# LABORATORY TESTS OF THE CONTROL OF THE CHILD SEATS USING METHOD FOR THE VIBRATION COMFORT OF CHILDREN TRANSPORTED IN THEM

**Andrzej Zuska, Emilia Szumska, Damian Frej***

Department of Automotive Engineering and Transport, Kielce University of Technology, Kielce, Poland

*E-mail of corresponding author: frejdamian@gmail.com

***Resume***

The article presents results of the laboratory studies of the impact of the child seats mounting method on the vibration comfort of children transported in them. The tested child seats were mounted forward facing the rear seat of a passenger car. The A seat was fastened with the ISOFIX base, while the B seat was fastened with standard car seat belts. During the tests, values of the vertical vibrations were measured on the seat of the child seat, the rear seat of the vehicle and the ISOFIX base. It was noted that the analyzed system, may be characterized by two different vibration transmission chains, which depend on the child seat mounting system (classic seat mounting system and ISOFIX system). These studies show the negative impact of using the ISOFIX base, which is confirmed by the Root Mean Square (RMS) values and the Vibration Dose Value (VDV), determined for the "A" seat secured with the ISOFIX base that were higher than the RMS and VDV for the "B" classic mounted seat.

Available online: https://doi.org/10.26552/com.C.2021.3.B187-B199

***Article info***

Received 16 September 2020
Accepted 6 November 2020
Online 9 April 2021

***Keywords:***

vehicle safety,
vibrations,
child seat,
vibrating comfort

ISSN 1335-4205 (print version)
ISSN 2585-7878 (online version)

## 1 Introduction

In many countries, transporting children in vehicles is possible only with use of appropriate seats, the purpose of which is to protect the children placed in them against the adverse effects of road accidents. The seats should be adjusted to the mass and height of a child. The choice of a child seat due to the rapidly changing anthropometric dimensions of a child should be vehicleried out with a particular vehicle. Proper placement and fastening of a child in the seat is the subject of many studies and scientific studies. Most scientists confirm that one of the main causes of serious injuries and even death of children involved in road accidents is incorrectly fastening the child in the seat. The paper [1] presents an analysis of accidents involving children up to the age of three, which occurred in the USA in 2011-2015. The authors found that more than half of the children involved in these accidents were not properly restrained in the vehicle seat. In the works [2-4] it was noted that improper installation of the seat in the vehicle may increase the risk of the child being injured in an accident. In order to meet social expectations, the authors of the work [5] developed an application for a smartphone, instructing how to properly install the vehicle seat in a vehicle. This application was subject to a questionnaire assessment, which shows that 100% of respondents found it useful and helpful.

A motor vehicle is a highly developed vibrating system, stimulated to vibrations by road surface irregularities and elements of the drive system such as the engine, clutch, gearbox, etc. Vibrations are particularly troublesome during the long journeys and may be a source of discomfort and have a negative impact on human health. Vibrations occurring while driving, depending on their amplitude, frequency and duration of impact, may affect the human body causing physical, physiological or psychological changes. Many scientific works and studies have confirmed the negative impact of vibrations on the human body. Examples can be found, among others in the works [6-8]. The permissible values of acceleration acting on an adult human have been the subject of many studies. For this purpose, both the measurement methods and the maximum vibration values themselves have been regulated by the International Standards Organization (ISO). The permissible values of vibrations affecting the human body are included in ISO 2631-1 [9] and British Standards BS 6841 [10]. Unfortunately, these standards apply only to adults and there are no appropriate standards by which to conduct research and assess the vibration comfort of children. For this purpose, the author of the work [11] proposed a method that allows to estimate the natural frequency of organs and parts of a child's body, based on data collected for an adult.

The concept of vibration comfort is associated with

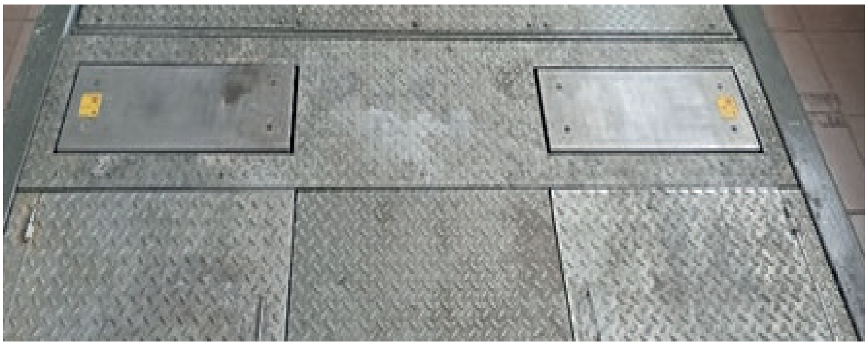

***Figure 1*** *View on the EUSAMA SA640*

***Table 1*** *Basic device parameters EUSAMA SA 640 [17]*

| | |
|---|---|
| frequency of the generated vibrations | 0 - 24 Hz |
| amplitude of generated vibrations | 3 mm |
| the power of the engines | 2x 2.5 kW |
| power protection | 3 x 20 A |

***Table 2*** *Technical parameters of child seats*

| basic parameters | seat A<br>avionaut aerofix | seat B<br>avionaut pixel |
|---|---|---|
| dimensions (cm): | | |
| height | 73 | 44 |
| width | 43 | 58 |
| depth | 66 | 70 |
| own mass (kg) | 4 | 2.5 |
| child's height (cm) | 67-105 | 45-86 |
| child's mass (kg) | up to17.5 | up to13 |

the risk of mechanical vibrations while driving a vehicle. Driving on a road with a relatively smooth surface generates accelerations with a wide frequency range (4-80 Hz), which are transferred to the vehicle body. For travelers it is felt through vibrations of the floor or seats [12]. Driving on uneven roads is particularly uncomfortable for the passengers and the driver of the vehicle.

The topic of the ride comfort of adult vehicle users is now quite thoroughly explored, as opposed to the issue of the comfort of children traveling in vehicle seats. The work [13] presents the results of vibration tests vehicleried out with the use of two child seats while driving on roads with different surfaces. The results showed that the vibrations measured in the seat cushion turned out to be higher than the vibrations in the driver's seat. Similar conclusions were presented in [14]. The presented analysis covers the level of vibrations acting on a child sitting in a vehicle seat with use of a 3-year-old child's dummy and a driver represented by the HYBRID III dummy. The tests were vehicleried out on roads with two different surfaces. The results of the research showed that the vibration comfort of a child sitting in a vehicle seat is worse (by over 10%) compared to the vibration comfort of an adult sitting on a passenger seat in a passenger vehicle. The authors also noted that the incorrect way of mounting the seat has an impact on increase in acceleration in the vertical direction. Results of the research included in [15] show that the degree of wheel imbalance affects the vibration comfort of a child placed in a child safety seat during the journey.

In [16], the authors addressed the issue of ergonomic comfort (convenience) when designing child vehicle seats. The pressure of the child's body on the seat and backrest was analyzed. The result of the research is a model that will enable the manufacturers of vehicle seats to select the appropriate materials and the angle of the backrest to the child's body.

## 2 Research methodology

The experimental studies were conducted under laboratory conditions. During these tests, the wheels of the rear axle of the test passenger vehicle were made to vibrate using the measuring plates of the EUSAMA SA.640 device (Figure 1). The EUSAMA SA640 (Table 1) device is used to test shock absorbers using the EUSAMA method and is a part of the Bosch Beissbarth diagnostic line, but in these tests it acted as a vibration generator.

a) b)

***Figure 2*** *View of the ISOFIX base: a) the base with the stabilizing handle folded out, b) the base with the folded stabilizing handle*

*a)* *b)*

***Figure 3*** *View of the tested vehicle seats: a)seat for transporting children up to 17,5 kg - „A", b) seat for transporting children up to 13 kg - „B"*

The aim of the experiment was to measure and analyze propagation of the vertical vibrations in two subsystems. One of them consisted of a passenger vehicle rear seat and a child seat with a classic fastening system, while the second subsystem consisted of a rear seat and a child seat with an ISOFIX base.

The ISOFIX base (Figure 2) is a solution that allows you to quickly and securely mount the seat in the vehicle without use of the seat belts. It is attached to the metal ISOFIX brackets located in the gap between the backrest and the vehicle seat with two ISOFIX brackets. Additionally, in the front part of the base there is the so-called leg supporting the base against the floor of a vehicle.

During the experiment, on the left-hand side of the rear seat there was an Avionaut AeroFIX seat for fixing, with an ISOFIX base, while on the right-hand side there was an Avionaut Pixel seat mounted in a classic way, i.e. with 3-point seat belts. The technical specifications of the seats are presented in Table 2.

The „A" seat is Avionaut AeroFIX (Figure 3a), designed to transport children with a height of 67-105 cm and a mass of up to 17.5 kg. The seat has been designed so that one can also transport a child in a rearward-facing position. The height of a rearward-facing child, however, must not exceed 105 cm. The vehicle seat's own mass is 4 kg. The seat has a side protection system that protects the child from the side impacts.

The „B" seat is an Avionaut Pixel (Figure 3b), designed for transporting children mass up to 13 kg and height 45-86 cm. The vehicle seat's own mass is 2.5 kg. The seat is made of a composite material with the EPP ARPRO designation, which does not deform during an impact, but thanks to its flexibility it absorbs energy, distributing it evenly in its structure. The seat is mounted in the vehicle using the Avionaut IQ ISOFIX

a) b)

c) d)

***Figure 4*** *Location of three-way sensors during the testing: a) vehicle rear seat under the child seat, b) the seat child seat (gray), c) ISOFIX , d) the seat child seat (red)*

base, which is connected directly to the ISOFIX system available in the vehicle. The correct installation of the seat base is indicated by a sound signal. The child seat can also be attached to the rear seat of a passenger vehicle using the standard seat belts.

During the measurements, the child seats were loaded with a mass imitating the child's mass, which was 5 kg, 7.5 kg, 10 kg, 12.5 kg and 15 kg, respectively. Acceleration on the vehicle's rear seat, child seat base (ISOFIX) and on the seat of child seats were recorded using the three-way acceleration sensors. The location of the three-way sensors during the testing is shown in Figure 4. The sampling frequency of the recorded signal was 1024 Hz.

The vehicle, in which the seats were installed, belongs to the upper-middle class (E segment) and comes from 2009. It was equipped by the air suspension, which could assume four positions: raised, comfortable, automatic and dynamic. During the tests, the suspension was set to the comfort position. The measurements were vehicleried out for three different values of air pressure in the tires, which were respectively: 0.27 MPa, 0.31 MPa and 0.35 MPa.

## 3 Data analysis

Results of the measurements were used to determine the time courses of truncated accelerations and the indicators for assessing the vibration comfort. Examples of the time courses of vertical vibrations, recorded on the seats of the tested child seats, are shown in Figures 5 to 15. When comparing the time courses of acceleration for the A (red) seat and B (gray) seat, it should be stated that for all the load variants of the seats, the acceleration values recorded on the seat A were greater than on the B seat. The biggest difference between these accelerations was recorded when the seats were loaded with a mass of 5 kg. On the other hand, the smallest when they were loaded with a mass of 10 kg. Due to the low legibility of the recorded signals, additional indicators were used for their further analysis.

The RMS, VDV and SEAT indicators were used to analyze the propagation of vibrations in the tested child seats. Their values, which were determined for selected elements of the tested child seats, are summarized in Table 3. Values of these indicators are presented graphically in Figures 15 to 22. The main assessment

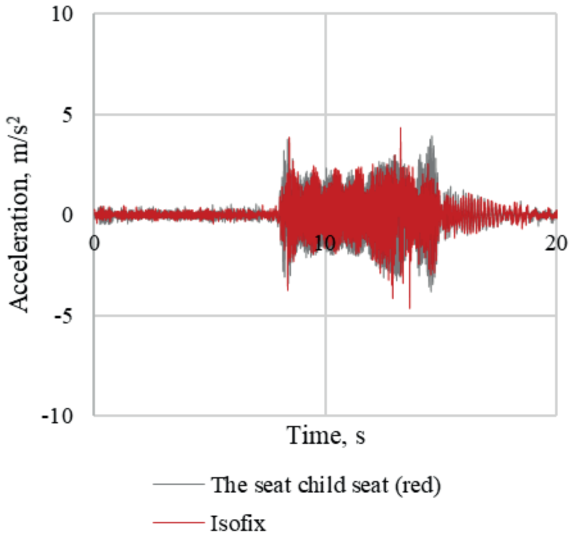

***Figure 5*** *Vertical accelerations recorded on the seat of the child seat A and on the ISOFIX base (air pressure in the tires 0.31 MPa, mass loading the child seat 15 kg)*

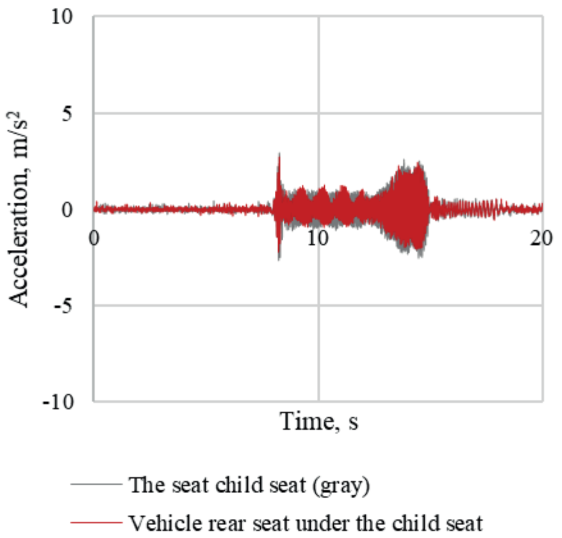

***Figure 6*** *Vertical accelerations recorded on the seat of the child seat B and the seat of the rear sofa under the seat (air pressure in the tires 0.31 MPa,mass loading the child seat 15 kg)*

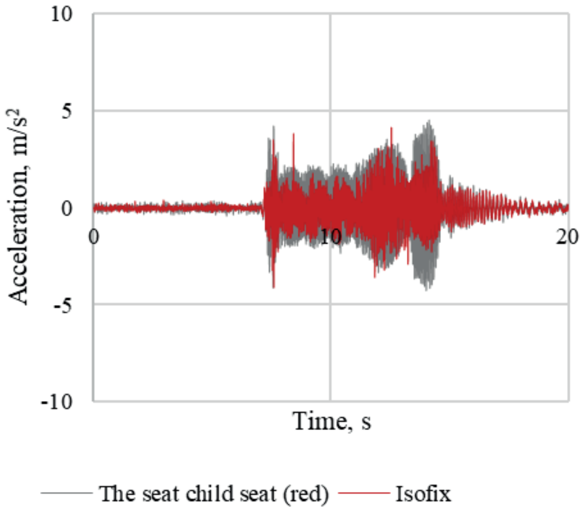

***Figure 7*** *Vertical accelerations recorded on the child seat A and ISOFIX base (air pressure in the tires 0.31 MPa, mass loading the child seat 12.5 kg)*

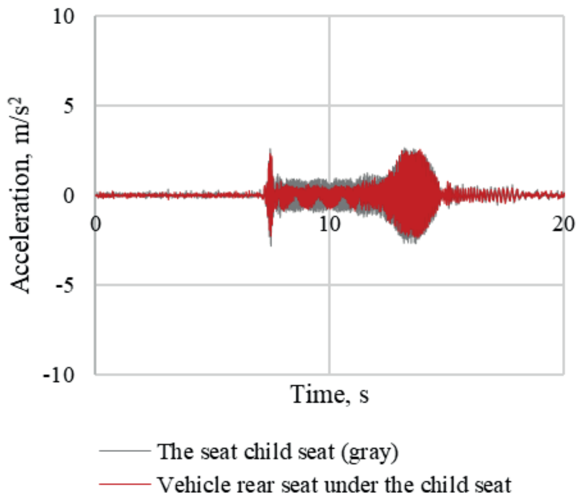

***Figure 8*** *Vertical accelerations recorded on the seat of the child seat B and the seat of the rear sofa under the seat (air pressure in the tires 0.31 MPa, mass loading the child seat 12.5 kg)*

of the impact of vibrations on vibration comfort while driving is the RMS value of accelerations acting in the direction of vertical - Equation (1). For accelerations *a(t)* registered as the stationary realization of the RMS stochastic process, it is the most common indicator of the vibration comfort assessment [17].

$$r.m.s = \left[\frac{1}{T}\int_0^T a^2(t)dt\right]^{\frac{1}{2}}, \qquad (1)$$

where: *a(t)* - recorded as a function of time t, value of acceleration acting in the vertical direction, m/s$^2$,
*T* - segment of the duration of the measurement, s.

The VDV (Vibration Dose Value) - Equation (2) indicator was developed for vibration analysis of the whole human body. The RMS and VDS values are not correlated with each other, because they accentuate the measured acceleration amplitudes in different ways. Both indicators do not estimate the impact of momentary shocks [17].

$$VDV = \left[\int_0^T a^4(t)dt\right]^{\frac{1}{4}}, \qquad (2)$$

where: *a(t)* - the frequency massed acceleration as a function of in time, m/s$^2$,
*T* - is the duration of measurement in s.

Using the accelerations recorded in selected points of the tested child seat, the SEAT index was determined. This index allows to assess the degree of damping of vibrations transmitted to the seat [5, 17]. This demonstrates the ability of the seat to damp vibrations

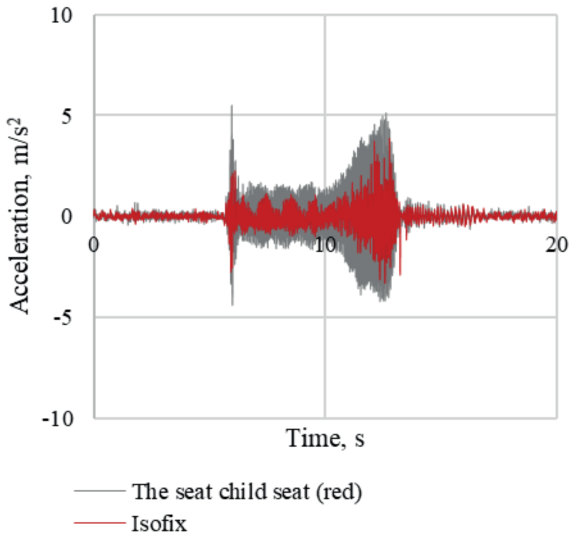

**Figure 9** *Vertical accelerations recorded on the seat of the child seat A and on the ISOFIX base (air pressure in the tires 0.31 MPa, mass loading the child seat 10 kg)*

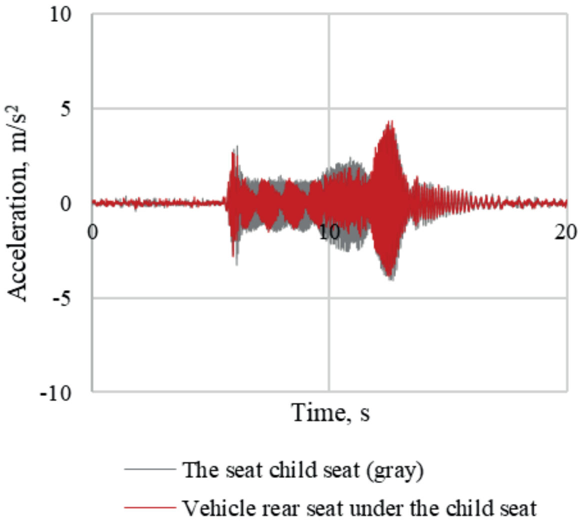

**Figure 10** *Vertical accelerations recorded on the seat of the child seat B and the seat of the rear sofa under the seat (air pressure in the tires 0.31 MPa, mass loading the child seat 10 kg)*

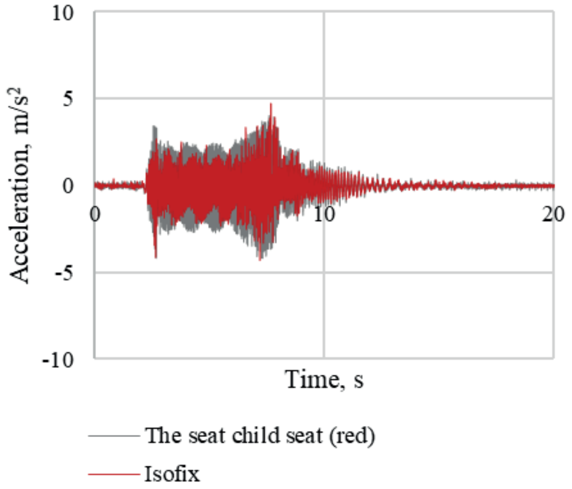

**Figure 11** *Vertical accelerations recorded on the seat of the child seat A and on the ISOFIX base (air pressure in the tires 0.31 MPa, mass loading the child seat 7.5 kg)*

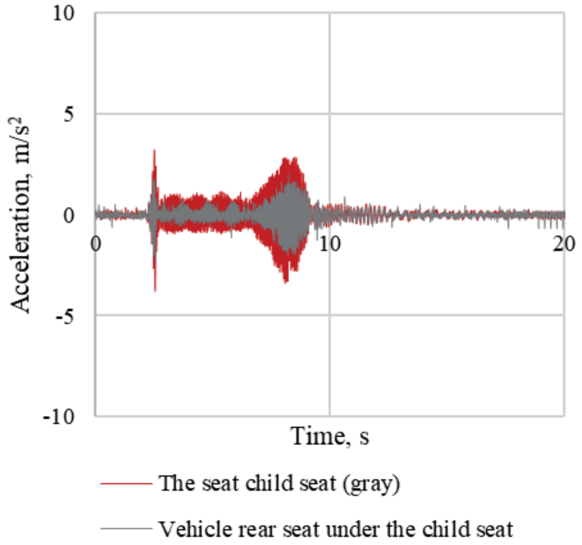

**Figure 12** *Vertical accelerations recorded on the seat of the child seat B and the seat of the rear sofa under the seat (air pressure in the tires 0.31 MPa, mass loading the child seat 7.5 kg)*

in a vehicle in such a way as to protect the driver and passengers from excessive vibration. The SEAT value - Equation (3) is used to describe the vibration isolation of the vehicle seat [13, 17].

$$SEAT = \frac{V.D.V_F}{V.D.V_P}, \tag{3}$$

where: $V.D.V_F$ - Vibration Dose Value determined for the vehicle seat,
$V.D.V_P$ - Vibration Dose Value determined for the surface to which the vehicle seat is attached.

Indicator values RMS and VDV were designated for two seats, differing in design. Two different methods were used to mount them - the classic method and the ISOFIXsystem. The tests were vehicleried out for three different values of air pressure in the tires of the test vehicle. During the measurements, the seats were loaded with five different masss: 5 kg, 7.5 kg, 10 kg, 12.5 kg and 15 kg. Two seats, three values of air pressure in the vehicle wheels and five different masses loading the tested seats, made it possible to conduct thirty different tests (fifteen for each seat). During these tests, the measured values were the vertical acceleration of the seat cushions, the acceleration of the rear seat of the vehicle and the acceleration of the ISOFIX base. Recorded waveforms of acceleration made it possible to determine the RMS and VDV.

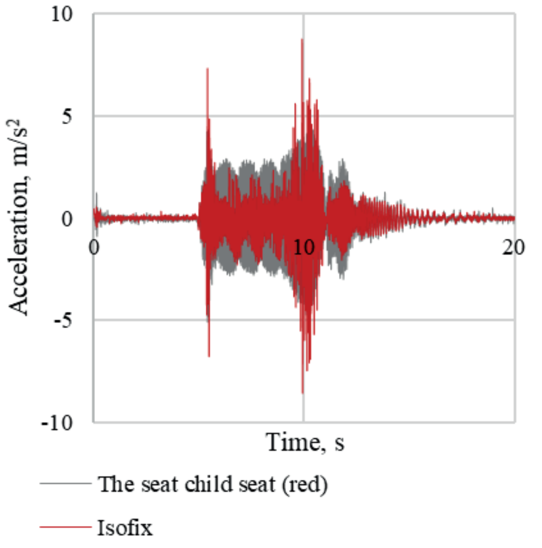

***Figure 13*** *Vertical accelerations recorded on the seat of the child seat A and on the ISOFIX base (air pressure in the tires 0.31 MPa, mass loading the child seat 5 kg)*

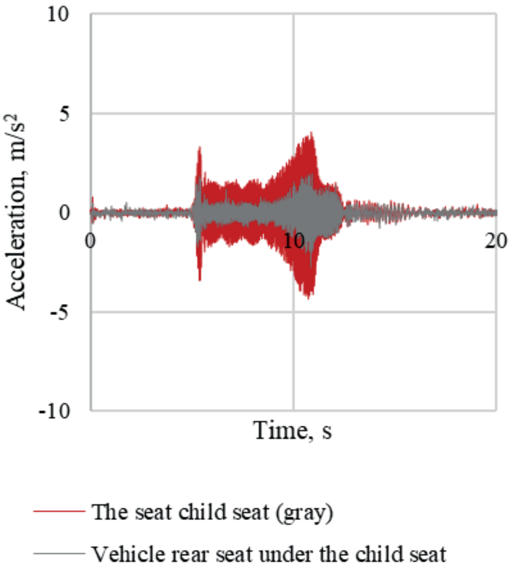

***Figure 14*** *Vertical accelerations recorded on the seat of the child seat B and the seat of the rear seat under the seat (air pressure in the tires 0.31 MPa, mass loading the child seat 5 kg)*

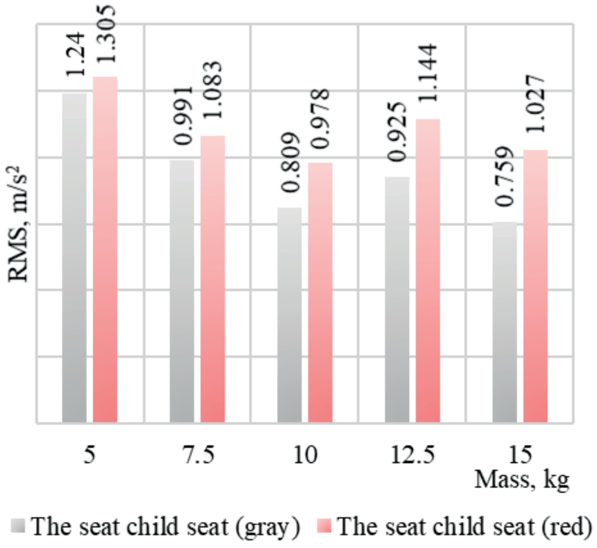

***Figure 15*** *RMS indicator for the seats of the tested child seats (air pressure in the tires 0.27 MPa)*

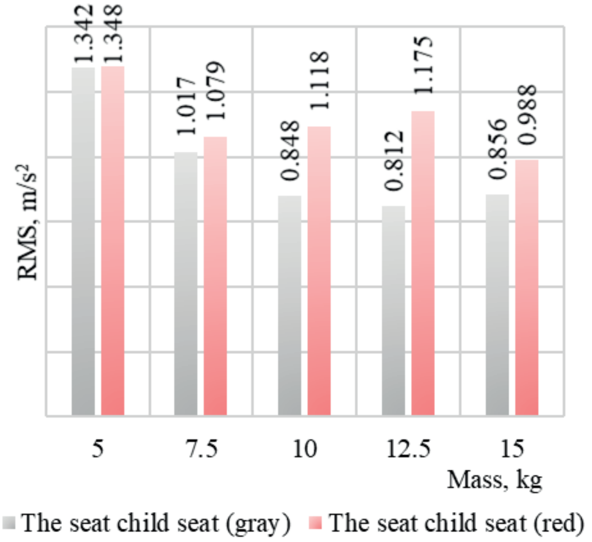

***Figure 16*** *RMS indicator for the seats of the tested child seats (air pressure in the tires 0.35 MPa)*

Values of RMS determined for the „A" seat mounted in the vehicle with the ISOFIX system are higher than the RMS for the classic „B" seat. The largest difference between the RMS values of the „A" seat and the RMS of the „B" seat, reaching 45%, was recorded only in one case, when the tested seats were loaded with a mass of 12.5 kg and the air pressure in the test vehicle wheels was 0.35 MPa. The influence of air pressure in the test vehicle wheels on the RMS value of the tested seats was insignificant. The vast majority of the RMS value increase for the tested vehicle seats under the influence of pressure increase did not exceed 10%.

Between the values of RMS determined for the „B" (gray) seat fitted in a classic way and the mass loading it, there is a high correlation and this relationship is significant. The correlation coefficient is -0.8 when the air pressure in the wheels of the tested vehicle was 0.31 MPa and increased to -0.86 when the air pressure in the wheels of the tested vehicle was 0.27 MPa. A negative value of the coefficient indicates a negative correlation. This means that the RMS value decreases as the mass loaded on the tested seat increases.

In the case of the „A" (red) seat fixed in the vehicle with the ISOFIX system, the correlation coefficient between the mass loaded on the seat and the RMS for one of the three test series is also high at -0.74. This value was obtained for tests during which the air pressure in the test wheels of the test vehicle was 0.35 MPa. In the

***Table 3** Values of RMS and VDV*

| mass loading on the child seat, kg | pressure in tires, MPa | indicator | child seat „B” | | child seat „A” | |
|---|---|---|---|---|---|---|
| | | | location of the acceleration sensor | | | |
| | | | vehicle rear seat under the child seat | the seat child seat | isofix | the seat child seat |
| 5 | 0.27 | RMS | 0.543 | 1.240 | 0.978 | 1.305 |
| | | VDV | 1.689 | 3.859 | 4.183 | 4.089 |
| | 0.31 | RMS | 0.577 | 1.304 | 1.075 | 1.316 |
| | | VDV | 1.780 | 4.058 | 4.687 | 4.130 |
| | 0.35 | RMS | 0.626 | 1.342 | 1.222 | 1.348 |
| | | VDV | 1.940 | 4.213 | 5.849 | 4.310 |
| 7.5 | 0.27 | RMS | 0.604 | 0.991 | 0.673 | 1.083 |
| | | VDV | 2.036 | 3.156 | 2.295 | 3.409 |
| | 0.31 | RMS | 0.599 | 1.011 | 0.829 | 1.148 |
| | | VDV | 2.056 | 3.234 | 2.843 | 3.636 |
| | 0.35 | RMS | 0.594 | 1.017 | 0.887 | 1.079 |
| | | VDV | 2.045 | 3.237 | 3.553 | 3.517 |
| 10 | 0.27 | RMS | 0.644 | 0.809 | 0.655 | 0.978 |
| | | VDV | 2.314 | 2.501 | 2.236 | 3.315 |
| | 0.31 | RMS | 0.768 | 0.943 | 0.901 | 0.977 |
| | | VDV | 2.784 | 2.959 | 3.597 | 3.120 |
| | 0.35 | RMS | 0.641 | 0.848 | 0.966 | 1.118 |
| | | VDV | 2.274 | 2.633 | 3.688 | 3.549 |
| 12.5 | 0.27 | RMS | 0.760 | 0.925 | 0.716 | 1.144 |
| | | VDV | 2.874 | 3.124 | 2.353 | 3.666 |
| | 0.31 | RMS | 0.792 | 0.948 | 0.781 | 1.184 |
| | | VDV | 2.946 | 3.161 | 2.610 | 3.789 |
| | 0.35 | RMS | 0.666 | 0.812 | 0.799 | 1.175 |
| | | VDV | 2.413 | 2.667 | 2.749 | 3.756 |
| 15 | 0.27 | RMS | 0.616 | 0.759 | 0.743 | 1.027 |
| | | VDV | 2.301 | 2.447 | 2.703 | 3.389 |
| | 0.31 | RMS | 0.765 | 0.939 | 0.861 | 0.998 |
| | | VDV | 2.756 | 2.959 | 3.181 | 3.157 |
| | 0.35 | RMS | 0.627 | 0.856 | 0.917 | 0.988 |
| | | VDV | 2.210 | 2.662 | 4.135 | 3.098 |

other two series, the correlation coefficient between the RMS of a seat „A” and the mass that weighs it on it is on a slightly lower level and ranges from -0.62 to -0.68. It proves a moderate correlation and a significant one.

The VDV values determined for the „A” seat, mounted in the vehicle with the ISOFIX system, are higher than the VDV values determined for the „B” seat, mounted in a conventional manner. These differences increase with increasing air pressure in the test vehicle wheels. The biggest difference between the VDV values of the „A” seat and the VDV of the „B” seat, reaching 40%, was recorded for the case when the tested seats were loaded with a mass of 12.5 kg and the air pressure in the test vehicle wheels was 0.35 MPa.

There is a high correlation between the VDV values determined for the „B” (gray) seat, mounted in a classic way and the mass that loads it and the relationship is significant. It amounted to -0.78 when the air pressure in the wheels of the tested vehicle was 0.27 MPa and increased to -0.85 when the air pressure in the wheels of the tested vehicle was 0.35 MPa. A negative value of the coefficient indicates a negative correlation. This means that the VDV value decreases as the mass loaded on the tested seat increases.

In the case of the „A” (red) seat, mounted in the vehicle with the ISOFIX system, the correlation coefficient for one of the three test series is also high at -0.78. This value was obtained for tests during which the air pressure in the test wheels of the test vehicle

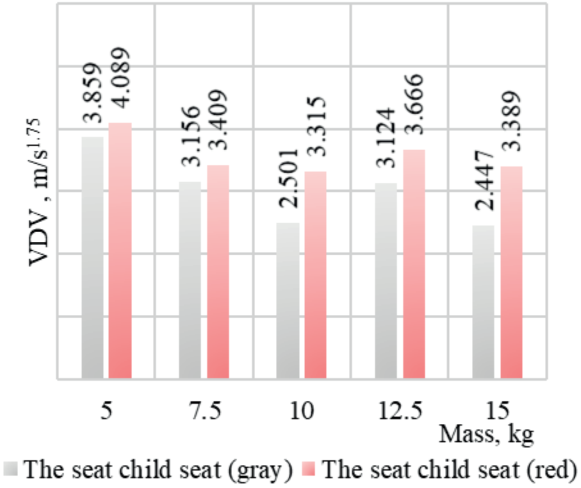

***Figure 17** The VDV indicator for the seats of the tested child seats (air pressure in the tires 0.27 MPa)*

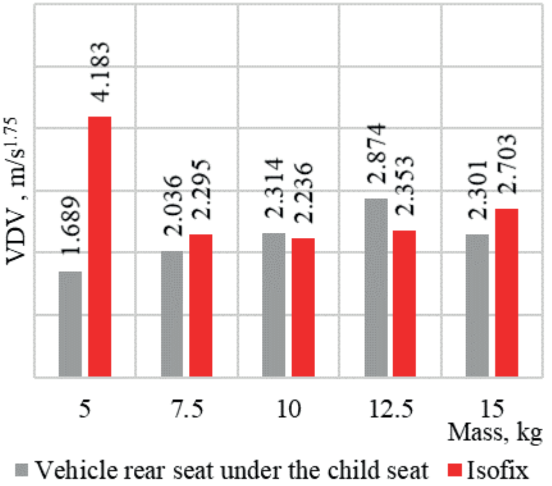

***Figure 18** The VDV indicator for the rear seat under the child seat and ISOFIX base (tire pressure 0.27 MPa)*

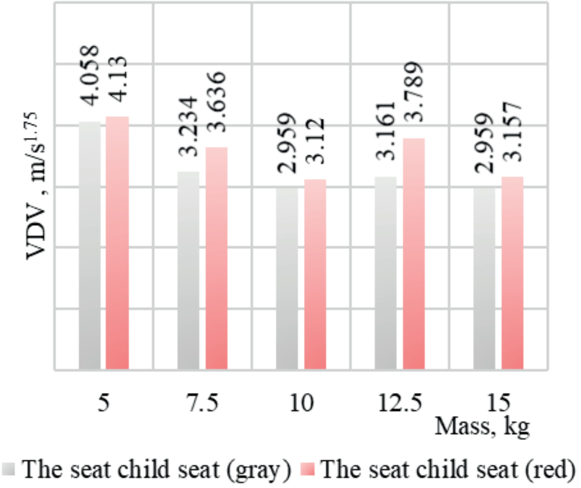

***Figure 19** The VDV indicator for the seats of the tested child seats (air pressure in the tires 0.31 MPa)*

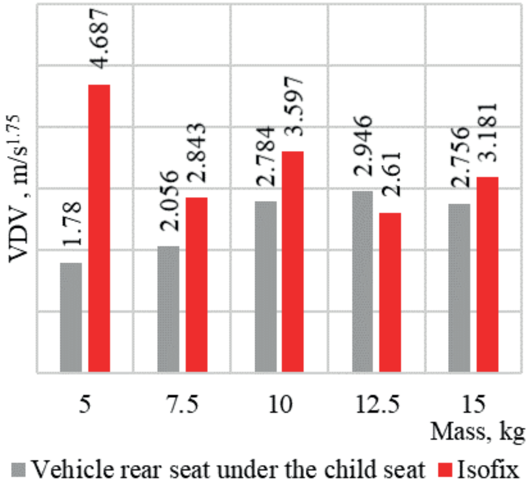

***Figure 20** The VDV indicator for the rear seat under the child seat and ISOFIX base (air pressure in the tires 0.31 MPa)*

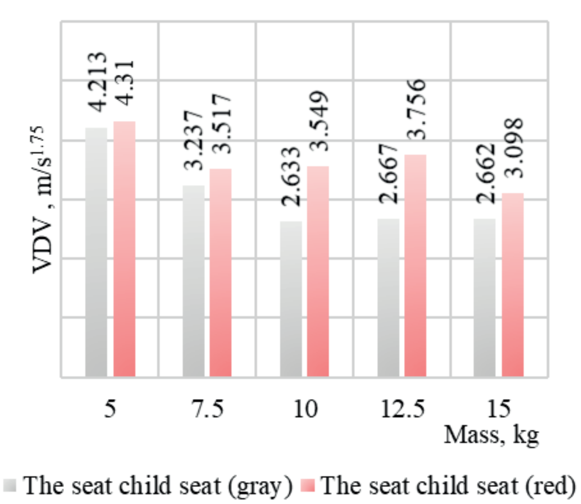

***Figure 21** The VDV indicator for the seats of the tested child seats (air pressure in the tires 0.35 MPa)*

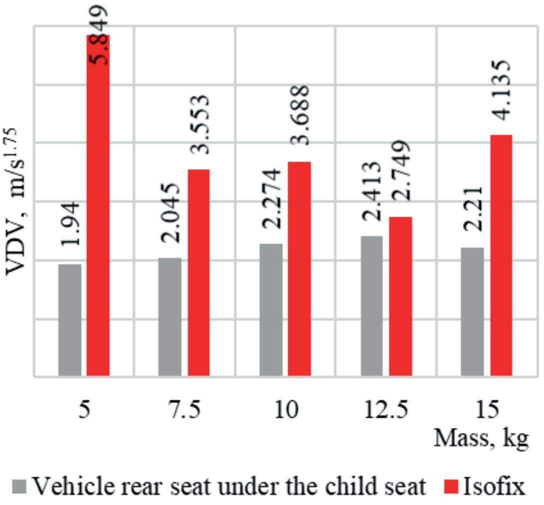

***Figure 22** The VDV indicator for the rear seat under the child seat and ISOFIX base (air pressure in the tires 0.35 MPa)*

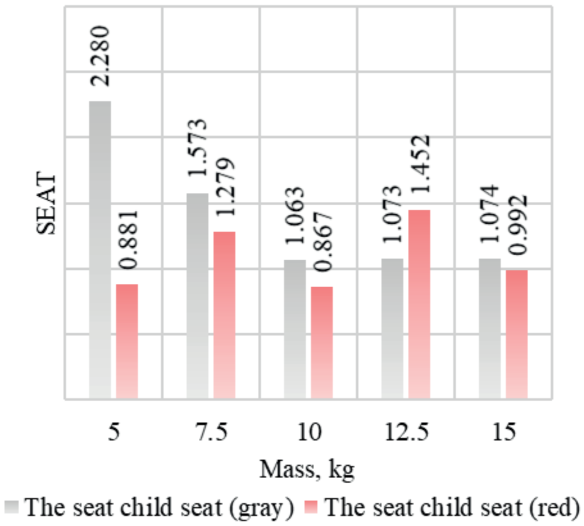

***Figure 23*** *The SEAT indicator (air pressure in the tires was 0.31 MPa)*

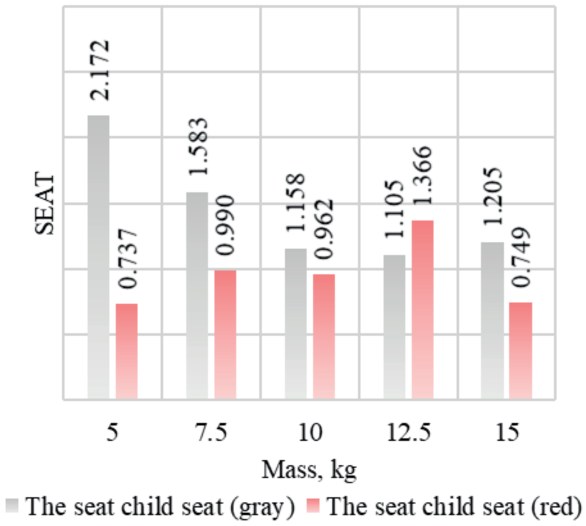

***Figure 24*** *The SEAT indicator (air pressure in the tires was 0.35 MPa)*

***Table 4*** *Correlation of the RMS indicator with the mass simulating the mass of a child (tire pressure 0.27 MPa)*

| mass simulating the mass of a child | indicator RMS | | | |
|---|---|---|---|---|
| | vehicle rear seat under the child seat | the seat child seat B | isofix | the seat child seat A |
| 5 | 0.543 | 1.240 | 0.978 | 1.305 |
| 7.5 | 0.604 | 0.991 | 0.673 | 1.083 |
| 10 | 0.644 | 0.809 | 0.655 | 0.978 |
| 12.5 | 0.760 | 0.925 | 0.716 | 1.144 |
| 15 | 0.616 | 0.759 | 0.743 | 1.027 |
| correlation coefficient | 0.598 | -0.861 | -0.517 | -0.618 |

***Table 5*** *Correlation of the RMS indicatorwith the mass simulating the mass of a child (tire pressure 0.31 MPa)*

| mass simulating the mass of a child | indicator RMS | | | |
|---|---|---|---|---|
| | vehicle rear seat under the child seat | the seat child seat B | isofix | the seat child seat A |
| 5 | 0.577 | 1.304 | 1.075 | 1.316 |
| 7.5 | 0.599 | 1.011 | 0.829 | 1.148 |
| 10 | 0.768 | 0.943 | 0.901 | 0.977 |
| 12.5 | 0.792 | 0.948 | 0.781 | 1.184 |
| 15 | 0.765 | 0.939 | 0.861 | 0.998 |
| correlation coefficient | 0.871 | -0.668 | -0.801 | -0.677 |

***Table 6*** *Correlation of the RMS indicator with the mass simulating the mass of a child (tire pressure 0.35 MPa)*

| mass simulating the mass of a child | indicator RMS | | | |
|---|---|---|---|---|
| | vehicle rear seat under the child seat | the seat child seat B | isofix | the seat child seat A |
| 5 | 0.626 | 1.342 | 1.222 | 1.348 |
| 7.5 | 0.594 | 1.017 | 0.887 | 1.079 |
| 10 | 0.641 | 0.848 | 0.966 | 1.118 |
| 12.5 | 0.666 | 0.812 | 0.799 | 1.175 |
| 15 | 0.627 | 0.856 | 0.917 | 0.988 |
| correlation coefficient | 0.447 | -0.692 | -0.847 | -0.736 |

***Table 7** Correlation of the VDV indicator with the mass simulating the mass of a child (tire pressure 0.27 MPa)*

| mass simulating the mass of a child | indicator VDV | | | |
|---|---|---|---|---|
| | vehicle rear seat under the child seat | the seat child seat B | isofix | the seat child seat A |
| 5 | 1.689 | 3.859 | 4.183 | 4.089 |
| 7.5 | 2.036 | 3.156 | 2.295 | 3.409 |
| 10 | 2.314 | 2.501 | 2.236 | 3.315 |
| 12.5 | 2.874 | 3.124 | 2.353 | 3.666 |
| 15 | 2.301 | 2.447 | 2.703 | 3.389 |
| correlation coefficient | 0.750 | -0.783 | -0.560 | -0.570 |

***Table 8** Correlation of the VDV indicator with the mass simulating the mass of a child (tire pressure 0.31 MPa)*

| mass simulating the mass of a child | indicator VDV | | | |
|---|---|---|---|---|
| | vehicle rear seat under the child seat | the seat child seat B | isofix | the seat child seat A |
| 5 | 1.780 | 4.058 | 4.687 | 4.130 |
| 7.5 | 2.056 | 3.234 | 2.843 | 3.636 |
| 10 | 2.784 | 2.959 | 3.597 | 3.120 |
| 12.5 | 2.946 | 3.161 | 2.610 | 3.789 |
| 15 | 2.756 | 2.959 | 3.181 | 3.157 |
| correlation coefficient | 0.875 | -0.789 | 0.627 | -0.660 |

***Table 9** Correlation of the indicator VDV with the mass simulating the mass of a child (tire pressure 0.35 MPa)*

| mass simulating the mass of a child | indicator VDV | | | |
|---|---|---|---|---|
| | vehicle rear seat under the child seat | the seat child seat B | isofix | the seat child seat A |
| 5 | 1.940 | 4.213 | 5.849 | 4.310 |
| 7.5 | 2.045 | 3.237 | 3.553 | 3.517 |
| 10 | 2.274 | 2.633 | 3.688 | 3.549 |
| 12.5 | 2.413 | 2.667 | 2.749 | 3.756 |
| 15 | 2.210 | 2.662 | 4.135 | 3.098 |
| correlation coefficient | 0.768 | -0.853 | -0.581 | -0.783 |

was 0.35 MPa. In the other two series, the correlation coefficient between the VDV of the „A" seat and the mass loaded on it is somewhat lower. The correlation coefficient for these cases ranged from -0.57 to -0.66. It proves a moderate correlation and a significant one.

Results of the VDV indicator are presented in figures 17-22 Based on the recorded accelerations, the VDV of the ISOFIX base and the VDV of the rear seat were also determined. In twelve cases, the VDV values for the ISOFIX base are higher than the VDV values for the rear bench seat. Only in three cases the situation was reverse and the VDV for the rear seat seat was higher than the VDV for ISOFIX. The increase in pressure in the test vehicle wheels also increased the difference between the VDV of the ISOFIX base and the VDV of the rear seat.

Figures 23 and 24 show the results of the SEAT index for the tested child seats, taking into account the mass representing the mass of the child and the pressure in the tires of the vehicle used for the tests. In most cases, the SEAT index for the B (gray) seat is higher than for the „A" (red) seat. Only in one trial, in which the seats were loaded with a mass of 12.5 kg, the situation was the reverse and the SEAT values for the A (red) seat were higher than the SEAT values for the „B" (gray) seat.

Analyzing the correlation indexes included in Tables 4 to 9, it should be stated that with increase of the weight loading the seat, the value of the VDV index decreases. The correlation coefficient between the mass loaded on the seat and the VDV indicator „B" (gray) ranges from - 0.78 for the case when the pressure in the test vehicle wheels was 0.27 MPa to -0.85 when the pressure in the test vehicle wheels was 0.35 MPa. These values prove the high correlation and the significant dependence.

## 4 Conclusions

The subject of the research is part of the issue of the vibration comfort of children transported in child seats. The presented research is a part of a whole series of research vehicleried out by employees of the Department of Motor Vehicles and Transport of the Kielce University of Technology.

They concern the spread of vibrations in the following system: vehicle (vehicle floor) - vehicle seat - child seat. It was pointed out that the analyzed system may have two different vibration transmission chains, which depend on the child seat mounting system (classic seat mounting system and ISOFIX system). The paper presents the results of empirical tests vehicleried out at the EUSAMA SA.640 stand, which in these tests acted as a generator of vibrations with a frequency of 0 to 25 Hz. It is noteworthy that the seats were stabilized with the ISOFIX base. It separates the child seat from the rear seat cushion and the seat is attached more securely than with standard seat belts.

However, this method of fastening may cause a reduction in the vibration comfort of children vehicleried in the seat. The negative impact of separating the seats from the rear seat using the ISOFIX base is confirmed by the RMS and VDV determined for the „A" seat secured with the ISOFIX base that were higher than the RMS and VDV for the „B" classic mounted seat.

## References

[1] LEE, G., POPE, C. N., NWOSU, A., MCKENZIE, L. B., ZHU, M. Child passenger fatality: child restraint system usage and contributing factors among the youngest passengers from 2011 to 2015. *Journal of Safety Research* [online]. 2019, **70**, p. 33-38. ISSN 0022-4375. Available from: https://doi.org/10.1016/j.jsr.2019.04.001

[2] BLAIR, J., PERDIOS, A., BABUL, S., YOUNG, K., BECKLES, J., PIKE, I., CRIPTON, P., SASGES, D., MULPURI, K., DESAPRIYA, E. The appropriate and inappropriate use of child restraint seats in Manitoba. *International Journal of Injury Control and Safety Promotion* [online]. 2008, **15**(3), p. 151-156. ISSN 1745-7300, eISSN 1745-7319. Available from: https://doi.org/10.1080/17457300802340980

[3] BROWN, J., FINCH, C. F., HATFIELD, J., BILSTON, L. E. Child restraint fitting stations reduce incorrect restraint use among child occupants. *Accident Analysis and Prevention* [online]. 2011, **43**(3), p. 1128-1133. ISSN 0001-4575. Available from: https://doi.org/10.1016/j.aap.2010.12.021

[4] CICCHINO, J. B., JERMAKIAN, J. S. Vehicle characteristics associated with LATCH use and correct use in real-world child restraint installations. *Journal of Safety Research* [online]. 2015, **53**, p. 77-85. ISSN 0022-4375. Available from: https://doi.org/10.1016/j.jsr.2015.03.009

[5] SCHWEBEL, D. C. TILLMAN, M. A, CREW, M., MULLER, M., JOHNSTON, A. Using interactive virtual presence to support accurate installation of child restraints: efficacy and parental perceptions. *Journal of Safety Research* [online]. 2017, **62**, p. 235-243. ISSN 0022-4375. Available from: https://doi.org/10.1016/j.jsr.2017.06.018

[6] KRAJNAK, K. Health effects associated with occupational exposure to hand-arm or whole body vibration. *Journal of Toxicology and Environmental Health, Part B arch* [online]. 2018, **21**(5), p. 320-334. ISSN 1093-7404, eISSN 1521-6950. Available from: https://doi.org/10.1080/10937404.2018.1557576

[7] QASSEM, W., OTHMAN, M. O., ABDUL-MAJEED, S. The effects of vertical and horizontal vibrations on the human body. *Medical Engineering and Physics* [online]. 1994, **16**(2), p. 151-161. ISSN 1350-4533. Available from: https://doi.org/10.1016/1350-4533(94)90028-0

[8] TROXEL, W. M., HELMUS, T. C., TSANG, F., PRICE, C. C. *Evaluating the impact of whole-body vibration (WBV) on fatigue and the implications for driver safety*. Santa Monica, Calif.: RAND Corporation, RR-1057-BOSE, 2015.

[9] ISO 2631-1: 1997 Mechanical vibration and shock. Evaluation of human exposure to whole-body vibration. Part 1: General requirements.

[10] BS 6841: 1987 Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock.

[11] WIECKOWSKI, D. An attempt to estimate natural frequencies of parts of the child's body / Proba oszacowania czestotliwosci drgan wlasnych czesci ciala dziecka (in Polish). *The Archives of Automotive Engineering - Archiwum Motoryzacji*. 2012, **55**(1), p. 61-74. ISSN 1234-754X, eISSN 2084-476X.

[12] WIECKOWSKI, D. Analysis domain of the time vertical vibration on account comfort child during ride in the vehicle / Analiza w dziedzinie czasu drgan pionowych ze wzgledu na komfort podrozowania dzieckaw samochodzie (in Polish). *Technical Transactions - Czasopismo Techniczne*. 2012,**10**(5-M), p. 73-91. ISSN 0011-4561, eISSN 2353-737X.

[13] GIACOMIN, J. Some observations regarding the vibrational environment in child safety seats. *Applied Ergonomics* [online. 2000, **31**(2), p. 207-215. ISSN 0003-6870. Available from: https://doi.org/10.1016/S0003-6870(99)00034-4

[14] WICHER, J., WIECKOWSKI, D. Influence of vibrations of the child seat on the comfort of child's ride in a vehicle / Wplyw drgan fotelika samochodowego na komfort podrozowania dziecka w samochodzie (in Polish). *Eksploatacja i Niezawodnosc*. 2010, **4**(48), p. 102-110. ISSN 1507-2711.

[15] FREJ, D., GRABSKI, P. The impact of the unbalanced rear wheel on the vibrating comfort of the child seat. *Transportation Research Procedia* [online]. 2019, **40**, p. 678-685. ISSN 2352-1465. Available from: https://doi.org/10.1016/j.trpro.2019.07.096

[16] LAI, H. - H., CHEN, CH. - H., CHEN, Y. - CH., YEH, J. - W., LAI, CH. F. Product design evaluation model of child vehicle seat using gray relational analysis. *Advanced Engineering Informatics* [online]. 2009, **23**(2), p. 165-173. ISSN 1474-0346. Available from: https://doi.org/10.1016/j.aei.2008.10.009

[17] FREJ, D., ZUSKA, A., CADGE, K. Analysis of vertical vibrations affecting a child transported in a child seat during a car passing over the release speed bump. *The Archives of Automotive Engineering - Archiwum Motoryzacji* [online]. 2019, **86**(4), p. 111-125. ISSN 1234-754X, eISSN 2084-476X. Available from: https://doi.org/10.14669/AM.VOL86.ART8