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The impact of vibrations on the comfort and safety of children in car seats: A review of current knowledge

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Abstract Vibrations in vehicles are a significant issue affecting passenger comfort and safety, particularly for children transported in car seats. Children's small bodies are more susceptible to the effects of vibrations, which can lead to discomfort and potential health problems. The greatest risks to humans caused by exposure to vibrations related to vehicle movement occur in road transport [1]. Vibration phenomena have been a subject of interest for many research centers and scientific institutions both nationally and internationally for many years, and numerous studies on this topic can be found in the literature [1-3]. Over the turn of the century, the amount of time people spend in cars has increased (and continues to do so), leading to a growing interest in children transported in car seats not only in terms of passive safety but also regarding the impact of vibrations [4]. Due to the effects of vibrations on children, especially vertical vibrations, long-distance travel is particularly significant. In this context, medical aspects must also be taken into account [1,3,5]. The Importance of Vibration Reduction in Car Seats Reducing vibrations in child car seats is essential for ensuring the comfort and safety of young passengers. High levels of vibration can negatively impact children's musculoskeletal systems and overall well-being during travel. Vibrations experienced during driving can cause various pathological symptoms in humans, including gastrointestinal issues, joint and muscle pain, vestibular symptoms, headaches, pain in the lumbar-sacral and cervical spine, as well as conditions such as kyphosis and lordosis, among others [6]. While the effects of vibrations on the adult human body are well documented evidenced by numerous regulations and research studies conducted by various institutions [7-22] research on their impact on children is still in its early stages. Homologation tests for child car seats are primarily focused on protection against the harmful effects of collisions and are mainly assessed through crash tests [22]. The aim of this publication is to review the literature on the impact of vibrations on a child's travel comfort, analyze research findings, and present proposals for innovative solutions.

Keywords: vibration reduction, child car seats, vibration comfort, automotive seating.

1. Introduction

1.1. Vibration comfort

In 2005, Giacomin's team conducted another study [3], where eight children were examined in a laboratory environment equipped with safety features compliant with international human testing standards. The force and acceleration were recorded at the entry point to the rigid seat at a sampling frequency of 200 Hz, with an analysis range from 1.0 to 45.0 Hz. The evaluation used double-normalized absorbed power measures, considering both input acceleration and the subjects' mass. The tests were conducted using specialized laboratory equipment designed for small children. The seat was mounted on an aluminium platform measuring 760 mm in length and 405 mm in width, secured with three load sensors. The platform was suspended on springs and linear bearings, allowing for system stiffness adjustment. This setup ensured that the system's first resonance frequency (comprising the child, seat, and platform) remained below 1 Hz. Vibrations were introduced using a V406 magnetic shaker (Ling Dynamic Systems, UK), powered by a PA100E amplifier. A monitoring and control system was implemented, consisting of Endurance Monitor software and an SCADAS II electronic unit (Leuven Measurement Systems International, Belgium). The software allowed test limits to be set, with a peak acceleration of 2.0 m/s^2 and a transmitted force of 100 N. To ensure additional safety, an emergency shutdown unit was also included, equipped with a manual emergency stop button from Leuven Measurement Systems International [5].

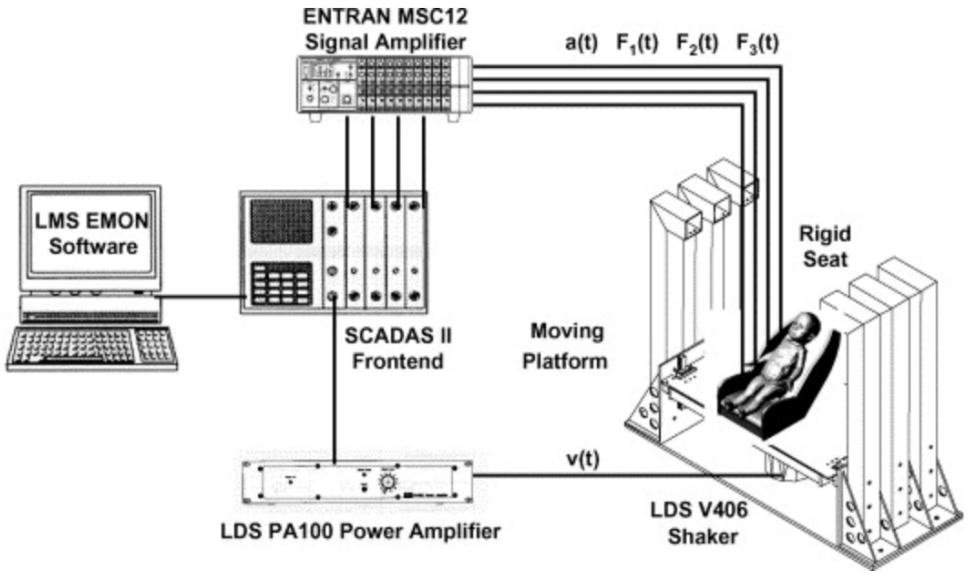

Figure 1. Graphical representation of the research site [4].

The research team Giacomin et al. [5] found that the mean peak power absorption frequency is around 7.4 Hz in young children, compared to a range of 4.0–5.0 Hz in adults. This suggests that whole-body vibration guidelines such as ISO 2631, which are based on adult data, may not be appropriate for children weighing less than 18 kg [11-15]. One potential factor influencing this conclusion is the difference in sitting posture during testing – children were tested in a rigid seat with back support, whereas the data for adults were based on a backless position. Until comparable data are available for adults with back support, caution should be exercised when applying these guidelines to children. The study also highlighted the lack of standards for assessing vibration comfort in children. Unlike adults, there are no guidelines for children specifying testing methods or the maximum seat time that would not result in adverse health consequences. Giacomin pointed out the need to create standards that would allow for a better assessment and improvement of children's driving comfort [3,5]. In this context, similar biomechanical modeling approaches have been used in studies of human postural coordination, where control models help to predict body response to vibration and balance disturbances [2].

In his recommendations, he suggested introducing new technological solutions that could improve the situation. One of them was to equip child seats with accelerometers that would monitor the level of vibrations transferred from the road surface to the seat. This would allow for more accurate tracking and assessment of the impact of vibrations on the child. Another solution was to improve the ISOFIX mounting system by adding damping elements that would effectively limit the transfer of vibrations from the ground to the child seat [5, 11-23]. Giacomin emphasized that long-term exposure of children to vibrations can negatively affect their health, especially in the case of longer journeys. Therefore, his research aims not only to increase driving comfort, but also to protect children's health. He postulated the continuation of work in this field, including testing a larger number of child seat models and taking into account different road conditions. His research indicates the need for further improvement of child seat designs and the development of standards that will improve their quality and safety [3,5].

1.2. Research on vertical vibrations acting on a child in a car seat

In 2012, the team of researchers Więckowski et al. conducted research on the influence of vertical vibrations on the comfort of driving a child transported in a car seat. The paper discusses the methods of laboratory vibration testing and their influence on the child's body [24]. Więckowski's research focuses on the analysis of vertical vibrations that affect children sitting in car seats while driving a car. Vertical vibrations were analysed in detail in terms of their harmfulness and influence on the child's comfort of driving [24].

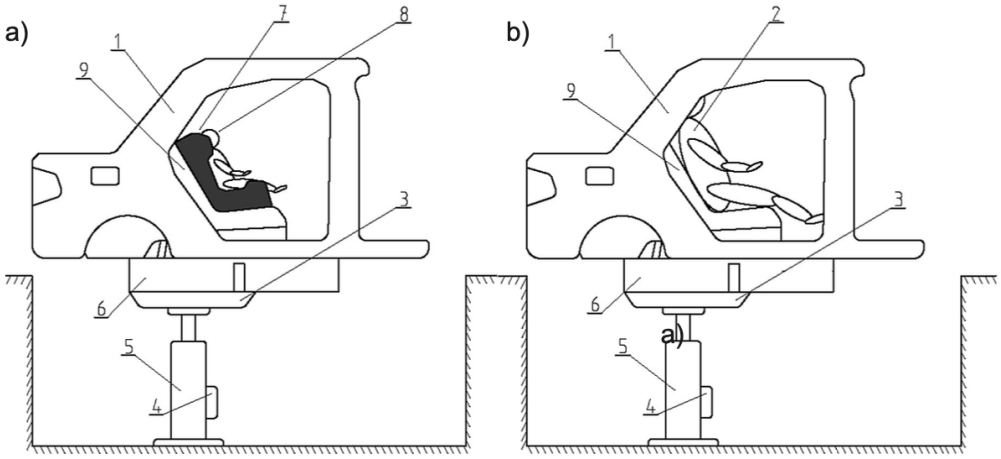

Figure 2. Graphical representation of the test stand a) view of the CHILD dummy seated in the seat b) view of the HYBRYD II dummy seated [24].

Więckowski draws attention to the differences in the perception of comfort between children and adults. The comfort level for children is often not favourable with current standards of car seats. Children are more sensitive to vibrations compared to adults, which requires special design solutions of seats to improve their comfort [24]. The research used both measurements of actual vibrations in vehicles and experiments with dummies representing children and adults. The differences in the impact of vibrations on children were analysed depending on the type of seat (standard attachment system vs. ISOFIX) [11-24]. The analyses carried out show that the design of the seat and the attachment system have a significant impact on the transfer of vibrations. Seats with the ISOFIX system showed better vibration damping properties compared to seats fastened with seat belts. The introduction of damping materials and a better design in terms of vibration reduction could significantly improve the child's comfort while driving. Dariusz Więckowski's research provides valuable information on the impact of vibrations on the comfort of children in car seats. They show that current seat designs may not provide sufficient comfort and that there is a need to develop new design and material solutions [24]. Different vibration frequencies have been found to have different effects on child comfort. Low-frequency vibrations (below 5 Hz) can cause discomfort and fatigue, while higher-frequency vibrations (above 20 Hz) can lead to irritability and stress.

1.3. The influence of an unbalanced rear wheel on the vibration comfort of a child seat

In 2019, the team of researchers Damian Frej and Pawel Grabski conducted research on the effect of an unbalanced rear wheel on the vibration comfort of a child seat. The frequency characteristics of vibrations to which a child is exposed when transported in a standard car seat were analysed [25]. The study analyses the effect of an unbalanced rear wheel on the magnitude and frequency characteristics of vibrations to which a child is subjected when transported in a standard car seat placed in the back seat of a passenger car. Research on the effect of an unbalanced rear wheel on the vibration comfort of a child seat was aimed at understanding how uneven mass distribution in the wheel affects the level of vibrations transferred to the child while driving [25]. Wheel imbalance, resulting from uneven mass in the tire or rim, generates additional dynamic forces during rotational movement. This causes vibrations with an increased amplitude, which are transmitted to the vehicle, and in particular to the seat on which the child is travelling. The study observed that wheel imbalance causes vibrations in a specific frequency range, which can be particularly bothersome for children [10]. These frequencies overlap with the resonance band of a small child's body, which is around 7.4 Hz (compared to 4-5 Hz in adults). Such resonance can significantly increase the sensation of vibration and cause greater discomfort, and in the long term even potential health effects such as muscle fatigue, anxiety or impaired concentration [25].

The experiment used a vibration platform to simulate different levels of wheel imbalance. The amplitude of vibrations transmitted to the child seat, placed in the test environment, was measured. The results showed that rear wheel imbalance significantly increased the level of vibrations transmitted to the seat in key frequencies affecting the child's comfort. Importantly, the impact of these vibrations was more noticeable in the case of children due to their lower body mass and differences in the structure of the musculoskeletal system [25]. The conclusions from the study indicate that regular wheel balancing is important, especially in vehicles transporting children in seats. This allows to minimize vibrations

transferred to the seat, which directly improves the comfort and safety of young passengers. Additionally, the studies suggest the need for further analysis to take into account differences in the design of seats and vibration-absorbing materials that may reduce their negative impact [25].

1.4. Laboratory tests of child seat attachment methods and vibration comfort

The Frej et al. research team conducted laboratory tests of child seat attachment methods and vibration comfort in 2021. The article presents the results of laboratory tests on the effect of the child seat attachment method on the vibration comfort of children transported in them. Seats attached using the ISOFIX base and standard seat belts were tested [24]. The study analyses the effect of different child seat installation methods on the vibration comfort of children transported in them. In particular, the effect of the ISOFIX base was tested in comparison with the classic installation of seats using seat belts [24]. Laboratory tests were conducted during which the values of vertical vibrations were measured on the child seat, the rear seat of the vehicle and on the ISOFIX base. These values were assessed in terms of vibration comfort using indicators such as Root Mean Square (RMS) and Vibration Dose Value (VDV) [24]. It was found that the use of the ISOFIX base has a positive effect on vibration comfort, as confirmed by lower RMS and VDV values compared to the classic installation of child seats. These results suggest that the method of installing child seats has a significant impact on the level of vibrations felt by the child [24].

In 2022, a team of researchers Frej et al. published a study analysing different models of child seats in terms of their ability to dampen vibrations and provide vibration comfort to children during car travel. Various parameters of the seats were taken into account, such as the materials used in their production, construction and fastening systems [26]. Laboratory tests were conducted to assess the level of vibrations transferred to the child seat during simulated road conditions. Advanced measurement techniques, such as accelerometers, were used to assess the magnitude and frequency of vibrations [26]. It was found that child seats made of materials with higher vibration damping capacity provide better vibration comfort. Seat models with more advanced attachment systems, such as ISOFIX, also showed better vibration damping properties [26]. The authors drew the following conclusions: currently, there are no standards for testing the vibration comfort of children. In order to better understand the problem of vibration transmission in child seat systems, it is advisable to conduct tests on a larger number of seat models. Further research is needed to develop standards for testing and assessing the vibration comfort of children. In addition, guidelines should be created specifying the maximum time a child can stay in a seat without risk to their health. The results of the study suggest that the choice of a child seat should take into account its vibration damping capacity to provide the child with maximum comfort during travel. Child seat manufacturers should focus on developing technologies and materials that increase the vibration damping capacity [26].

2. Proposal of innovative solutions

Based on the analysis of the literature and identified research gaps, the author proposes an original conceptual design of a suspension system for a child car seat aimed at reducing vibration transmission. This solution represents an innovative approach that combines passive and semi-active vibration reduction elements. The author of this publication proposes a suspension system for a child car seat that reduces vibrations occurring during driving. Thanks to the developed suspension system, it will be possible to reduce the harmful effects of vibrations on the body of children who come into contact with vibration processes during their transportation in motor vehicles. In order to reduce the level of acceleration acting on the child seat, it is suggested to introduce a damping element to the ISOFIX base, which would effectively limit the transfer of vibrations. Coil springs in the system were used to maintain static balance when the suspension system is loaded with the child's body in the project, their deflection is max. 20 mm. Shock absorbers were used to limit the theoretical infinite amplitudes of vibrations in an undamped system and to provide the effect of damped resonance, the stroke of the designed shock absorbers is 25 mm. Linear actuator with the system in static equilibrium, the actuator in the form of an electric linear actuator can work around the position of static equilibrium, generating a vibration reduction force, max. extension 50 mm. Linear guides - are used to ensure minimal friction in the system. Linear guides have a low coefficient of friction when the suspension system moves. Isofix is used for safety and stability of the system. Seats mounted on the Isofix base are more stable, safer and have better vibration damping properties (Figs. 3 - 5).

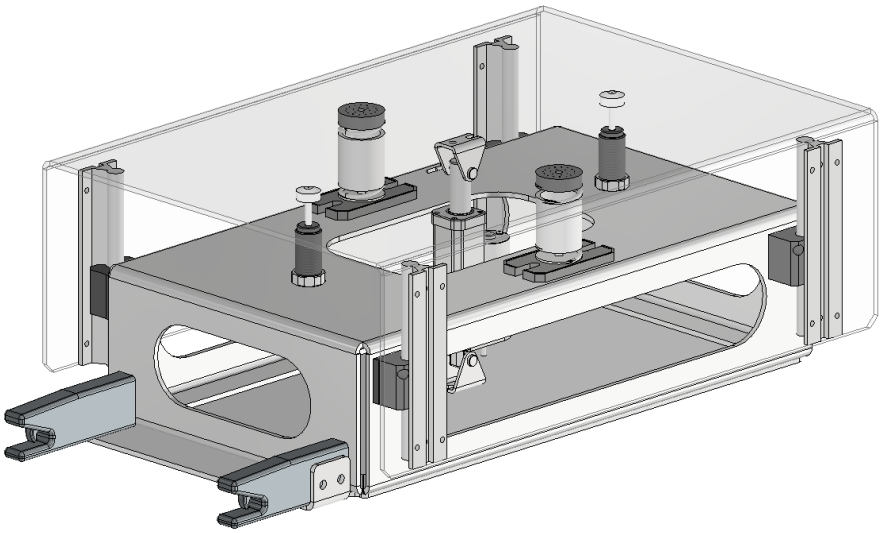

Figure 3. Design model of the suspension system for a child car seat.

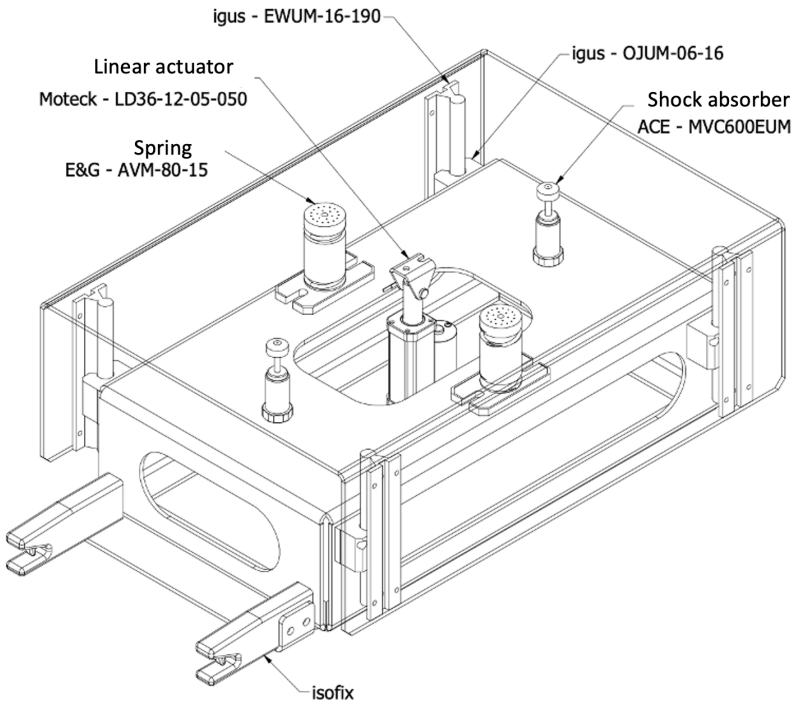

Figure 4. Design of a suspension system for a child car seat.

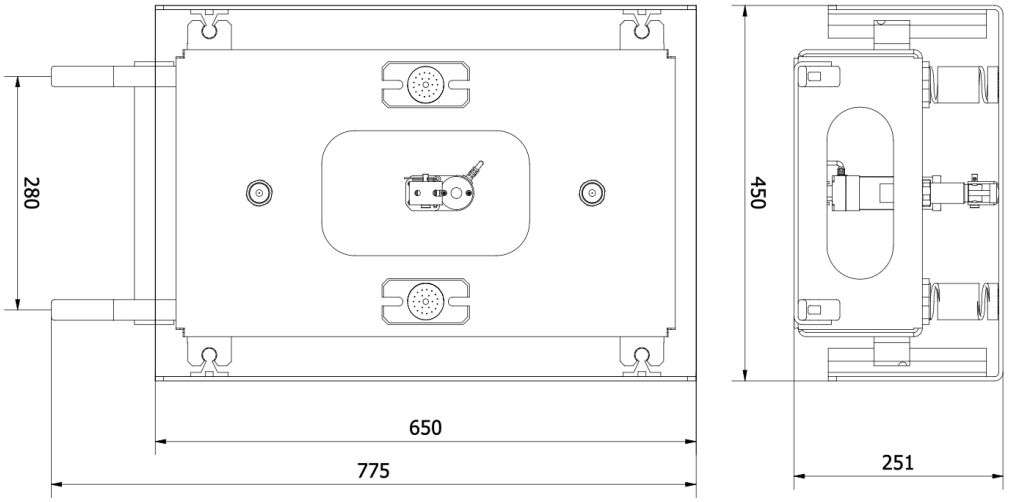

Figure 5. Design of the suspension system for a child car seat (dimensions [mm]).

The authors of the publication note the need for further research on this type of solution, which can contribute to improving the vibration comfort and, consequently, the health of children. The next stage involves building a prototype model and conducting tests using dummies. In the future, child seats should be equipped not only with standard sensors, such as puncture sensors, blood pressure sensors or systems monitoring correct attachment, but also with an accelerometer to measure the level of vibrations transferred from the road surface to the seat. Car seats equipped with modern vibration damping systems are designed to minimize the impact of vibrations on the child's body. Technologies such as flexible materials and shock absorption systems can significantly improve travel comfort by reducing the perceived vibrations and ensuring greater seat stability. Future research should focus on identifying the most effective vibration damping materials and technologies to provide children with maximum safety and comfort during car journeys.

3. Conclusions

The interest in the influence of vibrations on the comfort of children's travel has been ongoing since the early 2000s [3] but further research is still needed in this field. Car seats are a key element ensuring the safety of children during car journeys. In addition to protection against accidents, seats are also intended to minimize the impact of various dynamic factors, such as acceleration or vibration. One of the aspects that is gaining importance in the context of children's comfort and safety is the impact of vertical vibrations transferred to the child while driving. These vibrations can come from uneven road surfaces, shocks caused by mechanical features of the vehicle and fluctuations related to the driving speed [10,24,27]. Vertical vibrations transferred to the child while driving affect the body posture and stability of the seat. The child's body, especially in infants and small children, is more sensitive to various types of vibrations due to its immaturity and lower body weight compared to an adult. Vibrations can affect the spine, muscles, joints and nervous system, leading to discomfort and, in the long term, possible health problems [1,3,5]. One of the main problems resulting from long-term exposure to vibrations is excessive strain on the child's neck and back. In infants, whose skeletal system is not yet fully developed, vibrations can lead to micro-damages in the spine and disrupt the proper development of these structures. Long-term vibrations can also affect the balance system, which can lead to problems with motor coordination [1,28,29]. The impact of vertical vibrations on children traveling in car seats is an important topic that requires further research. Previous analyses indicate that these vibrations can have both short-term and long-term health consequences, especially in the context of the skeletal and nervous systems. Therefore, car seat designers should focus particularly on developing vibration-damping technologies that improve travel comfort and reduce health risks. It should also be remembered that proper adjustment of the seat position, its adjustment to the child's age and its correct attachment in the vehicle can significantly reduce the impact of vibrations [9].

It is not enough to simply place the child in the car seat to ensure their safety. Even the best seat will not fulfil its role if it is not properly attached in the vehicle. Choosing the right seat is more difficult than it seems,

because you have to take into account many factors, such as the type of attachment, the weight of the seat, the fit to the car seat and the child's dimensions. In addition, before buying, it is worth making sure that the child feels comfortable in it, that the belts are properly adjusted and do not cause discomfort [30].

Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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