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Preliminary assessment of vibrations received by children in gondola strollers

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Purpose: In this study, the authors attempted to determine whether and to what extent the vibrations generated while driving a baby stroller could pose a potential hazard to an infant. For this purpose, the measurement of whole body vibrations inside a baby stroller was carried out, using a dummy infant weighing 5 kg. *Methods*: The study was conducted using four baby strollers of similar overall weight and design. Based on the results, it was concluded that the vibrations occurring in the baby stroller exceed the comfort limit defined by ISO 2631 and could be potentially dangerous to children. *Results*: The comfort limit for the vertical axis is exceeded in the frequency range that corresponds to the resonant frequencies of the head (6–8 Hz), torso (6–17 Hz) or pelvis (6–17 Hz). For this type of study, the ISO 2631 standard can only be considered as a guideline in analyzing the results since the standard is intended for adults. There is no norm in the literature that defines the limit of vibrations acting on children. *Conclusions*: It seems necessary to develop a standard specifically for children. Based on the results obtained, the effect of speed and the way of driving a baby carriage on the magnitude of vibration received is evident.

Key words: *whole body vibrations, vibrations, baby carriages, infant, infant's health*

1. Introduction

Baby strollers have become indispensable equipment that helps transport an infant or toddler on long or even short walks [15]. The most important aspect in choosing a stroller should be the safety and comfort of the child [23]. However, movement in rough conditions (uneven terrain or the higher speed at which the caregiver is moving), can result in potentially dangerous vibrations transmitted by the stroller's structure onto the child's body [23].

The effects of vibration on the adult human body have been widely discussed in the literature, but few of the studies covered the effects of this stimulus on children. Studies conducted on adults in the supine position (during medical transport) show the risk of discomfort and even secondary injuries due to the effects of vibration [4], [21], [22]. The magnitude of the vibrations received and, therefore, the effects of vibrations on the human body, are impacted by a number of factors, such as the speed of the wheelchair, the material of the contact Surface [22], body weight, and even gender [21]. However, the dynamic response of a child and an adult is different, due to differences in tissue properties, anthropometric differences and body posture [24]. The differences between the child's body (its various stages of development) and that of an adult are so significant that a child should be treated differently from an adult [24].

To evaluate general vibrations acting on the human body, the ISO 2631 [11] standard is used, in which

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a comfort limit is defined, but it appears that due to the abovementioned aspects it should not be directly used to assess the effects of vibrations on the child's body.

There are a number of standards for baby strollers, but these standards are not as rigorous as those for car seats [23] and only cover the requirements for these devices and the methods for their inspection and condition assessment (ISO 31110 [12]). Tests conducted for baby strollers include the durability of the structure on uneven pavement, the effectiveness of the braking and immobilizing mechanism, the resistance of the safety systems or the torsional and tensile strength of individual components. That said, they do not explicitly specify the limits of vibrations received by the child [12], [19], [20]. The present technological development of baby strollers aims, in many cases, to change the visual design of the stroller, rather than to provide as much comfort as possible for children [23]. It seems important to expand the current knowledge of vibrations transmitted onto infants in baby strollers and to determine the impact of these vibrations on children's health.

Previous studies available in the literature include the problem of transmission of whole body vibrations by children, in travel strollers in which the child is in a sitting position [14], [16], [18]. Due to the different design of the stroller, these studies pay special attention to the effect of vibration on the lower limbs [14], [18]. There is a lot of literature on vibrations received in a child's seat while driving a car [5], [6], [17], [26], however, there is a lack of research on the effects of whole body vibrations on children in gondola strollers in the laying position [23].

Whole body vibrations can cause resonance of internal organs, disorders in the central and peripheral nervous systems, the gastrointestinal tract or organs of locomotion [7]. Papers on vibrations affecting newborns during their interhospital transport show that vibrations can cause elevated heart rates, increased leukocyte levels, pain-signaling behavior and, in extreme cases, brain damage [1], [8]–[10].

Więckowski [24] attempted to determine the natural frequency of a child's body parts based on the natural frequency of an adult's body parts. According to his study, the resonance frequencies of the lumbar and sacral regions fall within the range of 13–19 Hz, for the pelvis – 8–15 Hz, for the chest – 6–17 Hz, for the head – 6–8 Hz, and for the head and neck – 32–47 Hz. It should be noted that the estimation of the frequencies of the child's organs is a big approximation due to the fact that children grow unevenly and their mass changes almost daily [23].

In this paper, an attempt was made to determine the magnitude of the problem which is the transmission of vibrations from a baby stroller to the body of an infant. The analyzed problem was divided into two stages. In the first step, an effort was made to determine the effect of the road surface and the speed of the caregiver on the magnitude of the vibrations generated. In the second step, an analysis of the vibrations developing when the caregiver inflicts additional excitation to the baby carriage (rocking the child) was carried out.

The authors also attempted to determine the comfort range of a newborn while moving in a wheelchair using the ISO 2631 [11] standard available in the literature and the resonant frequency ranges determined by Więckowski [24]

2. Method of experimental research

The aim of the study was a preliminary evaluation of the whole body vibrations received by infants in the gondola of a gondola strollers while taking a walk. For the research, four baby strollers of similar total weight (13.4–16 kg) and construction made of aluminum, were

Fig. 1. Strollers used in the study: a) stroller S1 Tako Jumper X – 15.0 kg, b) stroller S2 Concord neo plus – 13.8 kg, c) stroller S3 Anex Sport – 13.4 kg, d) stroller S4 Jedo Fyn Classic – 14 kg

selected. All strollers used in the study had four solid wheels and spring suspension (Fig. 1). All strollers included in the study were previously used, with stroller S4 having the longest period of use.

A measurement of the whole body vibration received by the newborn was carried out for each baby carriage. The measurement was made using a SVAN 958 four-channel vibration meter from SVANTEK, with a SV 39A triaxial vibration transducer. The sensor was placed inside the pram, together with the arrangement of the axes in which the measurement was carried out, as shown in Fig. 2. A weight equal to 5 kg was placed on the sensor, which, according to the data provided by the World Health Organization WHO [2], corresponds to the average weight of an infant at two months of age.

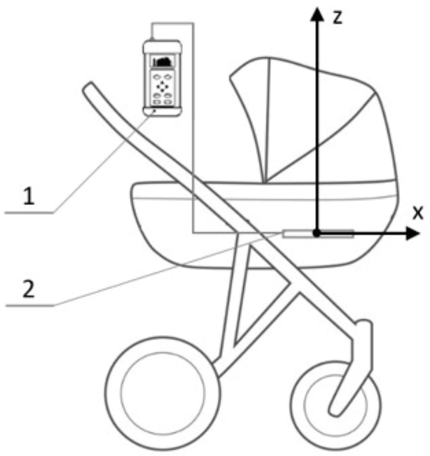

Fig. 2. Measuring stand with directions of vibration reception: 1 – disc with a three-axis sensor, 2 – vibration spectrum analyzer

For each cart, four runs were conducted on three different surfaces found in the public space, as shown in Fig. 3. Each run was carried out on a rectilinear section of 25 meters in length. In test one (T1), the stroller was steered at 4 km/h (the value of the average speed of normal walk), and in test two (T2) – at 7 km/h. In test three (T3), the stroller was steered at a speed of 4 km/h additionally with an oscillating motion along the *Z*-axis to reflect the rocking of the child in the stroller. In the T4 trial, an additional oscillatory motion was introduced along the *Y*-axis (horizontal direction), representing another variant of rocking the child by the parents. The registration of oscillations proceeded when the walking speed was stabilized, and the strollers were always steered by the same person.

The results obtained were compared with the values that correspond with the comfort limit given by the ISO 2631 standard [11].

In order to determine whether and to what extent a child's exposure to whole body vibration, riding in a gondola strollers may pose a risk to that child, the results obtained were cross-referenced to the ISO 2631 standard [11]. According to this evaluation method, each translational component of acceleration must be filtered out using the appropriate frequency weighting curve indicated and defined in the ISO standard. To assess the comfort of a person lying down, the W_d frequency weighting curve must be used for the horizontal (X, Y) axes and the W_k curve for the vertical (Z) axis [11]. The total weighted acceleration value aRMS is calculated using Eq. (1).

At the same time, attention was paid to the tertian bands, which correspond to the resonant frequencies of internal organs of children determined in the model studies by Więckowski [24].

$$a_w = \sqrt{k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2} \left[\frac{\mathrm{m}}{\mathrm{s}^2}\right],$$

where a_{wx}, a_{wy}, a_{wz} – orthogonal components of the frequency-weighted RMS acceleration [m/s^2]; k_x, k_y, k_z – multiplying factors (for the comfort assessment of the recumbent person, all multiplying factors are equal to 1).

3. Results

The first stage of the analysis was to compare the amplitude-frequency characteristics obtained for baby

Fig. 3. Types of surfaces used in the tests: PAV 1 – "bone" paving stones, PAV 2 – 0.6 × 0.6 m slab, PAV 3 – piccolino stones

carriage passes on all road surfaces at a speed of 4 km/h (reference measurement).

Examples of the amplitude-frequency characteristics obtained for the S3 stroller ride (Fig. 1) on various types of pavement (T1 test) are shown in Figs. 4–6. Due to the lack of a norm regarding the effects of vibrations on the body of children, the results obtained were compared with the comfort limit defined in the ISO 2631 standard [11], used for adults, which is also highlighted by other authors [23], [27], [28].

In the case of vibration for the axis, the comfort limit as defined by the ISO standard was exceeded for the PAV 3 pavement for the 1.6 Hz third-octave band. A similar trend was also observed for stroller S1. For strollers S2 and S4, the comfort limit for the *X*-axis was not exceeded.

For the *Y*-axis, exceedances of the comfort limit for the S3 stroller were found in the frequency range of 2 to 2.5 Hz for all pavements, 1.6 for PAV 1 and 3.15 Hz for PAV 3 pavements. For the remaining strollers, exceedances of the comfort limit for the *Y*-axis in these frequency ranges are also apparent mainly for PAV 1 and PAV 3 pavements. In addition, for stroller S4, a two-fold exceedance of the comfort limit for the PAV 2 pavement is visible for the 3.15 Hz third-octave band.

Based on the results for the S3 stroller, there is an observable exceedance of the comfort limit in the 4–10 Hz third-octave band for the *Z*-axis regardless of the type of pavement on which the gondola strollers was driven. The highest value of vibration was observed for PAV 3 pavement, that is, for piccolino pavement compared to PAV 1 and PAV 2 pavements, for frequencies in the range of 3.15–25 Hz. Above a frequency of 25 Hz, the highest vibration value is seen for PAV 1 surfaces. In the case of the drive over piccolino pavement (PAV 3),

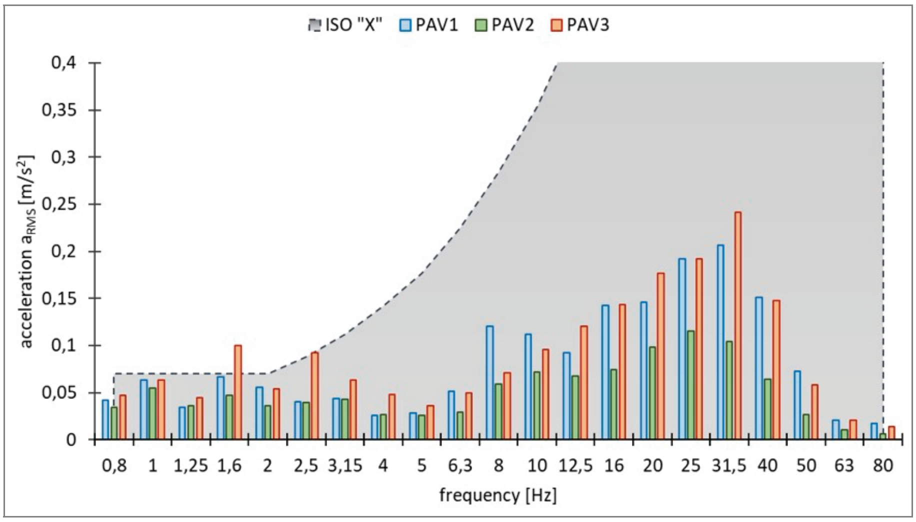

Fig. 4. Amplitude-frequency characteristics obtained during the T1 test for the S3 stroller in the *X*-axis direction

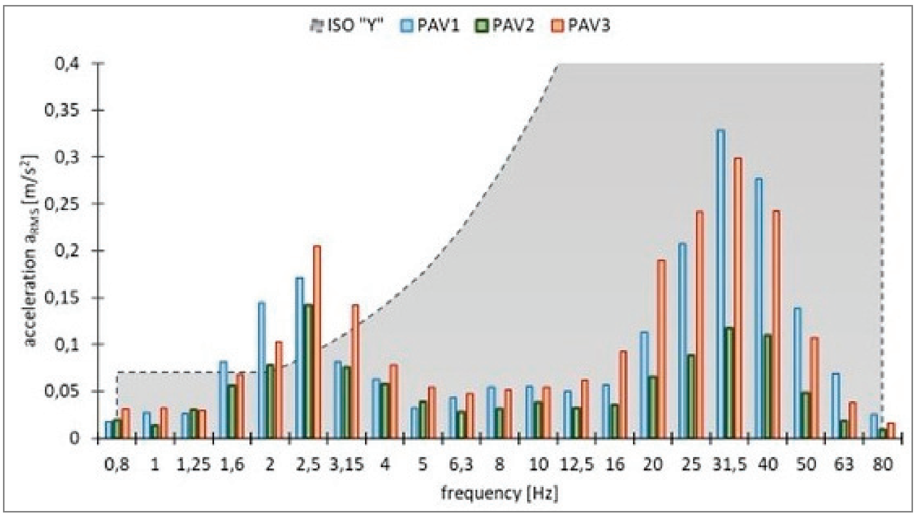

Fig. 5. Amplitude-frequency characteristics obtained during the T1 test for the S3 stroller in the *Y*-axis direction

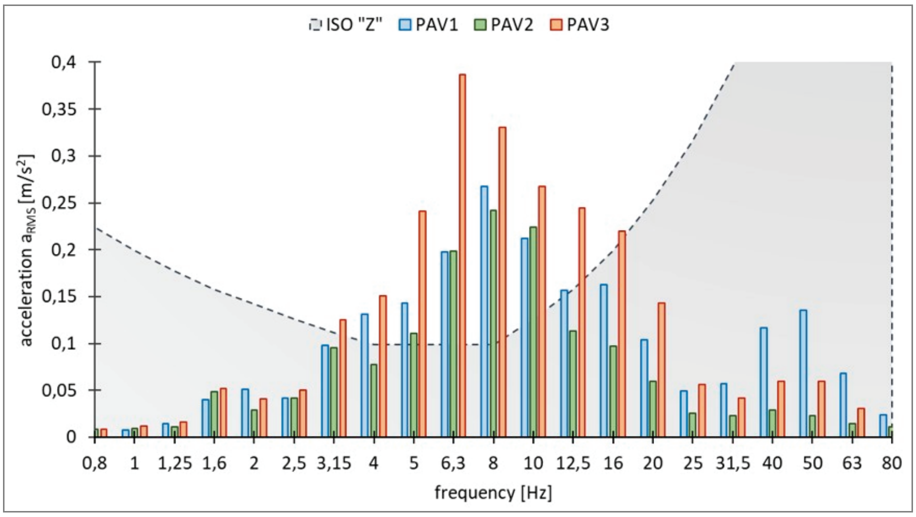

Fig. 6. Amplitude-frequency characteristics obtained during the T1 test for the S3 stroller in the *Z*-axis direction

the ISO-compliant comfort limit is exceeded by up to 4 times for the 6.3 Hz third-octave band.

For the remaining strollers, exceedances of the comfort limit are noticeable in similar frequency ranges. At the same time, for stroller S1 and S2 the values are lower than for stroller S3, while for stroller S4 the exceedances are highest in the range of 8–16 Hz (5 and 3 times the limit value, respectively).

In order to determine the impact of individual factors such as the speed of the baby carriage, or making an additional vertical or horizontal swinging motion (rocking the carriage), the measurements obtained in these trials (T2, T3 and T4) were related to the reference measurement (T1).

First, the effect of the travel speed of a gondola stoller on the magnitude of the received vibrations (aRMS value) was determined. To achieve this, for each third-octave band in the range specified by the ISO standard (0.8–80 Hz), the ratio of the acceleration values obtained when traveling at 7 km/h (T2 test) to the ratio when traveling at 4 km/h (T1 test) was determined for each of the analyzed axes, as shown in Figs. 7–9 for the example carriage S2.

When the value of the ratio $\frac{a_{T_2}}{a_{T_1}} = 1$ means that the value of acceleration does not depend on the speed of movement of the cart. When the value of the ratio $\frac{a_{T_2}}{a_{T_1}} < 1$ means that the vibrations during the T2 test (speed of 7 km/h) were reduced compared to the vibrations during the T1 test (speed of 4 km/h). When the value of the ratio $\frac{a_{T_2}}{a_{T_1}} > 1$ means that the value of vibration acceleration increases as the velocity increases.

For the *X*-axis and *Y*-axis, an increase in the value of the received vibrations is observed with an increase in the speed of the passage of the baby carriage $\left(\frac{a_{T_2}}{a_{T_1}} > 1\right)$. The largest increase in vibration with the speed of moving the baby carriage was observed for

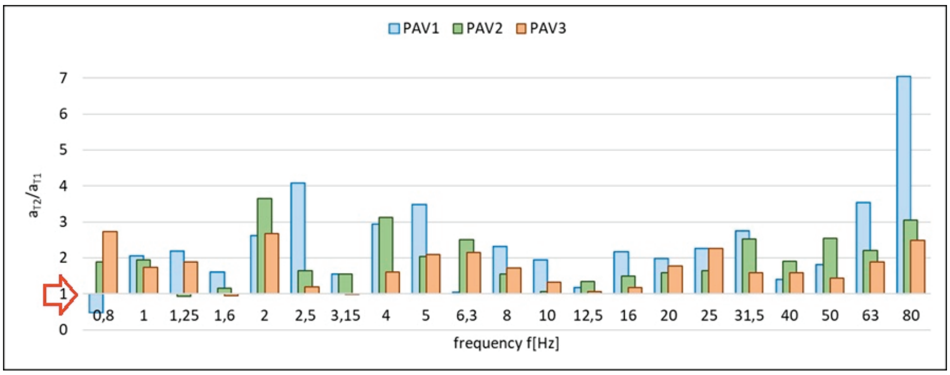

Fig. 7. Ratio of aT2/aT1 values in the frequency domain for the S2 stroller for the *X*-axis

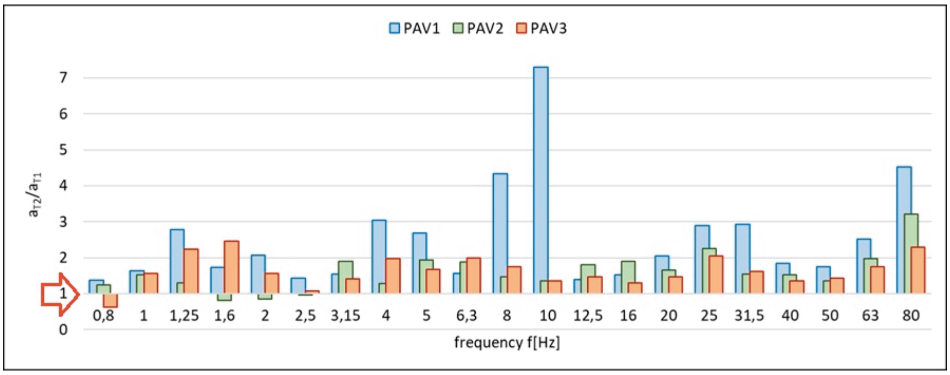

Fig. 8. Ratio of aT2/aT1 values in the frequency domain for the S2 stroller for the *Y*-axis

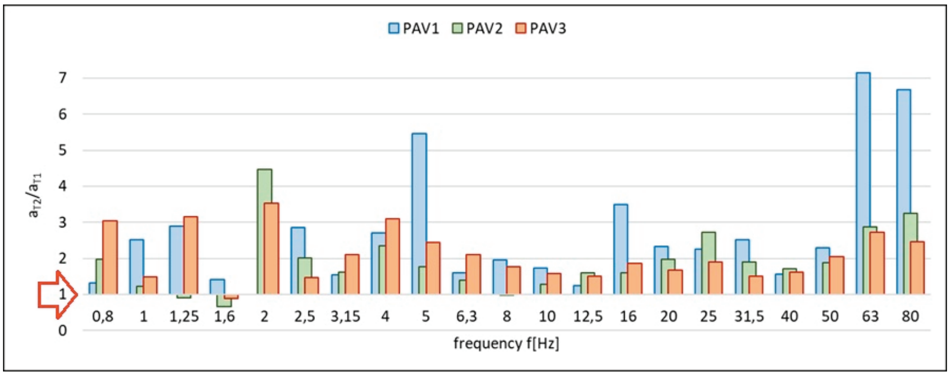

Fig. 9. Ratio of aT2/aT1 values in the frequency domain for the S2 stroller for the *Z*-axis

the PAV 1 pavement. For this pavement, the acceleration value in the T2 test was up to seven times higher compared to the T1 test for the S2 stroller.

Based on Figure 9, a value of $\frac{a_{T_2}}{a_{T_1}}$ above 1 is observed for each tertian band except for those with frequencies of 1.25–1.6 Hz of the PAV 2 surface. This means that as the speed of movement of the baby carriage increases, there is an increase in the value of vertical vibrations. On average, this is twice the increase in acceleration compared to moving at 4 km/h for the *Z*-axis. Also for this axis for PAV 1 pavement, the highest increase in vibration is observed as the moving speed increases.

Then, the influence of additional excitation applied to the stroller (vertical – test T3, horizontal – test T4) on the magnitude of received vibrations was checked. For this purpose, the ratios $\frac{a_{T_3}}{a_{T_1}}$ and $\frac{a_{T_4}}{a_{T_1}}$ were determined for each third octave band, which is presented in Figs. 10–15 for the stroller S2.

In the case of the *Z*-axis for carriage S2, an increase in vibration values is visible with the application of additional vertical forcing. For a frequency of 2.5 Hz,

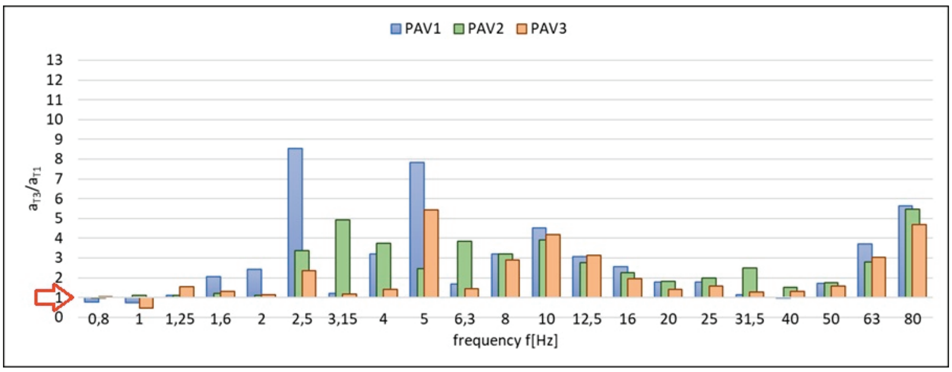

Fig. 10. Ratio of aT3/aT1 values in the frequency domain for the S2 stroller for the *X*-axis

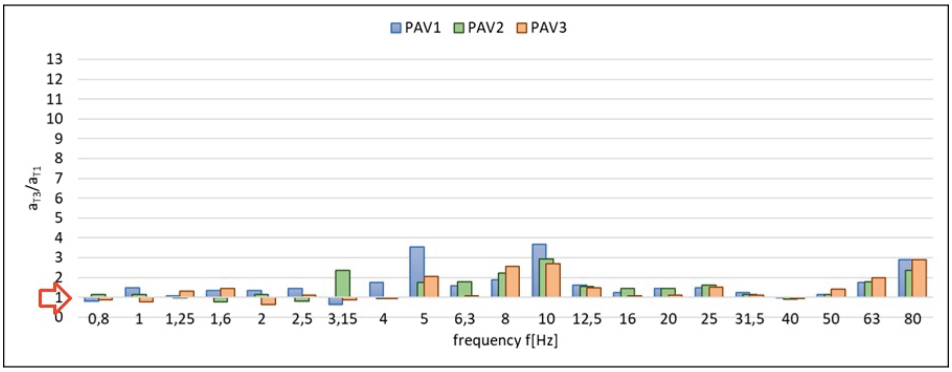

Fig. 11. Ratio of aT3/aT1 values in the frequency domain for the S2 stroller for the *Y*-axis

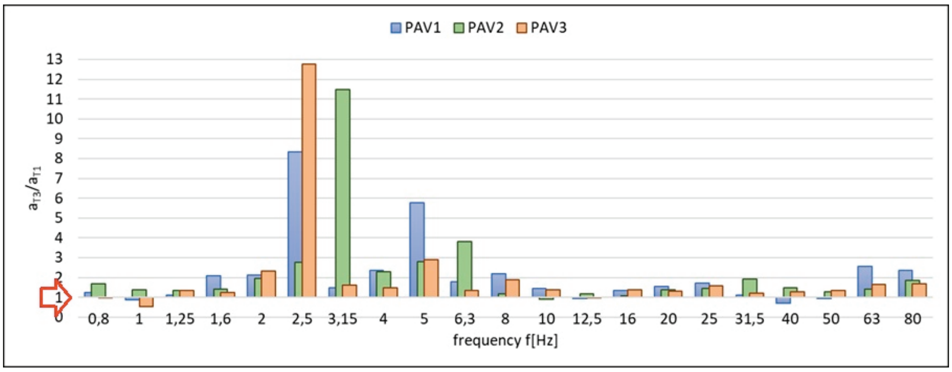

Fig. 12. Ratio of aT3/aT1 values in the frequency domain for the S2 stroller for the *Z*-axis

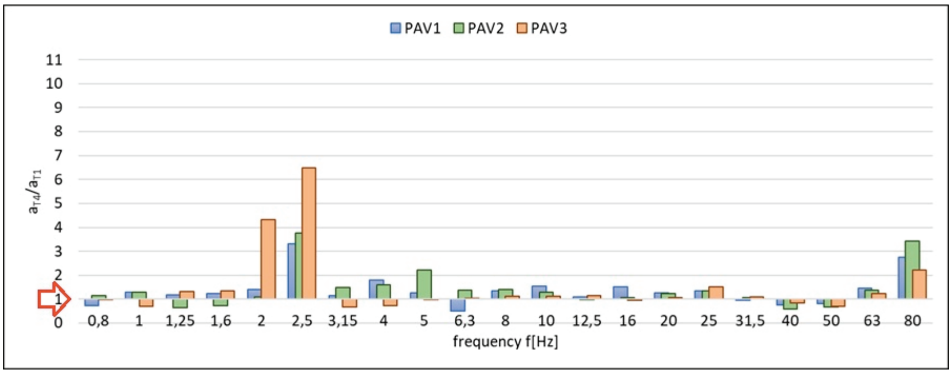

Fig. 13. Ratio of aT4/aT1 values in the frequency domain for the S2 stroller for the *X*-axis

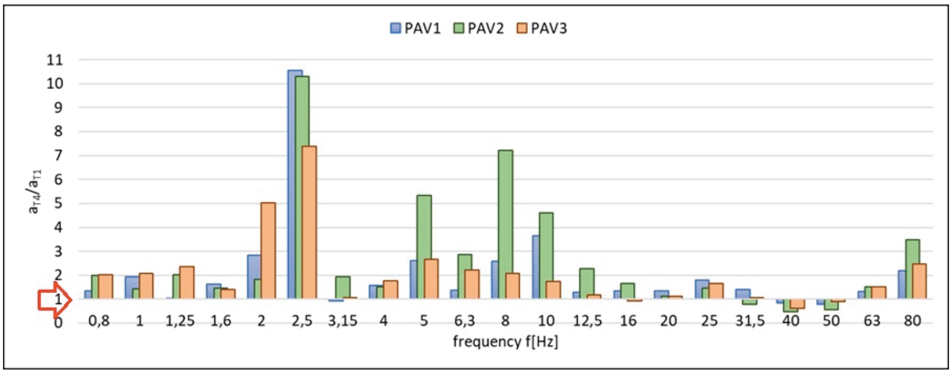

Fig. 14. Ratio of aT4/aT1 values in the frequency domain for the S2 stroller for the *Y*-axis

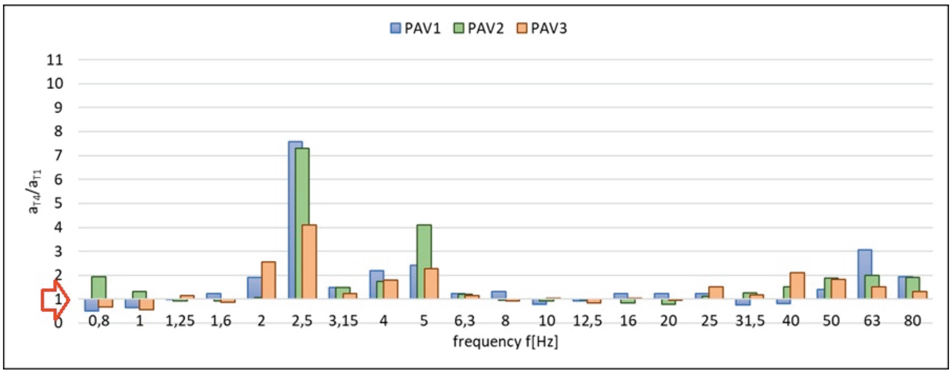

Fig. 15. Ratio of aT4/aT1 values in the frequency domain for the S2 stroller for the *Z*-axis

the largest increase in acceleration values is observed for PAV 1 (8 times T1 acceleration) and PAV 3 (13 times T1 acceleration). For the PAV 2 pavement, the largest increase in vibration values is seen at 3.15 Hz (12 times higher vibration than during the T1 run). For the *X*-axis, a similar trend was observed.

The value of $\frac{a_{T_4}}{a_{T_1}}$ is greater than 1 for frequencies of 2–6.3 Hz and 16–80 Hz for the *Z*-axis. In these tertian bands, the additional horizontal forcing increases the vertical vibration by an average of 1.5 times.

For horizontal oscillations along the *X*-axis, the value of $\frac{a_{T_4}}{a_{T_1}}$ is greater than 1 for frequencies of 2–6.3 Hz and above 25 Hz. On the other hand, for the *Y*-axis, the value of $\frac{a_{T_4}}{a_{T_1}}$ is above 1 for practically every third-order band (sometimes it is below 1 depending on the type of surface).

Table 1. Influence of different types of factors on the magnitude of received vibrations

	Pearson correlation coefficient		
	x	*y*	*z*
Velocity	0.86	0.72	0.86
Rocking in the vertical axis	0.62	0.30	0.62
Rocking in the horizontal axis	0.73	0.29	0.73

In order to determine which factor most significantly influences the magnitude of received vibrations in a pram, Pearson correlation coefficients were calculated, and the results are presented in Table 1. A positive strong correlation (correlation coefficient of 0.7–0.9) for all axes is observed between the magnitude of received vibrations and the speed at which the baby carriage moves. An average correlation (0.4–0.7) was found between the magnitude of received vibrations with additional forcing (vertical or horizontal) and the baseline test for the *X*-axis (in line with the direction of travel) and *Z*-axis (vertical axis, perpendicular to the cart bed). In contrast, the correlation was weak for the *Y*-axis.

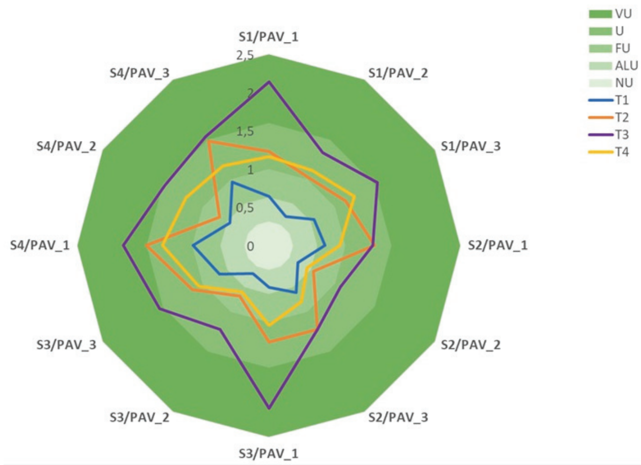

Fig. 16. Values calculated for all tests performed (where according to ISO standard NU – not uncomfortable, ALU – a little uncomfortable, FU – fairly uncomfortable, U – uncomfortable, VU – very uncomfortable))

In Figure 16 the calculated values of the aRMS acceleration based on Eq. (1) for all analyzed cases are summarized. According to ISO 2631, only values below 0.315 m/s^2 do not cause discomfort. Based on the values obtained, it is apparent that even moving at a speed of 4 km/h (T1 test), can cause discomfort according to the ISO standard. The lowest aRMS values are observed for the T1 test, while the highest values are observed for the 3 test. In the case of test T3, for a ride on a PAV 1 surface (bone-type pavement popularly used in residential areas) – the aRMS reached a value even higher than 2 m/s^2 for S1 and S3 strollers rides, which according to the ISO classification represents extremely uncomfortable conditions. The lowest value is observed for the T1 test, the PAV 1 surface, and is 0.44 which, according to the ISO standard classification, is a little uncomfortable. It is important to note that this classification (and the standard) is mainly applied to adults in the workplace, and the dynamic response of an adult and a child are different.

4. Discussion

This paper presents a pilot study of the magnitude of whole body vibrations generated in a gondola stroller when moving on different types of surfaces. The study also attempted to determine the effect of speed and additional vertical and horizontal forcing (reflecting the rocking motion often performed by parents to, for example, put a baby to sleep) on the magnitude of the received vibrations.

Due to the lack of a standard available in the literature relating to the evaluation of vibrations affecting children, the authors used the ISO-2631 standard [11] in this paper. It should be noted that this standard is used for adults in workplaces, which is significantly different from the conditions described in the following article. Nevertheless, the ISO 2631 standard as a criterion for evaluating whole body vibrations acting on a child was also presented in the articles [3], [23]. Based on the results obtained, it is apparent that the comfort limit defined by the ISO standard is exceeded, as early as when moving at a speed of 4 km/h (reference measurement – Test T1). With reference to the ISO standard, an exceedance of the comfort limit is observed in the 6.3–10 Hz range. Comparing these results with Więckowski's model studies, it can be concluded that, with respect to the child, higher acceleration values in the range of these tertian bands can negatively affect the head area (resonant frequency range of 6–8 Hz), trunk (6–17 Hz) or pelvis (6–17 Hz).

In the case of stroller S4, the comfort limit was exceeded for frequencies of 4–12.5 Hz, also for this stroller the highest average values of aRMS were found (Table 1), which could be due to the technical condition of the stroller (most worn).

When walking speed is increased, an increase in whole body vibration is observed in all tertian bands (in the range from 0.8 to 80 Hz) for all tested directions, making the comfort limit in extreme cases exceeded by up to 9 times. The study shows that increasing the walking speed from 4 km/h (T1 test) to 7 km/h (T2 test) results in an average doubling of whole body vibration.

Based on the results obtained, it is difficult to clearly define the impact of vibrations generated on typical surfaces on the comfort of a child. At the same time, determining a child's comfort is a very complicated task, and defining it involves a subjective assessment at the same time. The exceedances of the ISO 2631 standard in the studies conducted confirm the need to develop an appropriate standard for children's exposure to vibration. Such a standard would be applicable not only for transporting children in gondola strollers but also for baby car seat transport or medical transport [1], [8], [9], [13]. It also seems necessary to implement an appropriate procedure in the stroller design standard (ISO 31110) to test baby strollers for the mechanical vibrations generated during travel.

Exceeding the ISO standard when moving a child in a stroller is confirmed by a study conducted by Sierzputowski et al. In this study, two travel strollers, an old type and a new type, were compared and the test was conducted for a speed of 4 km/h. According to Muraki et al. [17], whole body vibrations can cause significant stress to the child and negatively affect the functioning of the person driving the stroller.

The effect of the type of pavement on the magnitude of received vibrations was observed. Higher acceleration values are found for paving blocks made up of smaller components (PAV 1, PAV 3) than on a surface with larger components (PAV 2). In addition, the measurement was performed on a predetermined measurement section in good technical condition. Under real travel conditions, movement takes place over various types of pavement with unevenness, poor maintenance, or over thresholds or curbs, which can cause higher vibration values. Lim's article [16] also noted the effect of pavement on the magnitude of vibrations received. His results show that vibration values obtained indoors (inside a building) have a lower value than those measured when moving outdoors (on sidewalks in public spaces).

The highest aRMS value was observed for the T3 run (1, 1 – 2, 1 m/s^2), which was caused by additional vertical forcing (Z-axis pendulum movement), while the lowest aRMS values were observed for the T1 run (0, 4 – 1 m/s^2). According to the ISO standard, the values achieved during the T1 test, i.e., moving the cart at a speed of 4 km/h, are within the range of a little uncomfortable or fairly uncomfortable, while *rms* values above 2 m/s^2 are considered extremely uncomfortable.

According to Dell'orto et al. [3], only strollers pushed over tarmac at 5 km·h^{-1} exhibited average acceleration values below the "health risk zone" for a daily duration of 4 hours. In contrast, strollers pushed over cobblestones and sidewalk slabs produced accelerations within the "health risk zone" with durations of less than 20 minutes. For this reason, the authors emphasize that there is a potential health risk if strong vibrations are experienced daily and repeatedly over extended periods [3].

The values of whole body vibration obtained in the study are similar to those presented in the work of Zuska and co-authors [25], in which the authors studied whole body vibration occurring on a child car seat, with an assumed child weight of 5 kg. According to the results presented by them, the aRMS values (for the vertical direction) are in the range of 0.3 to 0, 6 m/s^2 during a ride on an asphalt road, while on a gravel road they were 1.1 to 1, 9 m/s^2.

In the study by Donghui et al. [5], the authors demonstrated that when traveling in a child car seat, vibrations of up to approximately 0.6 m/s^2 a_{RMS} are generated at a vehicle speed of 70 km/h.

5. Conclusions

On the basis of the conducted research, it can be concluded that when children are being transported in deep strollers, they are exposed to vibrations of varying intensity, which also depend on the speed and additional excitations generated by the caregiver. The visible exceedances of the ISO 2631 standard, designed to assess the hazards of adults at the workplace, cannot be relied on as a foundation for a clear assessment of the impact of vibrations on children transported in gondola strollers. The difficulty in assessing the negative effects of vibration on a child's body is related to the lack of a dedicated assessment norm. The creation of a norm is hindered by the inability to obtain information about the child's subjective feelings. Nevertheless, the level of perceived vibrations in a pram is high enough to cause discomfort to children, and this issue should be further developed. Therefore, it seems necessary to develop an objective norm that is dedicated to children.

In addition, it was found that the magnitude of vibrations received is influenced by the speed of movement and the degree of wear and tear on the wheelchair. Adding a test to the norm that would include measurement of vibration could be crucial for prospective parents in selecting a baby carriage.

References

[1] BROWNING J., WALDING D., KLASEN J., DAVID Y., *Vibration issues of neonatal incubators during in-hospital transport*, J. Clin. Eng., 2008, 33, 74–77.

[2] *Centers for Disease Control and Prevention. Data Table for Girls Length-for-age and Weight-for-age Charts*. https://www.cdc.gov/growthcharts/cdc-growth-charts.htm

[3] DELL'ORTO G., DAAMS B., HAPPEE R., PAPAIOANNOU G., LOEVE A., MEIJERINK J., MOORE J. K., *Vibration Characterisation of Strollers and Cargo Bicycles for Transporting Infants: Including Recommendations for Users*, Designers, Manufacturers, and Researchers, 2025.

[4] DESHAW J., RAHMATALLA S., *Predictive discomfort of supine humans in whole- body vibration and shock environments*, Ergonomics, 2016, 59, 568–581, DOI: 10.1080/00140139.2015.1083125.

[5] DONGHUI H., JIE Z., YI Q., JIANYING A., JIN Z., *Vibration Comfort Evaluation of Child Safety Seat Based on Vehicle Ride Comfort*, 2023 IEEE 3rd International Conference on Electronic Technology, Communication and Information (ICETCI), Changchun, China, 2023, 1705–1713, DOI: 10.1109/ICETCI57876.2023.10176936.

[6] FREJ D., PODOSEK K., KELVIN T., *Overview of design solutions for child seats*, Archiwum Motoryzacji, 2021, 92 (2), DOI: 10.14669/AM.VOL92.ART3.

[7] GRIFFIN M.J., *Handbook of Human Vibration*, Elsevier, Amsterdam, The Netherlands, 1990.

[8] GROSEK S., MLAKAR G., VIDMAR I., IHAN A., PRIMOZIC J., *Heart rate and leukocytes after air and ground transportation in artificially ventilated neonates: A prospective observational study*, Intensive Care Med., 2009, 35, 161–165.

[9] GOSWAMI I., REDPATH S., LANGLOIS R.G., GREEN J.R., LEE K.S., WHYTE H.E., *A Whole-body vibration in neonatal transport: A review of current knowledge and future research challenges*, Early Hum. Dev., 2020, 146, 105051.

[10] HARRISON C., MCKECHNIE L., *How comfortable is neonatal transport?*, Acta Paediatr., 2011, 101, 143–147.

[11] ISO-2631-1: 2014. *Mechanical Vibration and Shock.* Part 1: *Evaluation of Human Exposure to Whole Body Vibration*, International Organization for Standardization, Geneva, Switzerland, 2014.

[12] ISO 31110:2020 *Wheeled child conveyances – Pushchairs and prams – Requirements and test methods.*

[13] JOYCE T., HUECKER M.R., *Pediatric Abusive Head Trauma*, Treasure Island, FL, USA, 2020.

[14] KAMIO C., AIHARA T., *Dynamic simulation of baby carriage under running condition: Analyzing vibration when passing over a level difference*, Mech. Eng. Lett., 2020, 6, 19-00376.

[15] KOH B.X., NIRMAL U., YUHAZRI M.Y., *Developments on Baby Strollers over the Last Decade*, Current Journal of Applied Science and Technology, 2019, 33 (6), 1–25, DOI: 10.9734/cjast/2019/v33i630105.

[16] LIM K.S., *A Study of Infant Comfort Level in a Baby Stroller*, Bachelor's Thesis, Tunku Abdul Rahman University College, Kuala Lumpur, Malaysia, 2018.

[17] MURAKI S., SAITO S., OOKURA M., *Physical Strain and Risk during Stroller Locomotion on Cross and Combined Slopes*, Advanced Engineering Forum, 2013, 10, 43–50, DOI: 10.4028/www.scientific.net/AEF.10.43.

[18] OKAJIMA H., OTA S., OTA R., *Dynamic Characteristics of Infants Riding on Stroller*, Proceedings of the ASME 2020 International Mechanical Engineering Congress and Exposition, Online, 16–19 November 2020.

[19] PN-EN 1888:2012. *Artykuły dla dzieci. Wózki dziecięce. Wymagania bezpieczeństwa i metody badań.*

[20] PN-EN 1888-1:2019-02. *Artykuły dla dzieci. Wózki dziecięce.* Część 1: *Wózki spacerowe i wózki głębokie.*

[21] RAHMATALLA S., DESHAW J., BARAZANJI K., *Biodynamics of supine humans and interaction with transport systems during vi-*

bration and shocks, J. Low Freq. Noise Vibr. Active Control., 2019, 38, 808–816, https://doi.org/10.1177/1461348417725957

[22] RAHMATALLA S., KINSLER R., QIAO G., DESHAW J., MAYER A., *Effect of gender, stature, and body mass on immobilized supine human response during an route care transport*, J. Low Freq. Noise Vibr. Active Control., 2021, 40, 3–17, https://doi.org/10.1177/1461348420911253

[23] SIERZPUTOWSKI G., WRÓBEL R., MIHAYLOV V., JANECZEK M., MAJEWSKA-PULSAKOWSKA M., JARZĄB S., *Pilot Studies of Vibrations Induced in Perambulators When Moving on Different Surfaces*, Appl. Sci., 2021, 11 (16), https://doi.org/10.3390/app11167746

[24] WIĘCKOWSKI D., *Próba oszacowania częstotliwości drgań własnych części ciała dziecka*, 2012, 159–172.

[25] ZUSKA A., FREJ D., JACKOWSKI J., ŻMUDA M., *Research and Analysis of the Propagation of Vertical Vibrations in the Arrangement of a Vehicle Seat – A Child's Seat*, Sensors, 2021, 21, 8230, https://doi.org/10.3390/s21248230

[26] ZUSKA A., SZUMSKA-FREJ D., *Analysis of the impact of a child seat mounting method on vertical vibrations affecting a child in a child seat*, 2020 XII International Science-Technical Conference AUTOMOTIVE SAFETY, Kielce, Poland, 2020, 1–8, DOI: 10.1109/automotivesafety47494.2020.9293503.

[27] SCHWANITZ S., STUFF A., ODENWALD S., *Exposure of Children in a Bicycle Trailer to Whole-Body Vibration*, Proceedings, 2020, 49, 114, https://doi.org/10.3390/proceedings2020049114

[28] NILSSON M., *Health risk aspects and comfort for infants in infant seats for cars*, 2005.