using. *Methods:* The assessment of the problem and discomfort for pregnant women, caused by the public transportation is based on a questionnaire including questions relating to the women's subjective feelings on well-being or discomfort when exposed to vibration during the ride in passenger cars or when using means of public transport. In the second stage of investigation, vibrations transmitted onto a sitting person during the tram or car ride were measured. *Results:* The survey shows that when travelling on a tram the women complained mostly of digestive or neurological disorders, during the car ride they suffered most acutely from digestive disorders, sensed enhanced foetus movements and reported problems with the osteoarticular system. Amplitude-frequency characteristics of the investigated vehicle types reveal that vibration amplitudes registered during the ride in a motor vehicle are higher than on tram (in the analysed frequency range). Furthermore, vibration accelerations in the z-axis direction registered during the tram ride exceed the vibration discomfort threshold, particularly for the 1/3 octave bands 5 and 6.3 Hz. These are frequency ranges corresponding to resonance frequencies of vital organs in the abdominal cavity (4.5–10 Hz). *Conclusions:* Correlating these results with frequencies reported in literature associated with subjective human responses to vibration, shows that pregnant women using public transport are likely to suffer from a variety of ailments caused by vibrations generated during the ride.

Key words: pregnant women, whole body vibration, vibration discomfort threshold, amplitude-frequency characteristic, public transport, means of transport

1. Introduction

Impact of vibrations on human body via a direct or indirect contact with a vibrating source is most diverse, in some cases leading to mechanical damage of tissues (for example when the frequency of high-energy excitation coincides with the resonance frequency of the body organ or system), or to psychomotor response triggered by vibration (stress or dysopia). Human body response to mechanical vibration depends mostly on frequency of the acting excitation, vibration amplitude and time exposure. Particularly

important is the direction of acting vibration and the presence of an external body support. Individual factors include the mass and position of body segments and the psycho-physiological conditions (tiredness or nervousness). How vibration impacts on pregnant women is another issue to be addressed, both in the context of ergonomy and external stimuli sensed by the woman's body during the activities beyond the workplace (for example, during the car ride or when using public transport).

Even though research efforts have been undertaken and certain measures put in place to minimise the negative impacts of vibration on humans during

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the everyday activities, very few authors have so far attempted to evaluate the effects of vibration on pregnant women in the context of reported complaints and potential health risk. There are studies presenting evidence of the detrimental effects of whole-body vibration on pregnancy [25]. This author found out that the higher risk of premature birth and menstruation disorders can be attributed to long-term exposure to whole body vibration, and no safe exposure limits can be established to avoid the enhanced risk to the woman's health in the prenatal period [25].

Numerous authors emphasise the role of quantitative assessment of vibration impacts on pregnant women in the course of everyday activities (workplace conditions, transport systems) [2]. Di Corleto [5] highlights the need for further research to investigate the effects of noise and vibration on pregnant women. It might be reasonable if employers were required to limit the vibration exposure for pregnant women to the lowest reasonable extent and this regulation should be incorporated in health monitoring guidelines or in relevant codes of practice.

A similar problem concerns the possibility of safe use of household appliances and physical training devices by pregnant women (physical activity and exercises are advised during pregnancy).

In the case of a device, such as vibration plate which serves, for example, for muscle strengthening and fat reduction, vibrations generated occur in the frequency range of 6–28 Hz. Manufacturers do not recommend vibration plates to be used by pregnant women (or even prohibit to use them), concluding that there are no current clinical studies showing the effects of these devices on pregnant woman.

In many European countries the working conditions for women, especially for pregnant women, are a subject of stringent regulations. In Poland, these issues are governed by the regulation [24] specifying the admissible levels of vibration exposure and imposing a restriction preventing pregnant women doing jobs involving whole-body vibration exposure (no admissible levels are provided, though). It is impossible, however, to entirely eliminate the impacts of vibration on women in everyday life, so it seems reasonable to define the safe limits of whole-body vibration.

The work by Van Dyke [27] provides a literature review of occupational risks and conditions negatively impacting on pregnant women at work. The study by Makowiec-Dąbrowska et al. [15] summarises the results of research on workplace conditions and maternal adverse outcomes in Poland. Their findings indicate that the workplace conditions of 75% of women

in the first trimester of pregnancy failed to comply with the respective regulations, and for 50% of them those conditions would not change for the entire period of pregnancy. Vibrations were found to be the occupational risk factor reported as nuisance and responsible for pregnancy complications, such as premature birth or child's low body mass at birth. The risk of a maternal adverse outcome would grow after the first trimester.

Similar observations were made by Croteau et al. [4] who assessed the association of premature deliveries with workplace conditions for pregnant women in Canada. Haelterman et al. [8] reported a weak association of preeclampsia with whole-body vibration exposure.

Mamelle et al. [16] investigated the relationship between premature births and work activity of pregnant women, concluding that the work on 'industrial machines' increases the risk of premature delivery. However, the authors failed to expressly attribute premature deliveries to vibration exposure, they also considered other factors, such as physical exertion, stress and environmental factors which also contribute to the general health condition.

Joubert [11] investigated the vibration impacts on professional drivers, both men and women. The extensive literature review ended with a conclusion that, based on gathered evidence, it is reasonable to suppose that long-term whole-body vibration exposure during the ride may be associated with disorders of the reproductive systems both in men and women, though the evidence is still weak and far from conclusive. Though incomplete and unverified, the available data should not be ignored altogether and may be regarded as an indicator of detrimental effects on the reproductive system, thus highlighting further research needs.

The main issue raised by numerous researchers is the difficulty involved in carrying experimental investigations with participation of pregnant women. Most studies are based on computer simulations (for example models used for assessing the characteristics of the woman-foetus system [7], [22], passenger safety tests in motor vehicles, using dummies [28] and experimental tests in which the risk to woman participants should be kept as low as possible [10].

Despite variety of available biomechanical models for assessing vibration transmitted onto a seated human body [22], Liang and Chiang [13] emphasise the need to adapt and modify them to suitably represent a pregnant woman's body.

Another source of information are experiments on animals, assuming the similar response to whole-body

vibration. Peters et al. [21] established the resonance frequency of an ewe's uterus to be 8–16 Hz. The authors came to the conclusion that vibrations at resonance frequencies do not affect the foetus or their impacts are minimised by the body. According to Nakamura et al. [19] and Penkov [20], vibration exposure contributes to the lower blood flow in the uterus in pregnant female rats, which might lead to complications.

Each system and each body organ has a specific natural frequency (Table 1). They determine individual subjective reactions which depend on displacements of internal organs and supporting body structures. These displacements are associated with vibration energy and individual features of the involved organs or body parts (such as mass). Actual values of resonance frequencies are also related to the body position [17], [22], [28]. When the admissible levels of vibration are exceeded, the organ can be injured or damaged. Sub-

jective conditions summarised in Table 2 are characteristics of particular frequency ranges which can be associated with particular complaints. It is reasonable to suppose that resonance vibrations of internal organs can be determined based on reported health conditions in humans (in this case women in the prenatal period). Such investigations can well rely on questionnaires.

The aim of the present study is the qualitative assessment of subjective responses and symptoms experienced by pregnant women during the ride in a passenger car and on tram. A questionnaire was conducted to determine the scale and severity of symptoms experienced by women in various stages of pregnancy when travelling in a passenger car or on public transport. Results were related to vibration levels measured during the ride in a passenger car and on tram.

The authors identified 1/3 octave bands in which the highest vibration accelerations are registered and related these to resonance frequencies of particular

Table 1. Literature review of resonance frequencies of human body parts and organs and the body's subjective response to vibration

Body part	Nader M. 1984 ¹ [18]	Zaborowski T. 1995 ¹ [29]	Nader M. 1984 ² [18]	Coermann R.R. ² [3]	Więckowski D. ³ [28]
Head	4–5; 17–25	4–5; 17–25	4.2; 5.5; 10.6; 24.0	5–30	6–8; 27–40
Shoulders and head	20–30	–	–	–	32–47
Jaw	6–8	6–8	–	–	9–13
Eye balls	60–90; 40–90	60–90	–	20–90	–
Abdominal cavity organs	4.5–10	4.5–10	–	4–8	–
Liver	3–4	3–4	–	–	–
Stomach	2–3	–	–	–	–
Urinary bladder	10–18	10–18	–	–	–
Kidneys	6–8	–	–	–	–
Chest	5–7; 4–11	–	–	5–9	8–11; 6–17
Lungs	4–11	–	–	–	–
Heart	4–6	–	–	–	–
Trachea, bronchi	12–16	12–16	–	–	–
Torso, upper part	4–5	–	–	–	–
Torso, lower part	4–6	–	6.1; 9.1; 11.4	–	–
Pelvis	5–9	10–18	–	–	8–14
Spine	10–12	8	–	10–12	16–19
Sacral spine	8–12	–	–	–	13–19
Lumbar spine	8–12	–	–	–	13–19
Lower limbs	5	5	–	2–20	8
Hips	5	–	5.3; 6.1; 9.1	5–9	8
Calves	20	–	6.1; 11.4	2–20	32
Feet	–	–	59.2	–	–
Upper limbs	4–5	3	–	–	6–8
Arms	16–30	–	5.5; 6.3; 11.4	16–30	25–47
Forearms	4–6	–	4.2; 6.3; 13.2; 21.3	5–10	6–9
Hand	20–30	–	6.3; 13.2; 19.6; 30.9	30–50	32–47

1 – resonance frequencies of human body parts obtained experimentally.

2 – resonance frequencies of human body parts derived from model testing.

3 – natural frequencies of body parts of a baby evaluated based on natural frequencies of an adult's body parts.

Table 2. Subjective response to whole-body vibration in the range 1–20 Hz

Symptoms	Frequency [Hz] [23]	Frequency regarded as a nuisance [Hz] [12]	Frequencies in which reactions are intense [Hz] [12]
General feeling of discomfort	4–9	1–20	4.5–9
Head symptoms	13–20	9–20	13–20
Lower Jaw symptoms	6–8	6–8	–
Influence on speech	13–20	–	–
Chest Pain	5–7	4–11	5–7
Abdominal pains	4–10	4–14	4.5–10
Urge to urinate	10–18	9–20	10–18
Increased muscle tone	13–20	10–20	13–20
Influence on breathing movements	4–8	4–8	–
Muscle contractions	4–9	–	–
Lumbar sacral spain	–	6.5–20	8–12
Rectal tenesmus	–	9–20	10.5–16

body organs, then strove to correlate the means of transport with the symptoms suffered by pregnant women.

2. Materials and methods

2.1. Questionnaire

In order to identify the scale and severity of symptoms pregnant women suffer from when travelling, an anonymous questionnaire was conducted via the Internet, consisting of 21 questions pertaining to women's subjective reactions, the symptoms they experienced due to whole-body vibrations during the ride on public transport and in a passenger car. There were 110 women participants aged 16–36 years (84% of respondents were aged between 20 and 30), in various stages of pregnancy or shortly after the childbirth.

2.2. Experimental tests

The next stage of the project consisted of measurements of vibration transmitted onto a sitting person during the tram ride or when travelling in a passenger car. No measurements were taken for a person travelling on a tram in the standing position.

Selection of the means of transport in the context of vibration exposure was prompted by the fact that a majority of women reported most intensive foetus movements during the car ride and that many women complained of neurological disorders when travelling

by tram. At the same time the tram and car ride was regarded as wearisome in similar degree (Fig. 2). Regarding the bus ride, which was considered to be a nuisance by three times more women than by those complaining of the tram ride, the digestive disorders were experienced mostly in the first trimester of pregnancy (which may be attributed to typical ailments associated with pregnancy and not necessarily triggered by vibrations).

Vibrations were registered during the tram ride, covering eight track sections denoted as MST1–MST8, in between four tram stops located at a varied distance from one another (490–660 m). The average speed of the tram ride was 36 km/hour. The 500-meter distance (control road section for the car ride) was covered 4 times (MSC1–MSC4), with the average velocity about 50 km/hour. Parameters of investigated vehicles are summarised in Table 3.

Table 3. Characteristics of the means of transport considered in the tests

Vehicle type/ model	Geometry of the vehicle (dimensions in [m])			track spacing/ wheel base [m]
	Length	Width	Height	
Tram/ 2014N-Krakowiak	42.8	2.4	3.6	1.435
Passenger car/ Skoda Octavia 1.9 TDI	4.5	1.7	1.4	2.566

The subject participating in the test was a 23-year old healthy woman (174 cm in height, weighing 60 kg) who was not pregnant, so she was not exposed to potential side-effects involved in the measurement procedure. The woman was subjected to vibration during the tram ride, she changed her location on the tram (moved from a seat located between

the wheel axles to that located directly over the tram wheel).

Vibrations were registered via a measurement system incorporating a four-channel vibration analyser SVANTEK SVAN 958 with a triaxial transducer SV 39A. A digital processor yields the estimates of measured parameters' signals (rms value of vibration acceleration in the 1/3 octave bands). Registered vibrations were in the range from 0.5 Hz to 10 kHz. The disc with vibration acceleration sensors was placed in the middle point of the seat on which the test participant was seated. Vibrations were measured in three directions of acting excitations. Measurement signals from the triaxial sensor passed to the spectrum analyser where they were recorded and processed using the program SvanPC++. The average time of measurement was 1 s.

3. Results

3.1. Questionnaire

The analysis of the survey's results revealed that 63% of women experienced some negative symptoms when travelling, as summarised in Fig 1.

A majority of women complained about general abdominal symptoms (50%), such as nausea, stomach ache or hardening with associated symptoms, such as dizziness and feeling of tiredness. 12% of participants reported enhanced foetus activity (in some cases described as feeling of uneasiness). 7% of women complained of dizziness passing into strong headache. Some women described their condition as nearing the loss of consciousness, one

woman had this sensation repeatedly. 7% of women reported the spine and shoulder aches, the feeling of heaviness in the chest and breathlessness. 5% of respondents felt feeble and complained of excessive tiredness. 20% reported a simultaneous occurrence of a variety of digestive, neurological and osteoarticular symptoms.

11% of participants reported some complications during their pregnancy, such as shortening of the uterine cervix, miscarriage or gestosis. They all pointed out to symptoms triggered by vibrations. The sensations frequently experienced during the ride included nausea, stomach ache, dizziness, feebleness, joint aching and more intensive foetus movements.

According to the survey (Fig. 2), the majority of pregnant women suffered mostly when travelling by bus (47%). The proportions of the remaining means of transport (minibus, car, tram) were similar (15–17%). One has to bear in mind, however, that the responses may be prompted by the need to choose a particular means of transport depending on the actual location of their place of residence and destination. At the same time, 90% of women stated that they assumed the sitting position during the ride, which seemed more comfortable and safer in the event of unexpected manoeuvres (rapid speed variations or reversing). However, in the sitting position vibrations are transmitted both via the seat and the backrest. Regarding the sitting position, there is no control of the seat position in the buses or trams, which negatively impacts on ride comfort.

The diagram in Fig. 3 represents the percentage fractions of symptoms reported by pregnant women during the ride by specified means of transport (passenger car, bus, minibus, tram). The analysis of feedback reveals that 49% of women suffered from diges-

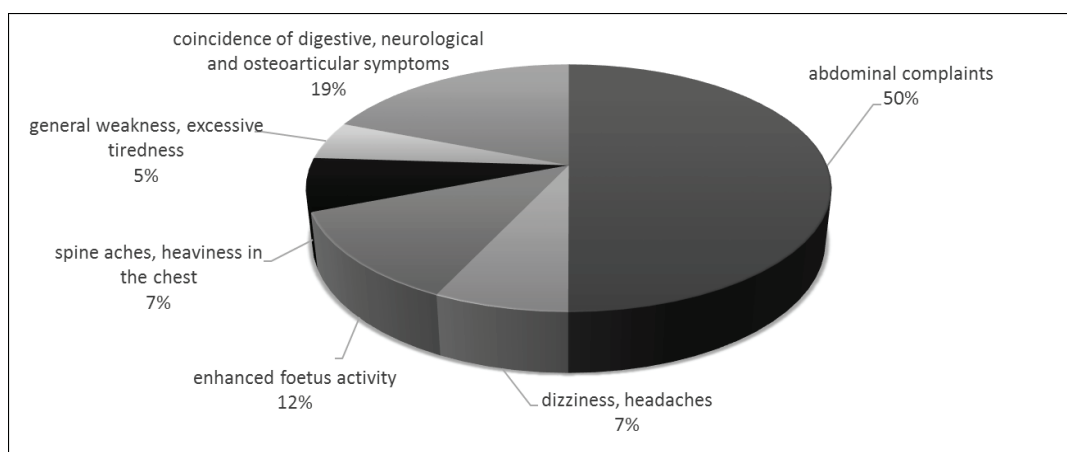


Fig. 1. Proportions of symptoms experienced by pregnant women during the ride

tive disorders (feeling of nausea, hardening of stomach) when travelling by bus, 19% of women experienced neurological disorders, 18% sensed more intensive foetus movements, 8% reported problems with the osteoarticular system, 4% felt excessive tiredness.

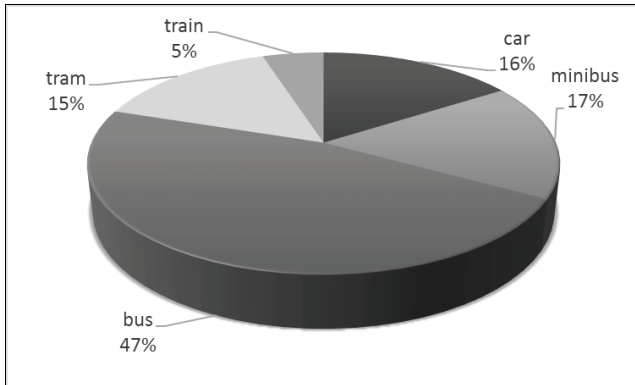


Fig. 2. Percentage fractions of means of transport (as perceived as nuisance by pregnant women during the ride – results of a questionnaire)

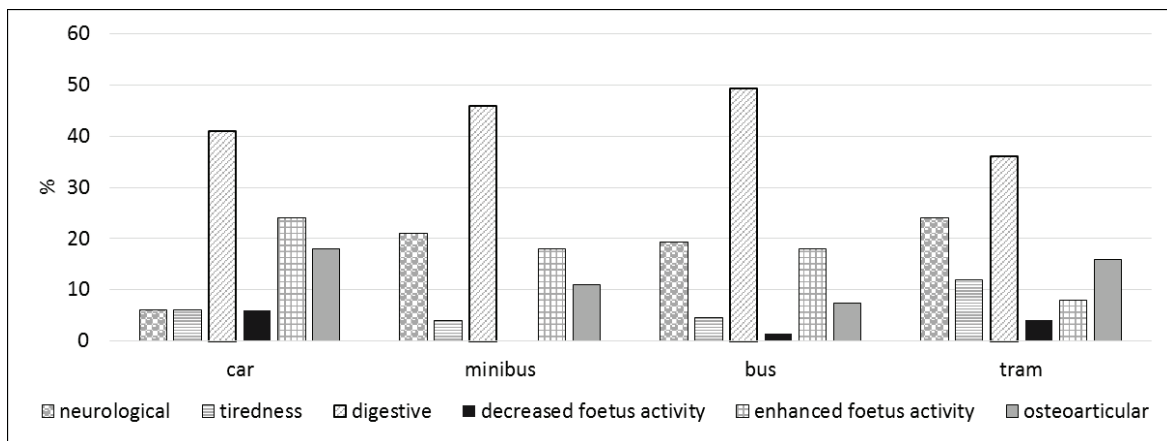


Fig. 3. Symptoms experienced in selected means of transport

Results pertaining to the minibus ride show a similar tendency. The largest number of women (46%) complained of digestive disorders, 21% experienced neurological symptoms. No woman reported weaker foetus movements.

In general, those women, who suffered most during the tram ride rather than on a bus or minibus, complained of digestive disorders and neurological symptoms (mostly dizziness, vertigo).

Among those who found the car ride most wearisome, 41% of women complained mostly of nausea, 24% sensed more intensive foetus movements. It appears that the participants perceive the ride in a passenger car as the source of vibration triggering the foetus movements.

47% of participating women have taken care to find the optimal seat when travelling by public transportation. For the majority of them it is a seat in the front part of the vehicle or carriage, only 7% choose the middle section (no participant indicated the rear part of the vehicle). Obviously, the choice of a seat may be associated with availability of seats on a crowded bus or tram and with hard to define psychological aspect (security in the event of emergency conditions, actual positions of seats for privileged passengers).

3.2. Experimental tests

Evaluation of measurement data consisted of three stages. In the first stage the amplitude-frequency characteristics were obtained in the range 0.8–100 Hz for vibrations in three directions (x -, y -, z -axes), registered on the seat of a tram and in a passenger car. Plots

MST1-MST9 shown in Figs. 4–6 were derived by averaging the vibration accelerations for each 1/3 octave band obtained from vibration measurements on the tram (vibration accelerations for individual 1/3 octave bands with the average time 1 s). The same procedure was applied to derive the plots MSC1-MSC4 (Figs. 7–9) pertaining to the car ride. Thus obtained vibration acceleration values a_{RMS} were related to the threshold of vibration perception specified in the standard ISO 2631 [9].

The average accelerations of vibration in three directions registered during the tram ride do not exceed the vibration threshold of discomfort. Particularly important are vibration accelerations in the low frequency range (up to 20 Hz), in consideration

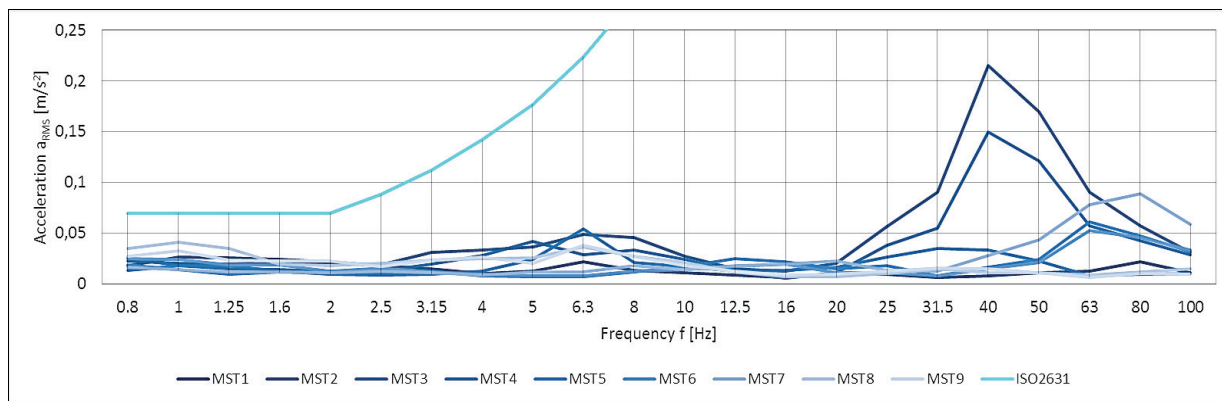


Fig. 4. Amplitude-frequency characteristics for the tram ride, vibration in x -axis direction

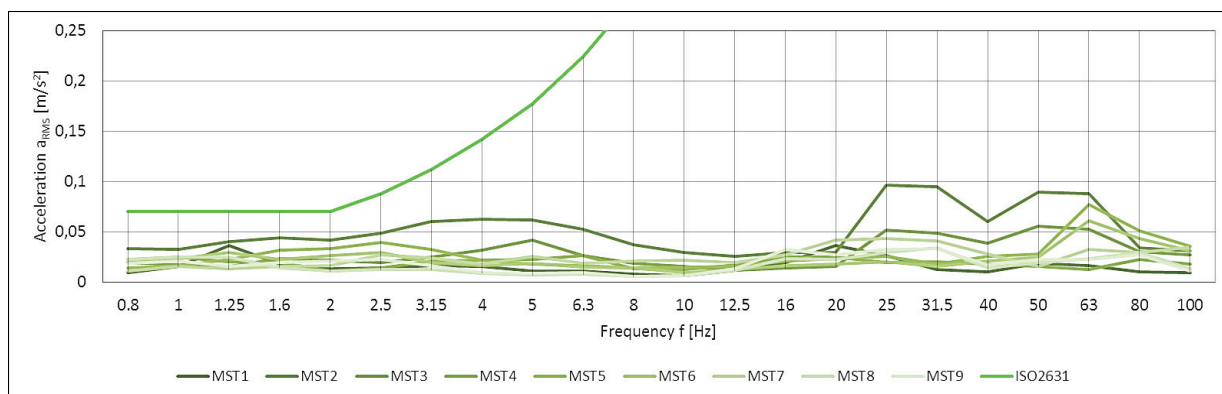


Fig. 5. Amplitude-frequency characteristics for the tram ride, vibration in y -axis direction

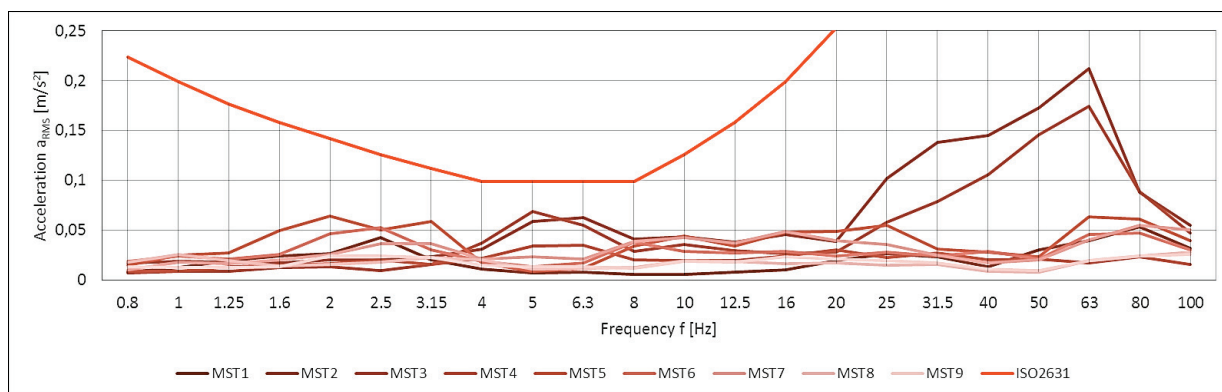


Fig. 6. Amplitude-frequency characteristics for the tram ride, vibration in z -axis direction

of resonance frequencies of human body organs (particularly those vital for pregnant women). It appears that variations of vibration accelerations in particular frequency bands are similar for subsequent passages of the vehicle ride (particularly in the y -axis direction) despite differences in track structure and the track cross-tie systems. Greater variability is observed for 1/3 octave bands between 3.15–8 Hz for the x -axis, the pertinent ranges in the z -axis direction were 1.6–3.15 Hz and 5–6.3 Hz. In

the frequency range exceeding 20 Hz, the vibration acceleration value a_{RMS} increased significantly for certain sections for vibration in the x - and z -axis directions.

Plots obtained for the car ride (Figs. 7–9) reveal that in the x -axis direction the largest discrepancies between vibration acceleration values are registered in the frequency range of 0.8–1.25 Hz and 10–63 Hz, in the direction of the y -axis these ranges are: 10–25 Hz and 50–63 Hz. The largest discrepancies are registered

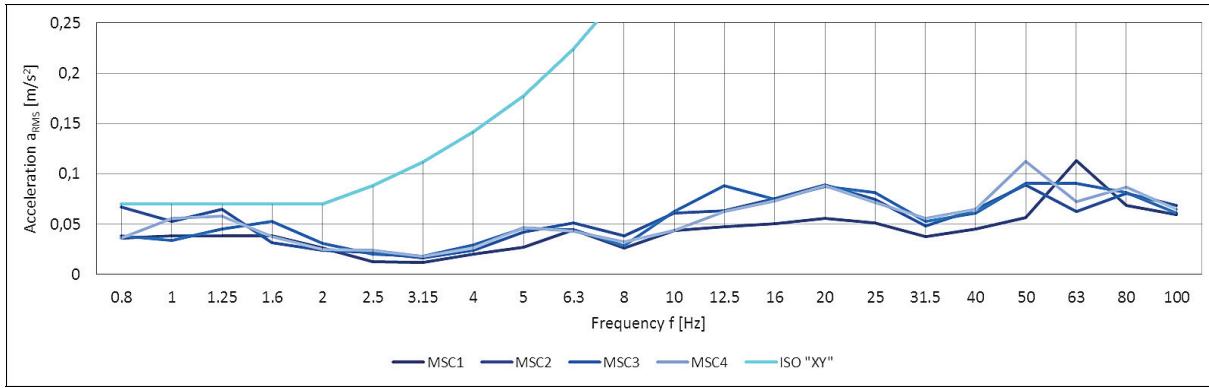


Fig. 7. Amplitude-frequency characteristics for the car ride, vibration in x -axis direction

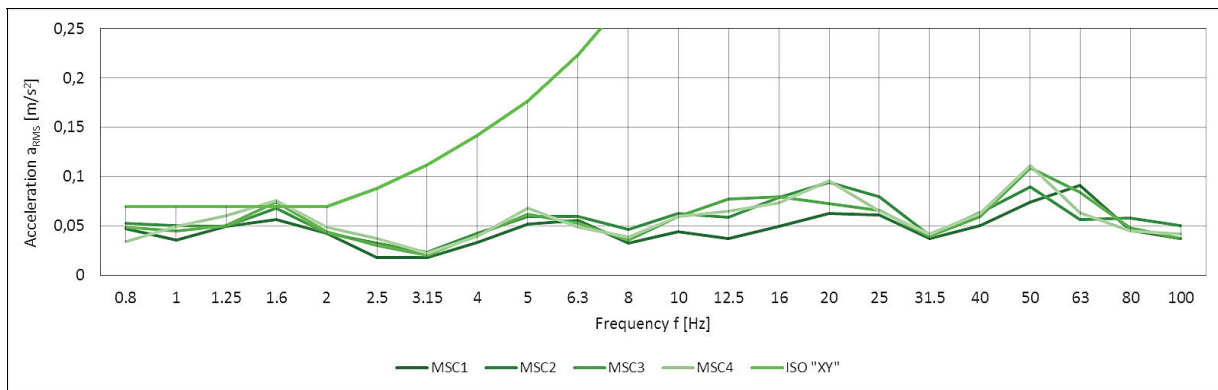


Fig. 8. Amplitude-frequency characteristics for the car ride, vibration in y -axis direction

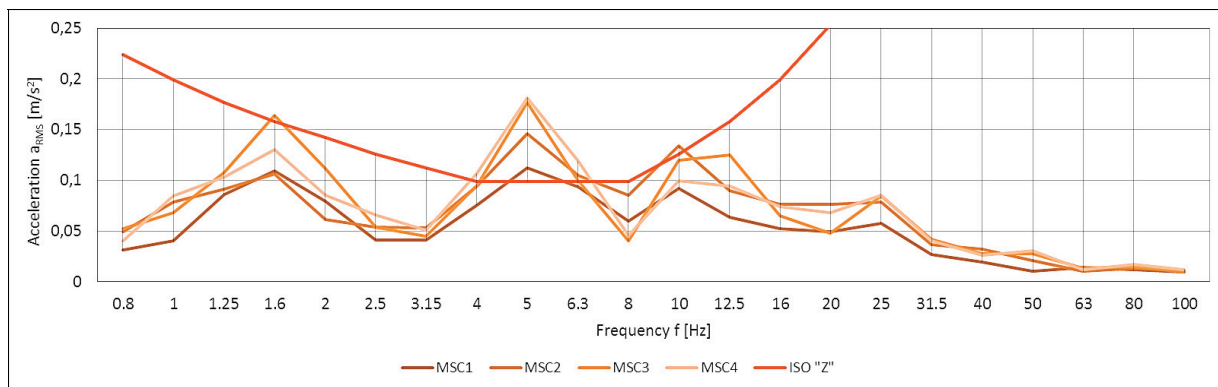


Fig. 9. Amplitude-frequency characteristics for the car ride, vibration in z -axis direction

for the z -axis direction (1/3-octave bands 1.6 Hz and 5 Hz and vibrations in the range 10–12.5 Hz), in the case of vertical vibrations the discrepancies of the rms acceleration values are found to be the greatest.

Regarding vibrations in the direction of x - and y -axes and in the low-frequency range, the measured values are nearing the comfort contour corresponding to the threshold of vibration perception, accordant with the standard ISO [9], in the direction of the z -axis the threshold of discomfort is exceeded for the 1/3-

octave bands 1.6, 4, 5, 6.3 and 10 Hz. These results are consistent with those summarised in Table 1, fully explaining the discomfort and symptoms experienced by pregnant women during a car ride.

The second stage of analysis of the results of the tests conducted was focused on variations of vibration acceleration values a_{RMS} for the given frequency, as a function of time and on variations of instantaneous accelerations related to the threshold of vibration perception specified in the ISO standard [9].

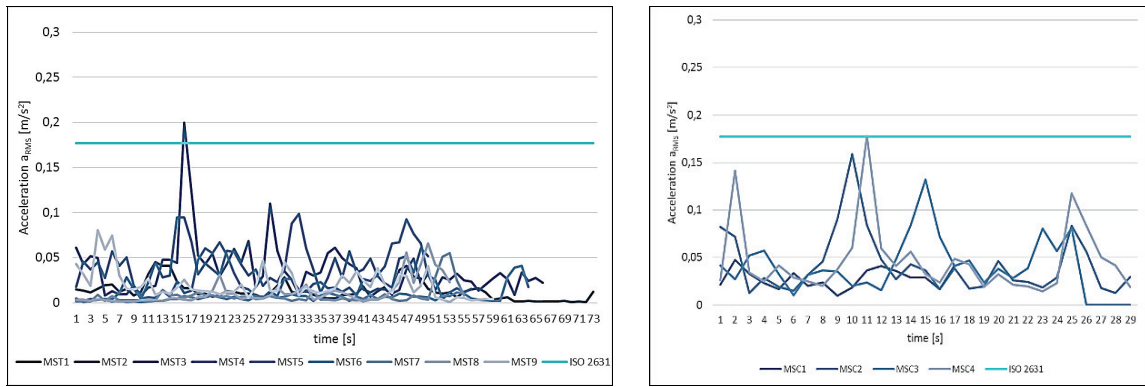


Fig. 10. Dependence of vibration in the x-axis direction on time, at the 5 Hz frequency, for tram and car ride

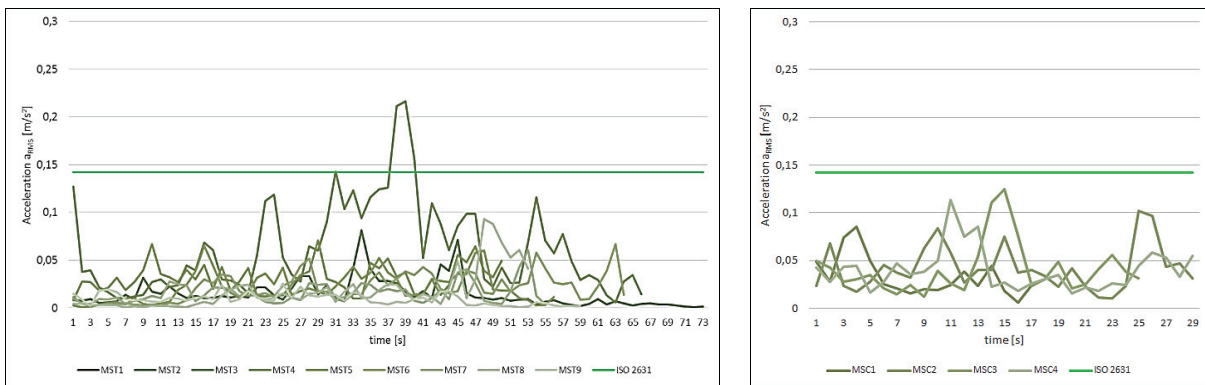


Fig. 11. Dependence of vibration in the y-axis direction on time, at the 4 Hz frequency, for tram and car ride

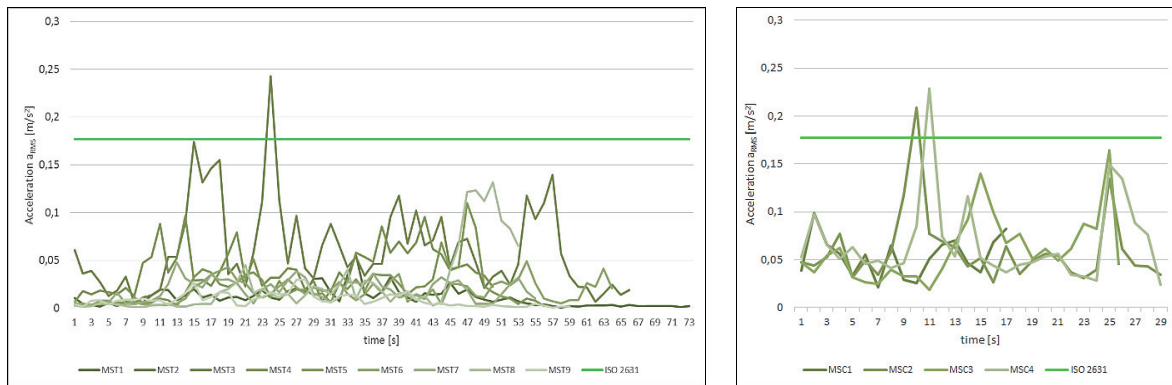


Fig. 12. Dependence of vibration in the y-axis direction on time, at the 5 Hz frequency, for tram and car ride

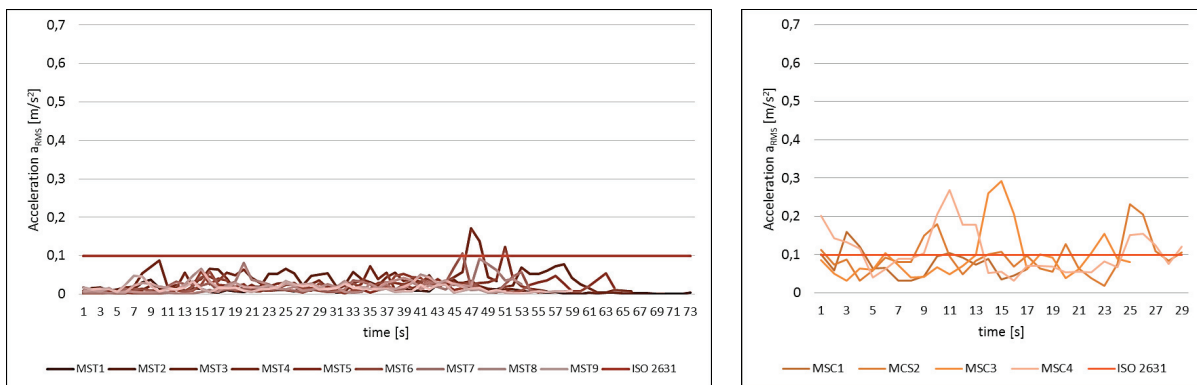


Fig. 13. Dependence of vibration in the z-axis direction on time, at the 4 Hz frequency, for tram and car ride

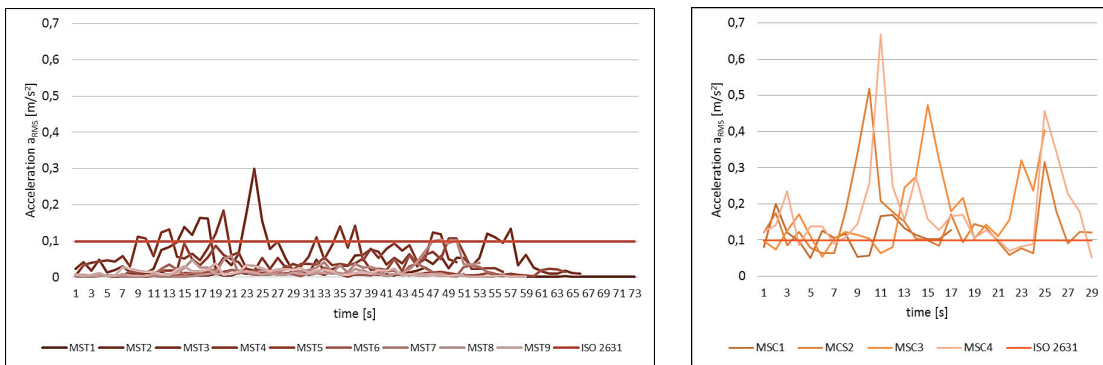


Fig. 14. Dependence of vibration in the direction of z-axis on time, at the 5 Hz frequency, for tram and car ride

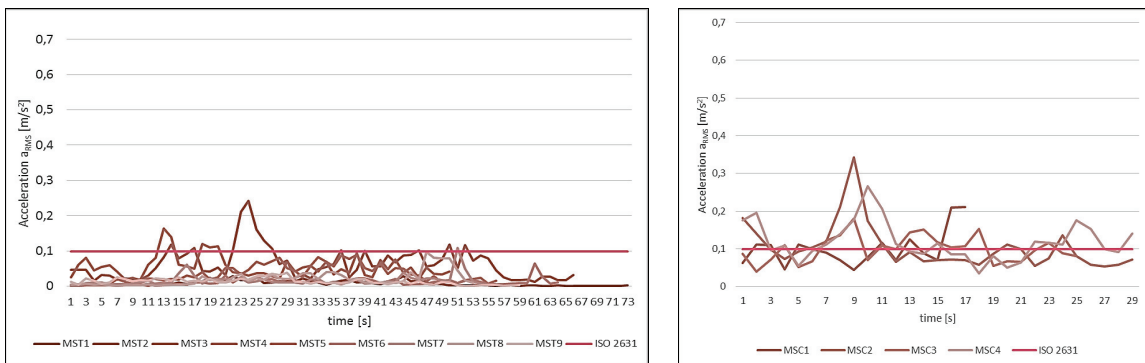


Fig. 15. Dependence of vibration in the direction of z-axis on time, at the 6.3 Hz frequency, for tram and car ride

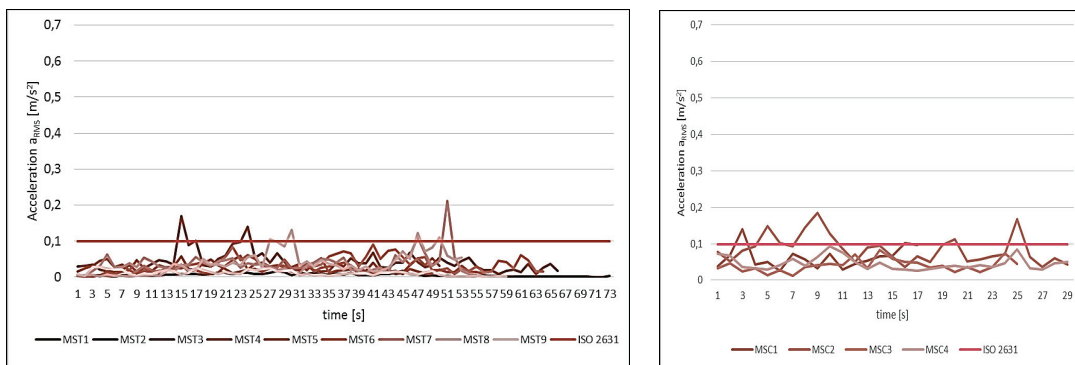


Fig. 16. Dependence of vibration in the direction of z-axis on time, at the 8 Hz frequency, for tram and car ride

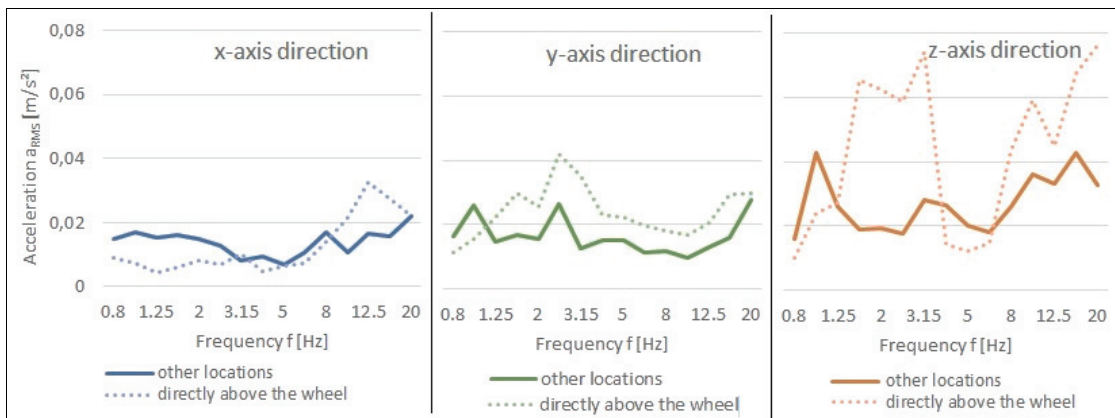


Fig. 17. Amplitude-frequency characteristics for the tram ride, depending on the seat location, in the frequency range up to 20 Hz: (a) x-axis, b) y-axis, c) z-axis

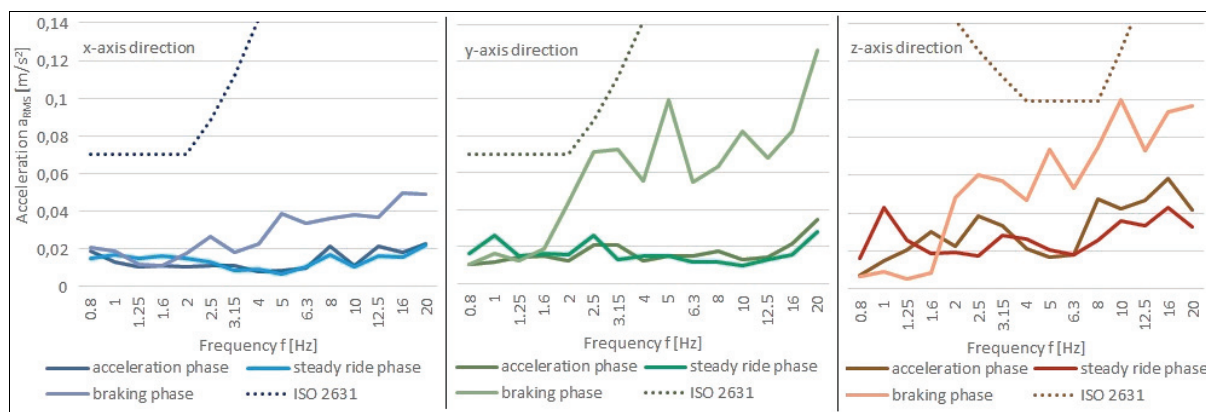


Fig. 18. Amplitude-frequency characteristic for the tram ride, depending on the phase of the ride, in the frequency range up to 20 Hz

Because of the risk which pregnant women are exposed to due to vibrations in the frequency range coinciding with resonance frequencies of the abdominal cavity organs, the 1/3-octave band range of 5–8 Hz was considered in the evaluation procedure. Figures 9–18 show comparison of the selected time dependencies obtained for the tram and car ride.

The third stage of analysis involved the comparison of vibration accelerations registered during the tram ride, depending on the location of the seat occupied by a pregnant woman (directly above the wheel, other locations) and in various stages of the ride (acceleration, steady ride, braking). Amplitude-frequency characteristics shown in Figs. 16–17 were obtained for 1/3-octave bands from 0.8 to 20 Hz. According to Table 1, those are frequency ranges coinciding with resonance frequencies of those body parts and organs associated with symptoms and ailments experienced by pregnant women when using the transport system.

Apparently, the location of the seat on a tram is of some importance. The greatest differences in a_{RMS} values were registered for vibration in the vertical axis (in z -axis direction) in the frequency range from 1.6 to 3.15 Hz (nearly threefold increase) and for frequencies 8, 10, 16 and 20 Hz. For horizontal vibrations (in the direction of x and y axes) the differences in registered accelerations were smaller and nearly identical throughout the investigated frequency range 0.8–20 Hz.

Plots in Fig. 18 indicate that the impacts of the braking phase produce most detrimental effects on tram passengers. Even though the maximal values of a_{RMS} do not exceed the levels specified in the relevant standard, the maximum level registered in the y -axis direction coincides with the 1/3-octave band 2.5–20 Hz, associated with reported symptoms. It is worthwhile to mention that the vehicle used in the study was very modern, for older vehicles those values might be even

higher. For horizontal vibrations (in x - and y -axis direction) the amplitude-frequency plots for the acceleration and steady ride phase were similar. In the case of vertical vibration (in z -axis direction), a_{RMS} values differed and the largest values were registered for 1/3-octave bands 1 Hz, 2.5 Hz and 8 Hz.

4. Discussion

This study investigated the extent of pregnant women exposure to vibrations triggered by the public transport system in an attempt to evaluate the scale and gravity of the problem. This issue is important as it is impossible to entirely eliminate or restrict the movements and travels of pregnant women similar to imposing the restrictions on workplace conditions. Pregnant women may be signed off of work but they still have to move around, go to see the doctor or even leave on a private trip.

Evaluation of impacts of vibrations triggered by public transport (in the town, suburban transport systems, passenger cars) is a most complicated issue involving a variety of factors that determine the magnitude of vibrations affecting humans. Of particular importance is time of exposure, yet in the present study the authors only made an attempt to evaluate the scale of the problem and identify the further research and methodical needs.

Results of the questionnaire indicate that symptoms most frequently experienced during the tram ride are digestive and neurological disorders. The a_{RMS} amplitude – frequency plots reveal that for horizontal vibration (particularly in the y -axis direction) in the low-frequency range the average vibration acceleration values slightly differ from the contour of vibration dis-

comfort threshold, more significant differences are registered in the higher frequency range. In the z -axis direction for the 1/3-octave band in the range from 3.15 to 6.3 Hz, the values of a_{RMS} are nearing the threshold of discomfort. Time dependences compiled in Figs. 10–16 show that even though the average a_{RMS} values in the x -axis and y -axis direction do not exceed the threshold of discomfort (Figs. 4 and 5), during some passages the instantaneous acceleration, the values do exceed the level defined in the standard specifying the threshold of discomfort in specified 1/3-octave bands (Figs. 10–12). For vibration in the z -axis direction the instantaneous values are higher than the threshold of vibration perception, which is apparent for 1/3-octave bands for frequencies of 5 and 6.3 Hz (Figs. 14 and 15). These are frequency ranges coinciding with resonance frequencies of head (4–5 Hz) [18], [29], stomach (2–3 Hz) [17], liver (3–4 Hz) [18], [29] and other abdominal cavity organs (4.5–10 Hz) [3], [18], [29]. Jelen and Dolezal [10] established that this range is nearing the frequency 5.4 Hz for horizontal vibrations and 7.7 Hz for vertical vibration, what they found to be particularly hazardous for pregnant women. The frequency range of 3–10 Hz, associated with abdominal cavity complaints, is also reported by researchers from the Naval Aerospace Medical Institute [26] and it can well explain the symptoms experienced by women. According to Zenz [30], vibrations in the frequency range of 5–10 Hz produce most detrimental effects on humans.

Relating those findings to amplitude-frequency characteristics obtained for particular stages of the tram ride and for various locations of the seat occupied by the woman, it can be concluded that the ride on a tram directly over the wheel during the braking phase is perceived as most wearisome. Women participating in the questionnaire also reported enhanced foetus movements during veering or braking.

During the car ride participants complained mostly of digestive disorders, reported more intense foetus movements and osteoarticular symptoms. Amplitude-frequency characteristics reveal higher vibration amplitudes throughout the investigated frequency range than during the tram ride. For horizontal vibrations (in the x and y -axis direction) in the frequency range 0.8–1.6 Hz, the average values of a_{RMS} are approaching the threshold of discomfort. According to [26], motion sickness symptoms are associated with the frequency range up to 2 Hz. Medium-intensity vibrations with the frequency 1–2 Hz cause excessive sleepiness. In the questionnaire women did not report the sleepiness whilst one woman travelling on a bus reported feeling depressive.

In the case of car ride, for vibration in the z -axis direction in the frequency range of 4–6.3 Hz, the average acceleration values exceed the vibration discomfort threshold whilst for 1/3-octave bands 1.6 Hz, 8 Hz and 10 Hz they are nearing the threshold value. Time dependences reveal the exceeded levels for the frequency range of 4–8 Hz, associated with resonance frequencies of abdominal cavity organs, as 3(4.5)–10 Hz reported by other authors [3], [18], [29]. With reference to Jeleń and Dolezal [10] who mentioned the frequency level 7.4 Hz for vertical vibration (in the z -axis direction) as potentially hazardous, it is reasonable to conclude that more intensive foetus movements might be attributed to exceeded a_{RMS} values in 1/3-octave bands 6.3 Hz and 8 Hz.

One has to bear in mind that 90% of participating women assume the sitting position during the ride on the tram (in the case of car ride that is the normal position), which seems justified from the standpoint of safety. However, according to Mansfield [17], a sitting person's sensitivity to vibration in the frequency range 5 Hz is 10 times greater than for 100 Hz. Furthermore, Bertuit et al. [1] explain that lumbar spine curvature during pregnancy changes from the average 32° to 50°, which may impact on a seated person's comfort during the ride, causing pain and enhanced sensitivity to vibration. Another factor is relaxation of ligaments and joints due to hormone changes [6].

One needs to bear in mind that the results obtained from the questionnaires are a subjective source of information, which is a certain restriction of the conducted studies. However, they may be preliminary tests because they do not pose any health risk in the research group and do not require the consent of the bioethics committee. The questionnaire is a good basis for determining the degree of a problem in a particular research group and for monitoring of factors which are changing. Furthermore, according to Maeda [14], the purpose of using experimental subjective methods is to understand human subjective impressions of the physical characteristics of vibration, to determine the relationship between the subjective perception of some aspect of the vibration and to evaluate the physical vibration characteristics and establish the target values for design of vibration environments in terms of human sensation of vibration characteristics.

Simultaneously, it is possible to compare the results obtained in questionnaires analyses with frequencies listed by Rasmussen [23] and Jurczak [12] as those associated with subjective responses in humans. It can be observed that the frequency range of 4–14 Hz is associated with abdominal pains, whilst the 6.5–8 Hz range is the lower threshold value associated with lumbar

and sacral spine aches. Furthermore, vibrations in the range of 1/3-octave bands from 4 Hz (even 1 Hz) to 9 Hz cause a general sensation of discomfort, which may be attributable to combination of ailing systems or body organs.

There are differences in individual responses to pregnancy among women as well as individual susceptibility and differences in lifestyle, diet and psychological conditions. That is why the authors treat this study as preliminary, being fully aware of the need to increase the number of respondents – test participants) and to more thoroughly analyse the reported symptoms and health conditions in close collaboration with a gynaecologist (taking into account the diseases and ailments reported prior to pregnancy). A more detailed description of factors responsible for triggering vibration on public transport should be fully merited.

5. Conclusions

Experimental tests and the analysis of questionnaire results indicate that travelling by car or on public transport during pregnancy may cause discomfort, leading to a variety of ailments. Comparison of vibration accelerations measured during the car ride and when travelling on a modern tram indicates that vibration acceleration values generated during the car ride are higher than those sensed by a person travelling on a tram. Car ride can cause digestive disorders and more intensive foetus activity, while tram ride is associated with ailments of the digestive system and with neurological symptoms (headaches). Besides, a pregnant woman occupying a seat directly above the tram wheel may experience a wider variety of symptoms than a woman sitting in between the wheel sets.

The authors are fully aware that the answers to the questions asked are mostly subjective, hence identification of symptoms and ailments simply by adopting the cause-and-effect principle may lead to too far-reaching or erroneous conclusions.

Nevertheless, the results of analysis summarised in this study reveal certain correlations which can help make pregnant women more comfortable during their travels. The authors hope that further studies investigating the impacts of vibrations on pregnant women using public transport (include both placement sensors in other zones of the human body and the seat as well as correlated with other physiological parameters) may be used to determine the safe limits of whole-body vibration exposure in such conditions.

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