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Experimental study of the influence of using polyurethane cushion to reduce vibration received by a wheelchair user

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Purpose: The aim of this experimental study was to compare the ability of polyurethane cushions of three arbitrary selected thicknesses to minimize vibrations transmitted from the wheelchair to its user. *Methods*: Measurements were made during passive motion on five different surfaces often found in public spaces. Two tests were carried out during the measurements. In the first test, the sensor was located directly on the surface of the wheelchair seat. In the second test, a polyurethane cushion was placed on the seat, on which the measuring sensor was then placed. *Results*: The study showed that regardless of the surface on which the wheelchair user moves, the threshold defined in the ISO standard for frequencies in the range of 4–40 Hz was exceeded. However, thanks to the use of polyurethane cushions, vibration damping was visible for frequencies ranging from 10 to 40 Hz. The impact of the user's weight on the magnitude of the perceived vibrations was also observed. *Conclusions*: Studies show that wheelchair users are exposed to whole body vibration that can negatively affect their health. Cushions made of polyurethane seem to be a promising solution to reduce whole body vibration in the frequency range that is burdensome and harmful to human health.

Key words: *wheelchair, whole-body vibration, cushion*

1. Introduction

There are studies showing the positive effect of whole body vibration (WBV) in the treatment of osteoporosis [41] and in increasing the strength and power of the muscles of the lower limbs [31], [36]. The exposure to vibration also has a detrimental effect on the human body [3], [11]. When we consider the positive impact of WBV on the human body, e.g., in the treatment of osteoporosis, we are dealing with vibrations in the frequency range of 30–40 Hz and short exposure times (less than 1 hour per week) [32]. In the case of people using a wheelchair, the time of exposure to vibrations is much longer (about 10 hours a day [8]) and the amount of perceived vibrations depends on many factors, including the type of surface on which the person is moving in a wheelchair [11], [14], [16], [21], [25], [38].

There are standards relating to the construction of a wheelchair, but these standards do not contain limits for exposure to whole body vibrations of people with disabilities using this device [28]. In turn, the existing standards specifying the whole body vibration limit refer to the exposure of an able-bodied worker to this factor [20], [29]. These guidelines do not consider vibration exposure in everyday life and do not reflect the health/safety/comfort needs of people with disabilities, using wheelchairs. In paper [1], the differences in the sitting position (of wheelchair users (bas-

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ketball players) who cannot and can walk were shown. Especially the lumbar lordosis and thoracic kyphosis angles were different between the metioned groups and different from able-bodied sedentary people. This shows the need to conduct individualized detailed analyzes for people with disabilities if needed. The whole body vibration exposure may explain some of the comorbidities of manual wheelchair users, such as lower back pain [34], [44]. In addition to its harmful effects on health, WBV also increases the fatigue index of a person exposed to it [40]. This, in turn, may limit the activity and participation in social life of manual wheelchair (MWC) users. MWC propulsion strategies and users' medical conditions can affect the transmission of vibrations through the body due to the specific muscle control and posture of people with disabilities [32]. What's more, shortening the daily time of using the MWC is unfeasible, because it is thanks to the MWC that people with disabilities can actively participate in social life [32]. Therefore, studies on exposure and transmission of vibrations through the body, specific to manual wheelchair users, are very important [12]. This is all the more important because despite the existence of the ISO 16840-3:2014 [29] standard for wheelchair seat cushion damping, MWC users still suffer from pain in the lumbar and cervical spine [7], [34].

Designing a wheelchair presents a double challenge of limiting the mechanical work required to travel a certain distance and the vibration transmittance [9]. An example of a design topic related to limiting the effort put into moving the wheelchair is the problem of bearing resistance negligible during wheelchair locomotion was discussed in [4]. Results of analyses could help enhancing the models of manual wheelchairs. Paying attention to the second mentioned problem of reducing vibrations transmitted to the wheelchair occupant, it is worth noting that this issue is a challenge for designers because increasing the vibration absorption capacity of a wheelchair may increase the amount of energy needed to drive this device [9]. In the case of minimizing the vibrations received by the wheelchair user, the most common goal is to reduce the vibrations on the seat of this device [30].

One of the methods of minimizing the whole body vibrations is the use of dampers in wheelchairs and the modification of the suspension system of the wheelchair. Unfortunately, this solution increases the weight of the device and its cost [27]. In addition, wheelchair suspensions are designed to absorb vertical vibrations, so their ability to absorb three-dimensional vibration components is limited. The magnitude of the perceived vibrations may also be affected by other elements of the wheelchair, such as the type of wheels, the material of which the frame is made [18] or additional equipment such as a seat cushion [12], [27]. While some wheelchair frame designs and additional wheelchair components can reduce vibration, they add weight and cost to the device, while the cushion is interchangeable between the frames and is available to any wheelchair user.

In the case of wheelchairs, seat cushions are used to improve the posture of the person using the device and to prevent pressure sores [5], [26], [33]. There are four types of cushions: foam, air + foam, gel + foam or air. The cushion on the seat of MWC can also be used to reduce whole body vibration as it affects the transmission of vibrations to the person in both normal and parallel directions to the seat. Therefore, learning about the damping properties of wheelchair cushions will help clinicians in the selection of this element so as to prevent the formation of bedsores, but also to reduce the exposure to the impact load of the user of this device, and thus reduce the discomfort and risk of injury [5], [7]. Loads on the musculoskeletal system of the lumbar spine during sitting position are discussed in [43] while discussing a wider range of research.

The use of a cushion on the wheelchair seat seems to be an easy and cheap way to reduce mechanical vibrations, but research shows that this solution is not always effective. Studies have shown that sometimes the wheelchair seat cushion amplifies vibrations in the frequency range harmful to the human body [7], [15], [24]. Additionally, it was observed that the user/cushion system could reduce shock amplitude but not vibration transmittance [32].

Thanks to tests conducted in accordance with the ISO 16840 standard (Annex C), differences in the damping capacity between seat cushions depending on what material they are made of [22], [29] have been observed. According to Lariviere [32], the ISO 16840 validation of seat cushions is not yet fully adjusted.

DiGiovine et al. [15] conducted tests on four seat cushions (contoured foam, air bladder with a foam base, viscoelastic material with foam base, air) on 32 different types of wheelchairs. During these tests, wheelchair users moved around a previously prepared obstacle course. The obstacles have been selected to cause vibrations across the entire frequency spectrum that a wheelchair user encounters. This study showed no significant differences in vibration damping between these cushions. In studies by Garcia-Mendez et al. [24], five types of cushions were tested. Permeability measurements in the seated position were obtained during field tests with 14 able-bodied subjects. In this study, air cushion were shown to provide better vibration damping than gel or foam cushions.

The type of cushion (foam, gel, etc.) that exhibits less vibration damping ratio between the seat and the head may vary depending on the wheelchair user. DiGiovine and co-authors observed that vibration permeability varies depending on whether the study involved people with disabilities or non-disabled people. These differences are also visible between people with different type of disabilities [15], [40]. In the case of users with full muscle control (i.e., able-bodied people), the cushion with the lowest damping properties, i.e., a cushion filled with foam and air, showed the lowest transmittance of seat vibrations to the head. On the other hand, among the disabled people, the damping properties between the tested cushions were not found either. The most likely reason for such differences between users is the impact of the cushion on stability and user support [15], [40]. Another reason for these differences may be related to the weight of the participant, as both stiffness and damping properties depend on the preload of the cushion [24].Therefore, the weight of the participant may affect the transmission of vibrations and, consequently, the ability of the cushion to absorb vibrations.

Research presented by Asgarifar and co-authors [2] shows that cushions made of polyurethane play an important role in damping vibrations transmitted to the user while moving on a tractor. Therefore, the aim of this study was to assess the impact of the use of polyurethane cushions on the reduction of vibrations received by the user of a manual wheelchair. In this study, three polyurethane cushions of different thickness were evaluated and compared. The cushion material was chosen due to the fact that it is easily accessible, thanks to which each wheelchair user could use this solution to reduce WBV. Many studies show that wheelchair users feel the greatest discomfort under the influence of vertical vibrations, which also reach higher values compared to horizontal vibrations [9], [34]. However, the importance of the anterior-posterior direction in terms of vibration magnitude is still little discussed [32]. Therefore, the paper attempts to assess the magnitude of WBV in all three directions.

2. Method of experimental research

Two tests were conducted in the study to evaluate the vibration transmission of the wheelchair cushion. In both trials, the subjects were seated in a Sunrix Medica cross-folding universal wheelchair, model Unix Breezy, weighing 18 kg. The wheelchair had a steel frame, solid tires, with a soft textile upholstery seat. The wheelchair occupant was pushed by an external source along typical paved outdoor paths. Measurements were carried out on rectilinear sections, without a significant inclination of the terrain. In the first test, vibrations were measured directly on the wheelchair seat without a cushion under the occupant. In the second, a polyurethane cushion was placed under the passenger and the vibrations on the upper surface of the cushion were measured.

The measurements were made in several measurement sessions, which will be presented and described below. Measurements of vibration acceleration were performed during individual sessions. The measurements were carried out in terms of identifying the dominant 1/3 octave bands in the vibration spectrum.

A four-channel spectrum analyzer SVAN 945 was used for the tests. A disk for measuring vibrations with a general impact on the wheelchair occupant – SVANTEK SVAN SV39A sensor (three-way sensor) – was used as a vibration sensor. During the test, a signal of acceleration changes over time was recorded with a sampling frequency of 12 000 Hz. This signal was processed in the SvanPC program in order to determine the amplitude-frequency characteristics. Vibration measurements were aimed at:

- identification of 1/3 octave bands with the highest value; values for 1/3 octave bands will be referenced to ISO 2631;
- determination of the relation between the value of vibration acceleration on the seat and on the cushion located on the seat.

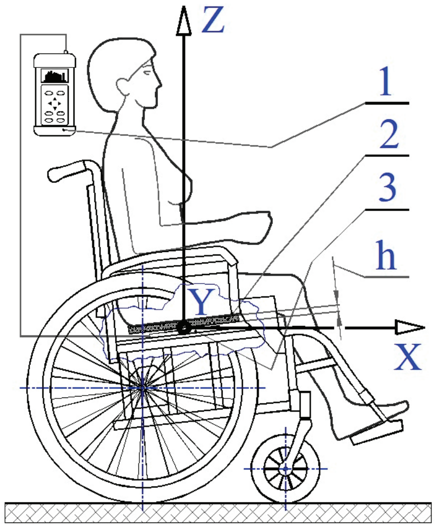

Fig. 1. Measuring stand with directions of vibration reception: 1 – disc with a three-axis sensor, 2 – cushion made of polyurethane, 3 – vibration spectrum analyzer, *h* – thickness of the polyurethane cushion

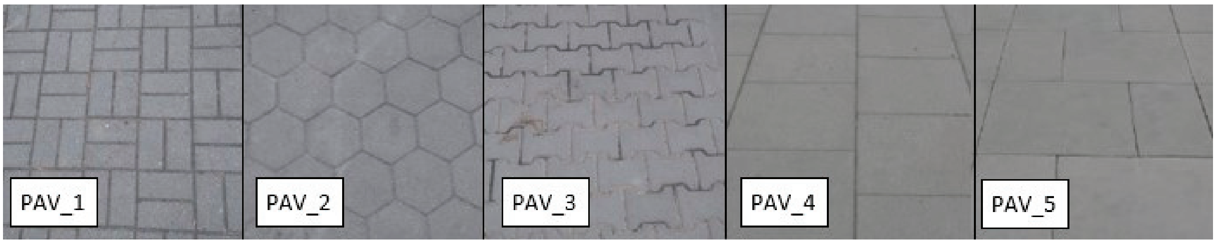

Fig. 2. Types of surfaces used in the tests: PAV_1 – "mosaic" paving stones , PAV_2 – hexagonal slab, PAV_3 – "bone" paving stones, PAV_4 – 50×50 cm slab, PAV_5 – 60×60 cm slab

The test stand is shown in Fig. 1. Two tests were carried out during the measurements. During the tests, runs were carried out on various surfaces, on a previously selected measurement section (Fig. 2). These were the surfaces most often found in public space, such as asphalt or cobblestone. Each run was performed twice. During each of the trials, the wheelchair user was pushed by an external source to eliminate the impact of the driving style on the magnitude of the perceived vibrations. Seat cushions made of polyurethane, of three different thicknesses: 30 mm, 40 mm and 50 mm, were used in the tests. The study used open-pore foam, which is widely used in car seats to minimize vibration. Foam with a density of 30 kg/m^3 was used.

During the tests, changes in the amplitude of the vibration signal over time were recorded (the measurement was made with a sampling frequency of 12 kHz). The vibration measurement was recorded in three directions, as shown in Fig. 1. During each run, time measurements were carried out with an accuracy of +/–1 s, while efforts were made tomaintain a constant speed of the wheelchair (1.2 ± 0.09 m/s). The length of the measurement section was 60 meters. The vibration signal was then processed using specialized programs for signal processing of this type, SvanPC++.

The research group consisted of four able-bodied women with the following height and weight: P1 (175 cm, 68 kg), P2 (160 cm, 85 kg), P1 (170 cm, 55 kg), P1 (174 cm, 60 kg).

Amplitude-frequency characteristics were obtained on the basis of the performed tests. A comparison of vibration amplitudes measured on the polyurethane cushion and on the wheelchair seat was made. On the basis of the obtained results, the vibration damping ratio (VDR), defined for the selected direction, was determined in accordance with the formula (1).

$$\mathrm{VDR} = \frac{a_{\mathrm{cushion}}}{a_{\mathrm{seat}}}, \qquad (1)$$

where: a_{cushion} – acceleration values measured on the cushion for a given direction, a_{seat} – acceleration values measured on the seat for a given direction.

The VDR was calculated for each 1/3-octave band using the average vibration value of that band. The value of the VDR coefficient equal to 1 means vibrations with the same amplitudes on the seat and polyurethane cushion. The coefficient VDR below 1 means that the vibrations on the seat were lower than the vibrations recorded on the seat, so the vibrations were weakened as a result of the use of the seat cushion. On the other hand, the coefficient VDR greater than 1 means the strengthening of vibrations, i.e., vibrations on the polyurethane cushion obtained higher values than vibrations on the seat. The effectiveness of using a polyurethane cushion to reduce whole body vibration acting on the MWC occupants was assessed on the basis of the vibration damping ratio.

3. Results of measurements and analyses

Exemplary results of vibration measurements, carried out in terms of the effectiveness of the cushion used between the seat and the wheelchair occupant, are shown in Figs. 3–13. The graphs have been prepared for three mutually perpendicular directions of vibration impact. The impact of the weight and height of the wheelchair occupant on the effectiveness of the absorption of general vibrations by the cushion and the impact of the thickness of the cushion on vibration reduction were considered.

In Figure 3, the amplitude-frequency characteristics for the *Z* axis obtained for occupant P1 on all types of surfaces, without the use of a seat cushion are shown. Relations between the type of surface and the occurrence of exceeding both the comfort limit defined by ISO 2631 were observed. Exceeding the comfort limit defined by ISO 2631 is visible for frequencies in the range of 4 to 40 Hz for all tested surfaces, which indicates the need general vibration reduction in this frequency range. Especially considering that these are the resonance frequencies of human

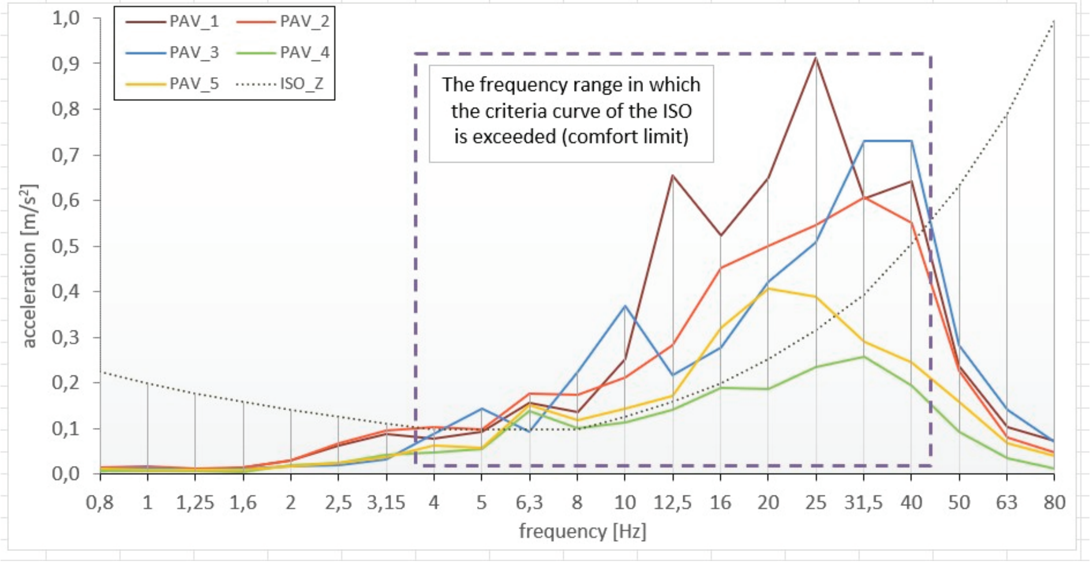

Fig. 3. Amplitude-frequency characteristics ("*Z*" direction) for all tested surfaces for occupant P1, with the marked area for which the ISO criteria curve is exceeded (comfort limit)

internal organs, including the spine (8–10 Hz), which can cause pain in people affected by these vibrations. The highest acceleration values were observed for the surface of "mosaic" paving Stones, while the lowest were observed for the surface of 50 × 50 cm slab.

3.1. Influence of cushion thickness on vibration absorption

In Figure 4, the amplitude-frequency characteristics obtained for the passages of person P1 on the hexagonal slab surface during the passage without a seat cushion and with polyurethane cushions 30, 40 and 50 mm thick are shown. It is visible that the limit of comfort defined in the ISO standard has been exceeded, both for passages without seat cushions and for passages with cushions. Exceeding the comfort limit is observed for frequencies in the range of 4–40 Hz in the case of driving without a seat cushion. In the case of journeys with seat cushions, the standard is exceeded for frequencies in the range of approx. 4–25 Hz. At the same time, a slight decrease in the acceleration value is observed with the increase in the thickness of

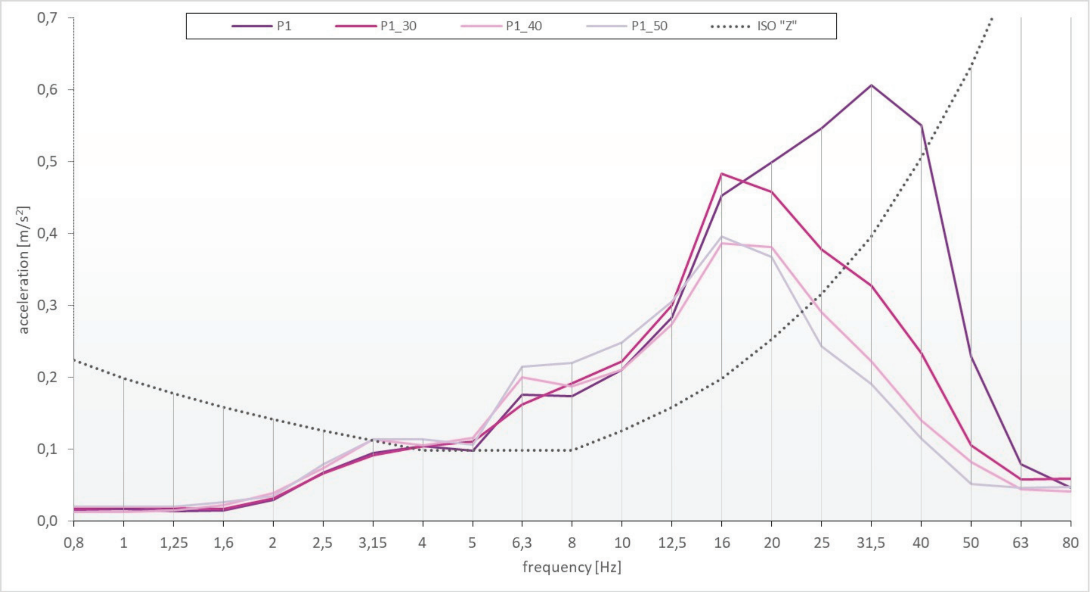

Fig. 4. The amplitude-frequency characteristics ("*Z*" direction) for the hexagonal surface (PAV2), for occupant P1, for passages without a cushion and with subsequent cushions (30, 40, 50 mm) with reference to the ISO standard (comfort limit)

the cushion. The difference in the whole body vibrations was observed when changing the cushion from 30 to 40 mm. A similar trend was not observed between 40 and 50 mm cushions.

In Figures 5–8, the change in the vibration damping ratio for "*Z*" direction as a function of frequency for the hexagonal slab pavement is shown. The graphs show the area of exceeding the comfort limit defined in ISO, which was determined on the basis of the obtained amplitude-frequency characteristics during the wheelchair occupant's journeys on various surfaces without the use of a seat cushion. A decrease in the value of the vibration damping ratio below 1 was observed in the frequency range from 10 to 40 Hz for all thicknesses of polyurethane cushions and for all subjects, except for the results obtained for occupant P4 when running with a 30 mm thick cushion. This tendency was observed while driving on each of the five tested surfaces for all persons participating in the study. For the frequency of 10 Hz, the value of the coefficient VDR was above one.

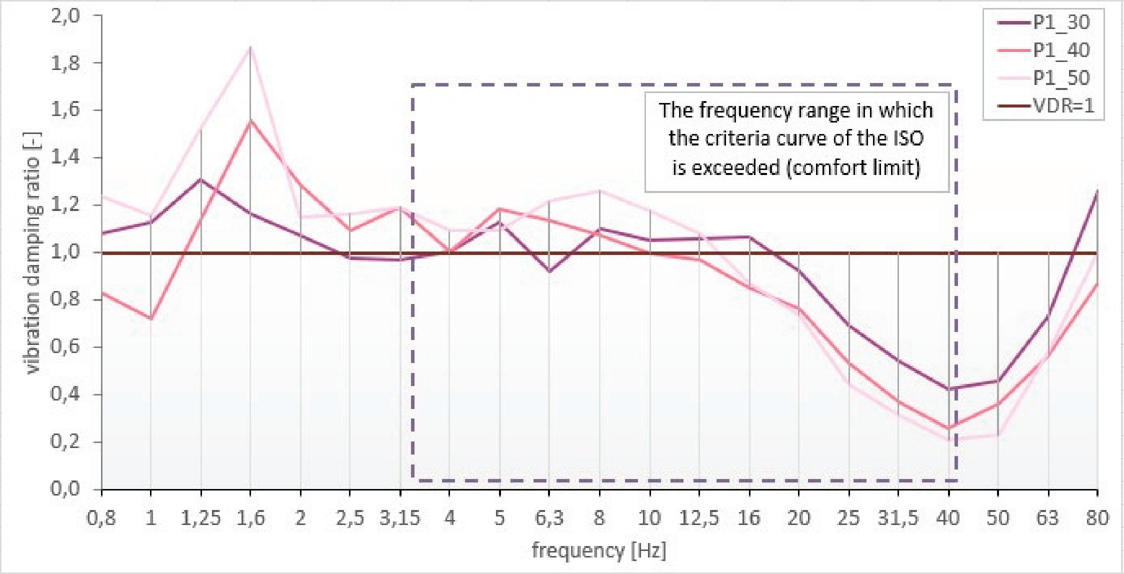

Fig. 5. Change of vibration damping ratio ("*Z*" direction) as a function of frequency for a hexagonal surface with a marked range of exceeding the ISO standard comfort limit for occupant P1

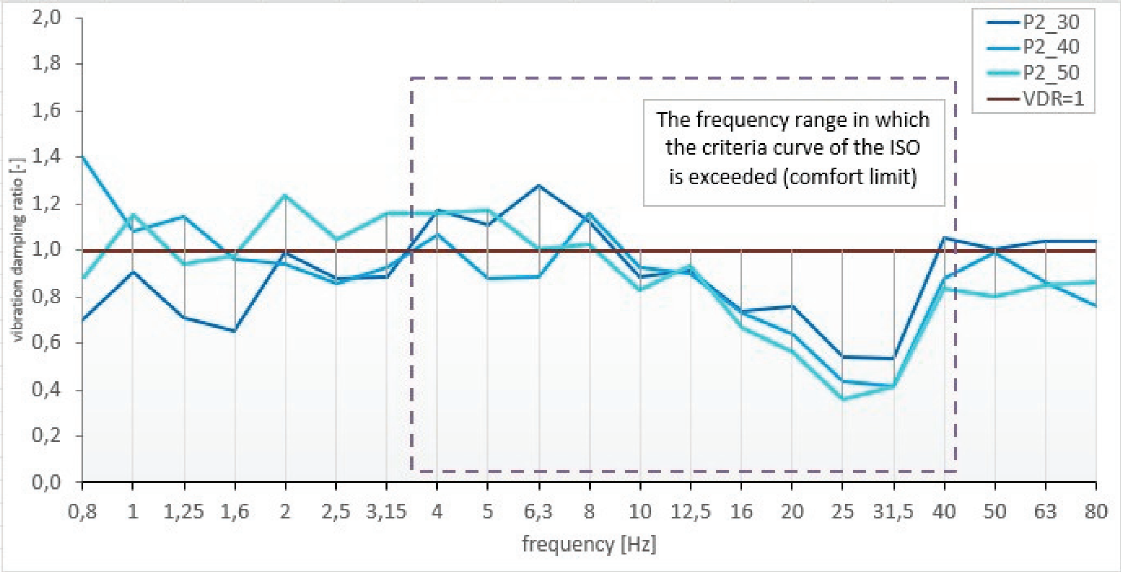

Fig. 6. Change of vibration damping ratio ("*Z*" direction) as a function of frequency for a hexagonal surface with a marked range of exceeding the ISO standard comfort limit for occupant P2

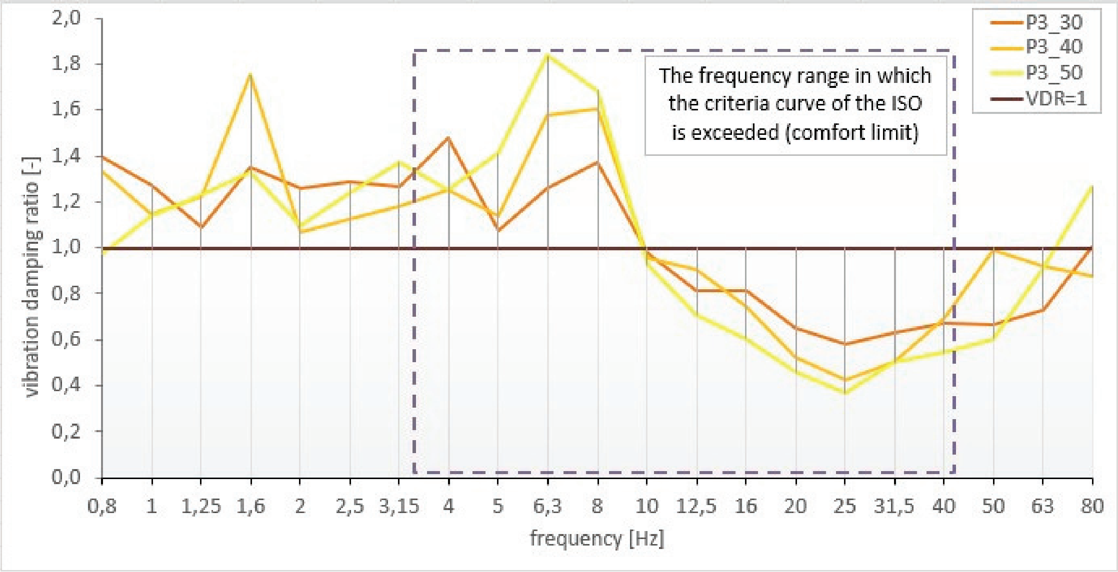

Fig. 7. Change of vibration damping ratio (“*Z*” direction) as a function of frequency for a hexagonal surface with a marked range of exceeding the ISO standard comfort limit for occupant P3

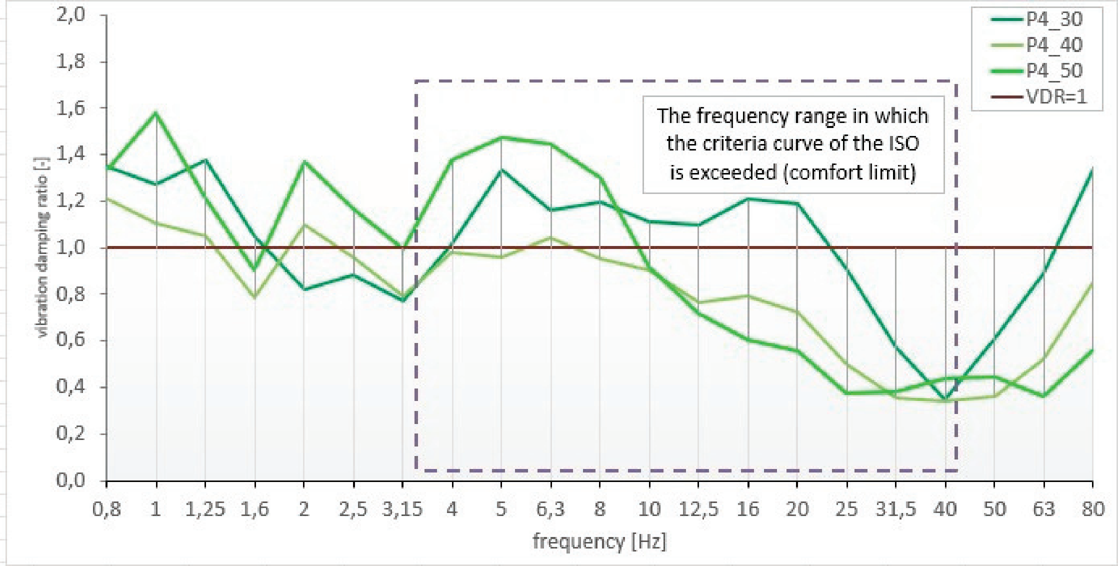

Fig. 8. Change of vibration damping ratio (“*Z*” direction) as a function of frequency for a hexagonal surface with a marked range of exceeding the ISO standard comfort limit for occupant P4

3.2. Influence of the occupant’s weight and height on vibration absorption

In Figures 9–13, the results obtained for driving on a hexagonal surface for all four test persons are shown. The chart also shows the spine resonant frequency range (8–12.5 Hz). In all rides, the impact of the participant’s weight and height on the magnitude of the perceived vibrations and on the value of the cushion damping coefficient was observed. The greatest differences were observed during the passage of the test persons on a cushion 30 mm thick. For a passage with a 30 mm thick cushion for occupant P1 (68 kg) and P4 (60 kg), the VDR coefficient is less than 1 for the frequency of 20–63 Hz. For occupant P2 (85 kg) this range was smaller and was 10–40 Hz. However, for the participant with the smallest body weight (P3 – 55 kg), the VDR coefficient was less than 1 for frequencies from 10 to 80 Hz. In addition, for occupant P2, i.e., the occupant with the highest body weight, a value of the VDR coefficient below 1 was observed for the frequency of 0.8–3.15 Hz. Thus, subjects with lower body weight had a VDR below 1 for a wider range of frequencies (one-third octave bands) compared to subjects with higher body weight. Similar relationships were observed for all tested surfaces.

In the case of a cushion with a thickness of 40 mm, for all tested participants, the value of the coefficient VDR is less than 1 for frequencies in the range of 10–100 Hz.

In the case of a 50 mm thick cushion for occupant P2, i.e., the participant with the highest body weight, the VDR coefficient is less than 1 in the frequency range of 6.3–100 Hz. For the remaining respondents, this range is smaller.

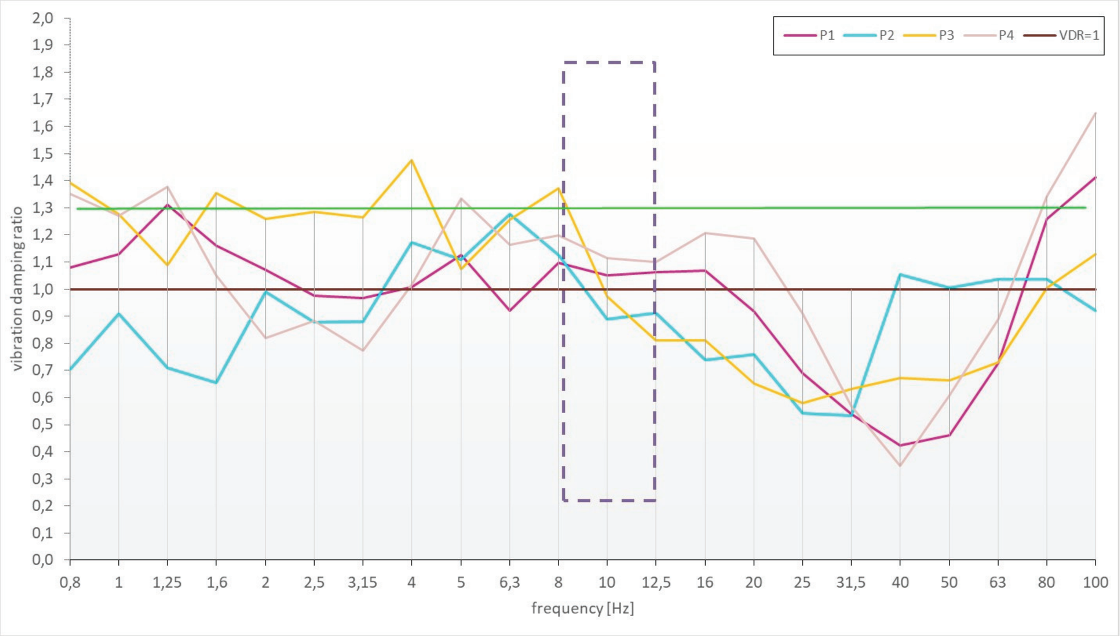

Fig. 9. Values of the vibration damping ratio ("*Z*" direction) for driving on the "hexagon" surface, for a 30 mm thick cushion with a marked range of resonant frequencies of the spine

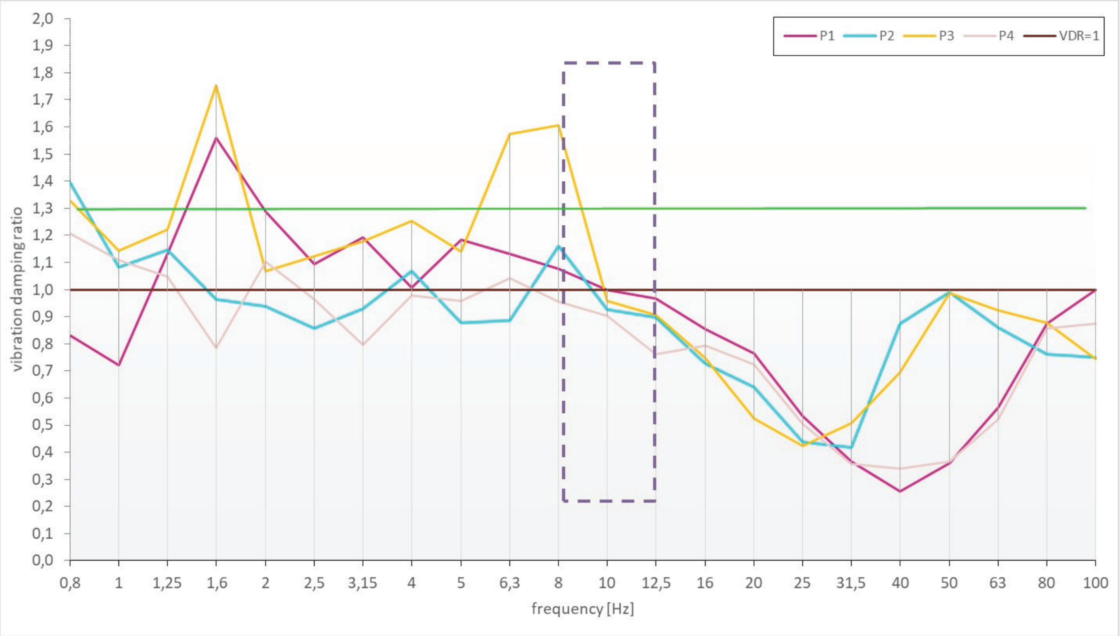

Fig. 10. Values of the vibration damping ratio ("*Z*" direction) for driving on the "hexagon" surface, for a 40 mm thick cushion with a marked range of resonant frequencies of the spine

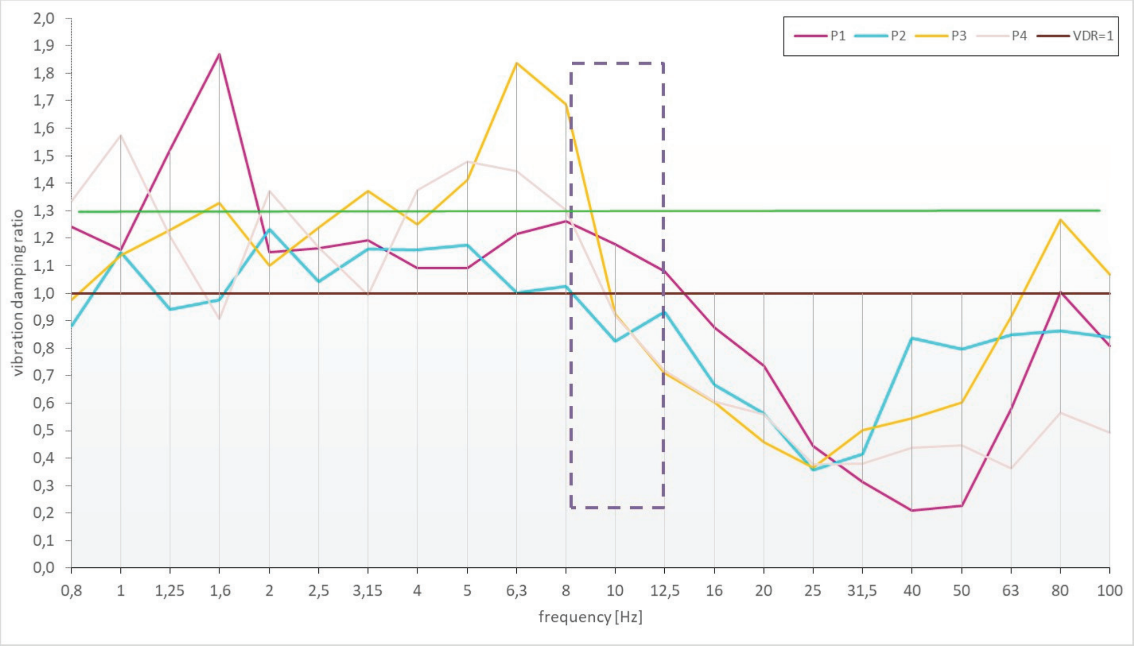

Fig. 11. Values of the vibration damping ratio (“*Z*” direction) for driving on the “hexagon” surface, for a 50 mm thick cushion with a marked range of resonant frequencies of the spine

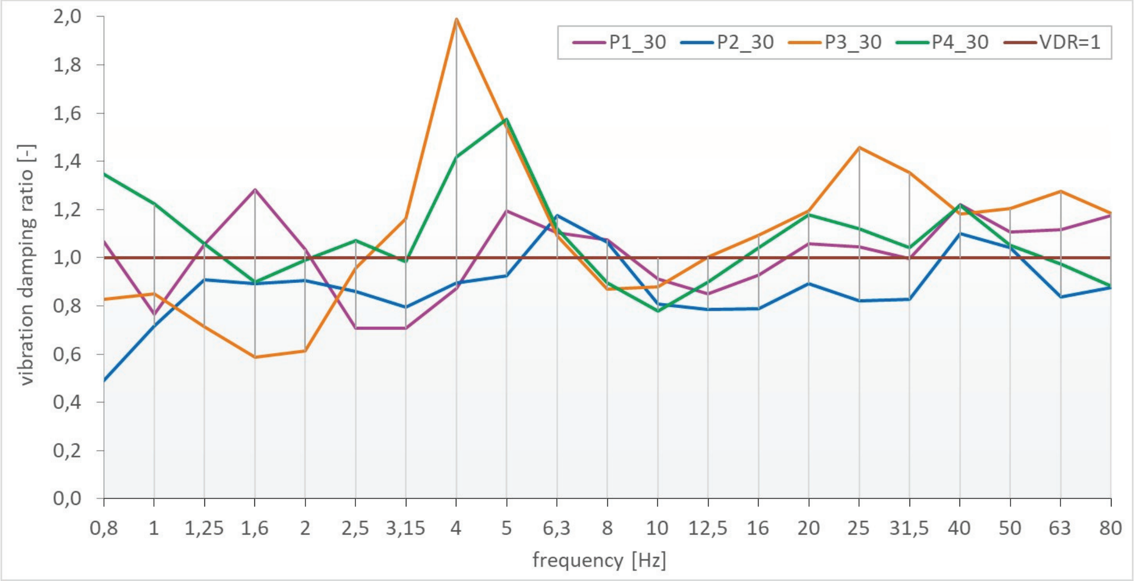

Fig. 12. Values of the vibration damping ratio (“*X*” direction) for driving on the “hexagon” surface, for a 30 mm thick cushion

The value of the vibration damping ratio was also calculated for lateral vibration directions and graphs of changes in the value of the VDR coefficient as a function of frequency were prepared. In the case of the *x*-axis, no clear tendency was observed in which frequency range the cushion causes vibration reduction. For occupant P2, the vibration damping ratio is below zero for all frequencies except 5–8 Hz. For occupant P3, vibration damping is observed for frequencies below 2.5 Hz, for other frequencies the VDR value was above 1.

In the case, of the *y*-axis, VDR coefficient values were observed to be less than 1 in the frequency range 0.8–3.15 for all participants. This tendency was similar in all tested surfaces.

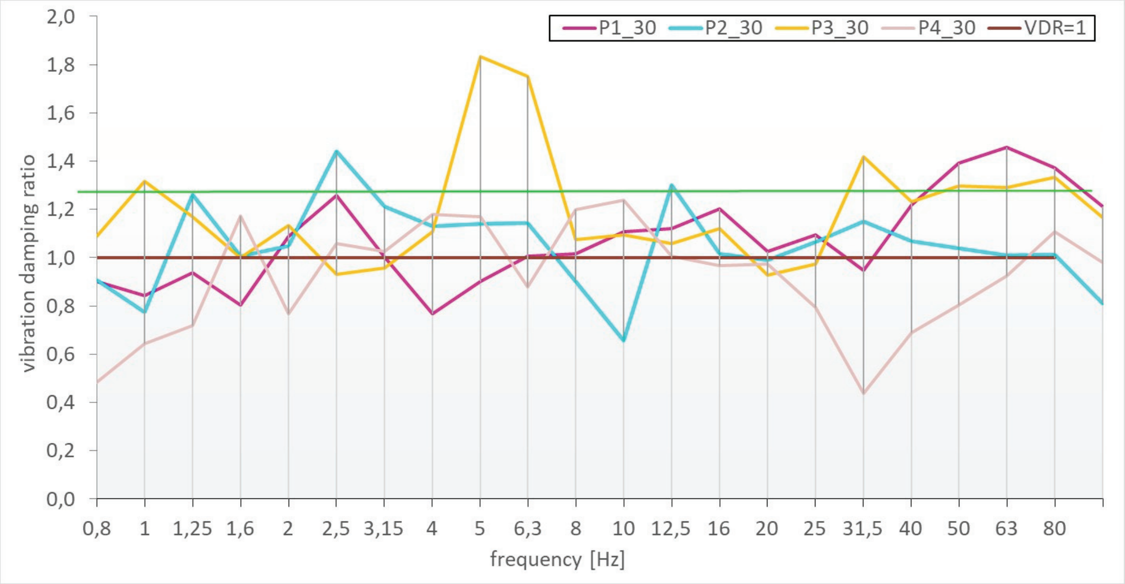

Fig. 13. Values of the vibration damping ratio ("*Y*" direction) for driving on the "hexagon" surface, for a 30 mm thick cushion

4. Discussion

The conducted tests have shown that in the frequency range from 4–40 Hz, the ISO standard is exceeded, regardless of the surface on which the wheelchair occupant moves. This excess can be considered particularly dangerous due to the fact that these are low frequencies, which are the natural frequencies of internal organs, including the spine (8–12.5 Hz). This may explain the fact that wheelchair users complain of pain in the lumbar spine [10], [17], [24], [37]. Thus, it is important to reduce these whole body vibrations to ensure the safety and comfort of wheelchair users.

During the tests, the wheelchair occupants were pushed by an external source, which eliminated the influence of the drive technique of this device on the magnitude of the perceived vibrations. In papers [7], [11], [21], it was found that the level of vibration increases with the speed of driving in a wheelchair. In order to eliminate this factor, the speed of the ride was the same in each test and was 1.2 ± 0,08 m/s. According to Lariviere et al. [32], the speed at which wheelchair users propel themselves in everyday life [32].

Studies have shown that the level of perceived vibrations varies depending on the surface on which a person in a wheelchair moves. The tested surfaces had different geometry and size of component elements. Smaller elements of paving stones with more complex geometry have a greater number of joints of its individual elements and thus more joints of tiles per one turn of the wheel (one cycle of movement), which is associated with a greater number of whole body vibrations received by the user. The measurement sections selected for the experiment constituted a surface in good technical condition, without any visible damage. On the other hand, a wheelchair user, while moving around the public space, encounters various obstacles in the form of curbs or damaged surfaces, which results in an increase in the level of whole body vibration perceived by the person using this device. Research by Wolf et al. [42] confirms this. Duvall and co-authors [19] observed a correlation between surface roughness and the magnitude of the perceived vibration. They found that as the surface roughness increases, the accelerations increase and the wheelchair user's subjective assessment of the surface quality decreases. Differences in the level of perceived vibrations depending on the surface on which the wheelchair user moves were also found in the work of Dziechciowski et al. [21].

Research have shown that thanks to the use of a polyurethane cushion, vertical whole body vibrations affecting the participant on all tested surfaces in the frequency range from 10 to 40 Hz are reduced. For low frequencies in the range up to 10 Hz, signal amplification is observed due to the use of a seat cushion, regardless of the thickness of the polyurethane cushion. A similar relationship, i.e., the amplification of vibrations in the frequency range harmful to the human body (4–12 Hz), was found in [15], [17], [24]. However, according to the tests carried out, the limit given by the ISO standard is exceeded for frequencies above 10 Hz. Also from this frequency, the VDR coefficient is less than 1. Thus, the use of a polyurethane cushion seems to be an effective way to reduce vertical vibrations in this area.

The study showed that for a cushion thickness of 40 mm, a decrease in acceleration values is observed in relation to a cushion of 30 mm, while increasing the cushion thickness above 40 mm does not reduce vibrations. The lack of correlation may be related to the properties of the polyurethane material and the preload caused by the seated person. In addition, thetransmission of vibrations through the cushions is affected by the surrounding structure (i.e., MWC frame and user) [32].

Polyurethane foams are also used in the automotive industry to absorb whole body vibration. Studies by Mehta et al. [35] show that the high-density PU-based damping material provides good whole body vibration absorbing, additionally, it was observed that the vibration damping was maximal with the thinner material of the seat cushions.

Asgarifar and co-authors [2] studied the damping properties of three different thickness polyurethane cushions used in tractor seats. They observed that the value of vibration absorption in the foam with the greatest thickness is the lowest, while for the other two thicknesses (60, 80 mm) these values are very similar. In addition, in the case of foams with a thickness of 60 and 80 mm, they observed that vibrations are damped at all frequencies, while for a 100 mm thick cushion, the damping was for frequencies above 32 Hz.

No unequivocal relationship was observed in the case of reduction of horizontal vibrations by polyurethane cushions. However, vibration damping by cushions for frequencies below 4 Hz seems to be promising. In the case of lateral vibrations, the impact of the participant's height on the magnitude of the perceived vibrations was observed. In the case of occupant P2, i.e., the shortest person, the seat cushion damped vibrations. Differences in the level of perceived vibrations in the case of lateral vibrations could be related to the location of the center of gravity related to the height of participants.

The impact of the participant's weight on the VDR coefficient was observed. With the increase in weight, the damping properties of the polyurethane cushion worsens. Similar conclusions were presented by Gracia-Mendez and co-authors in their work, a person with a higher body mass damped vibrations better. The preload caused by the weight of the participant affects the stiffness and damping properties of the cushion, and consequently the transmission of vibrations through the cushion. The influence of the mass on the magnitude of the received vibrations has not been clearly defined. Although lighter users are expected to receive more vibration at higher frequencies, this conclusion has not been observed in experimental studies [13], [39]. The study by Skendraui and co-authors suggests that the weight of the user has the greatest influence the repartition of the frequency content, but not the amount of vibration [39]. In addition, according to Lariviere and co-authors [32], the human body has different vibration and shock absorbing capacities, which may result in differences in the level of perceived vibrations.

5. Conclusions

Studies show that wheelchair occupants are exposed to whole body vibration that can negatively affect their health. Additionally, the outdoor environment is not fully adapted to universal wheelchair users, nor is MWC optimized for users. Due to the fact that many factors affect the magnitude of the perceived vibration, conclusions regarding the impact of each MWC element are still difficult to assess. Cushions made of polyurethane seem to be a promising solution to reduce whole body vibration in the frequency range that is burdensome and harmful to human health. Horizontal vibration analysis is important when analyzing the resonance frequencies of internal organs such as the liver or stomach. These vibrations can affect the comfort of the user, they can cause a feeling of irritability or drowsiness. In further studies, it is necessary to deepen the research on the impact of horizontal vibrations on the wheelchair user.

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