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Experimental analysis of vertical vibrations in child car seats with a swivel base

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INTRODUCTION

Despite growing awareness, many children in Poland are still improperly restrained in vehicles, which increases the risk of injury or death. Road accidents involving children remain a major concern.

The key problem is vertical vibrations transmitted to child car seats. Stakeholders include car seat manufacturers, safety regulators, researchers, and parents.

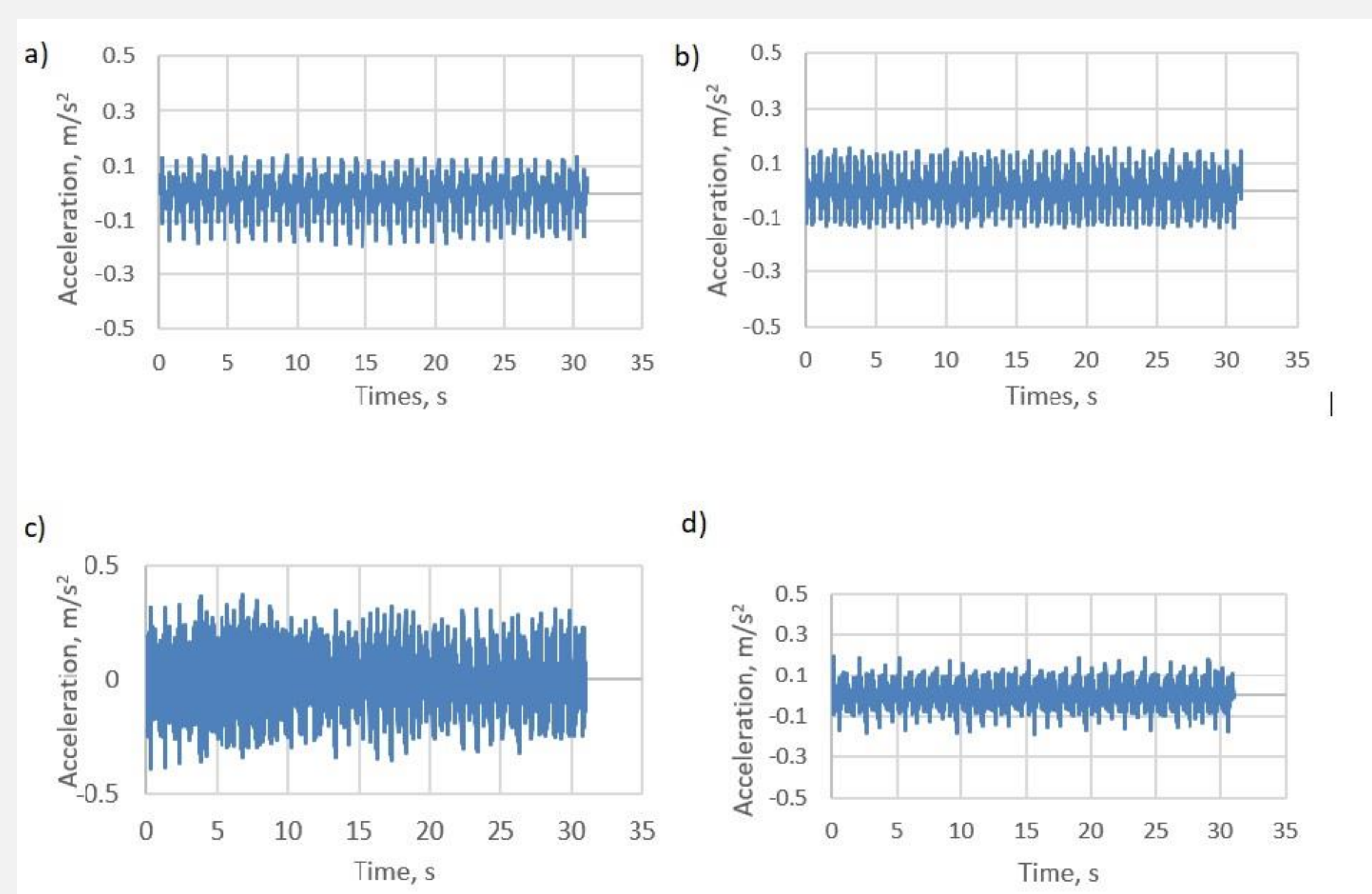
The research aims to assess vibration damping in seats with swivel bases, improve safety design, and raise awareness on better seating solutions to enhance child comfort and health.

MATERIALS, METHODS & IMPLEMENTATION

The experimental study involved four child car seat models with integrated swivel bases from three major manufacturers, aimed at analyzing vertical vibration transmission through the seat structure. Each seat was mounted on a rigid platform connected to a dynamic actuator, simulating vertical oscillations with a 10 mm amplitude and 1 Hz frequency, in compliance with ISO 2631-1 and BS 6841 standards. PCB Electronics Model 656B41 triaxial accelerometers were placed on the seat base, swivel mechanism, and seat surface, with data captured by an LMS SCADAS SCR02 recorder at a 256 Hz sampling rate. Three test repetitions per model ensured measurement reliability, using an MTS test stand capable of generating excitations in the 0–100 Hz range. Post-processing included computing vibration comfort metrics—RMS, VDV, and RMQ—which showed clear variation among seats, with Car Seat C having the highest vertical acceleration and lowest comfort. The methodology enabled accurate quantification of vibration transmission and highlighted the importance of swivel base design in effective vibration isolation.

RESULTS

The experimental results revealed substantial differences in the vertical vibration damping performance among the four tested child car seat models with integrated swivel bases. Car Seat A exhibited the best vibration comfort, with the lowest Root Mean Square (0.13 m/s²), Vibration Dose Value (0.18 m/s³), and Root Mean Quad (0.11 m/s²), indicating effective vibration attenuation. In contrast, Car Seat C recorded the highest values across all vibration metrics—RMS at 0.35 m/s², VDV at 0.42 m/s³, and RMQ at 0.25 m/s²—demonstrating the poorest performance in terms of vibration isolation. Car Seat B showed similar vibration characteristics to Seat A, suggesting well-engineered base and material design, while Car Seat D performed moderately, ranking between Seats B and C.



Time-domain acceleration plots confirmed these findings, showing that Seat C had larger amplitudes and less stable responses, indicating a need for improved swivel base geometry and materials.

CONCLUSION & IMPLEMENTATION PATH

The study concluded that the vibration damping performance of child car seats with integrated swivel bases varies significantly depending on design and material composition. Car Seat A demonstrated superior vibration isolation properties, recording the lowest RMS, VDV, and RMQ values, which indicates high comfort and safety levels. In contrast, Car Seat C showed the poorest performance, with the highest vertical acceleration indicators, suggesting inadequate damping characteristics and a potential risk to passenger comfort. The findings emphasized the critical role of swivel base geometry in minimizing vertical vibrations transferred to a child's body during vehicle movement. Time-domain acceleration plots confirmed dynamic instability in Car Seat C, highlighting the need for improved structural tuning in its base mechanism. The impact of this research lies in its contribution to safer child transportation systems by identifying mechanical design flaws that influence vibrational exposure. The study promotes design optimization strategies for car seat manufacturers aiming to enhance biomechanical protection and ride comfort for infants. The implementation of standardized laboratory methodologies and objective vibration metrics establishes a foundation for regulatory testing in future safety assessments. Further research should investigate the performance of swivel-based car seats in real-world driving scenarios, such as urban potholes and highway transitions. Upcoming studies are expected to incorporate physiological sensors and advanced dummies to correlate mechanical vibration metrics with actual child discomfort thresholds.