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HEAD MOTION ANALYSIS OF THE KPSIT C50 DUMMY IN SIMULATED LOW-SPEED COLLISIONS

Summary. This study focuses on the KPSIT C50 dummy to examine the impact of modifications to seat belts and vehicle seating. With the increasing frequency of sudden braking and vehicle collisions, particularly during traffic jams, understanding these factors is crucial. Experiments were conducted on a specially designed teaching platform that measures seat belt forces and the displacement of various body parts (whether of a dummy or a human volunteer) during low-speed crash tests. This research is part of a comprehensive investigation involving crash tests with volunteers and KPSIT physical dummies. A total of 150 volunteers participated, organized into specific percentile groups. The study compared the displacement of the head centers of the KPST C50 dummy with that of volunteers categorized as C50. The findings highlight that utilizing a sports seat with four-point seat belts significantly limits head movement during low-speed collisions. This type of seating offers enhanced safety by minimizing the risk of head injuries from impacts with the steering column in collisions where the airbag has not been activated. Additionally, the results indicate that standard passenger vehicle seat belts allow for more forward head movement during a collision.

1. INTRODUCTION

Crash tests are a crucial component of evaluations conducted by vehicle manufacturers to assess how well a vehicle withstands collisions and protects passengers. These tests originated in the 1950s and have significantly contributed to improved road safety. The results provide valuable insights during the vehicle design phase, which occurs before a vehicle is approved for use on the road. Since the 1970s, regulations have required manufacturers to conduct crash tests to ensure vehicles meet specific safety standards. These standards are intended to protect the lives and health of road users by ensuring that new vehicle models are safe in the event of an accident. If a model does not meet these standards, it cannot be approved for use, highlighting the importance of tests in the vehicle design process.

In the European Union, EC type approval is crucial, although independent institutions also often conduct tests. One of the most important vehicle safety assessment programs is the European New Vehicle Assessment Programme (Euro NCAP). This organization plays a significant role in evaluating vehicle safety, which is critical for manufacturers aiming to provide the highest level of protection.

The specific tests and their parameters may vary depending on the guidelines and requirements of the organization conducting the tests. Current Euro NCAP crash tests include:

- Frontal offset collision: This consists of two tests. The first involves a frontal collision with the entire surface of the vehicle against a stationary wall at 50 km/h. In the second, the vehicle collides with a mobile barrier weighing 1,400 kg, simulating an average road vehicle, with both vehicles moving at 50 km/h and the collision area covering 50% of the vehicle's front surface.

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- Side collision: A 900-kg barrier strikes the side of the vehicle at the height of the central pillar at a speed of 50 km/h.
- Pole test: The vehicle moves sideways at a speed of 29 km/h and hits a vertical obstacle, which is also at the height of the central pillar.
- Pedestrian collision test: This test uses dummies to simulate a pedestrian being hit by a vehicle traveling at 40 km/h.

Additional tests may include rear collisions, rollovers, motorcycle crashes, and impacts with energy-absorbing barriers. Anthropometric dummies specifically designed for these crash scenarios provide crucial data for improving vehicle designs. These dummies are equipped with various sensors that record the forces acting on the body during a collision.

It is important to note that the tests mentioned above address only the most common types of injuries resulting from rear-end collisions. However, such accidents can also lead to knee, wrist, and elbow injuries; abdominal pain; internal injuries; and severe headaches. Spinal injuries pose a significant burden on individuals involved in road accidents, as average lifetime treatment costs range from $428,000 to $1.35 million.

Vehicle safety can be divided into two main aspects: active and passive safety. Active safety includes all vehicle features that reduce the likelihood of an accident, such as anti-slip systems, wheel-lock prevention, and brake assistance. In contrast, passive safety focuses on mitigating the effects of an existing collision through controlled crumple zones, deformable steering columns, and a reinforced cabin structure.

The introduction of modern safety systems, such as dynamic driving properties, lateral, directional, and longitudinal stabilization systems, as well as maneuvering assistance systems, significantly contributes to improved road safety. Contemporary vehicles are also designed to enhance visibility and driving comfort, which is crucial for minimizing the risk of accidents.

The effectiveness of crash tests depends on meticulous design and the use of high-quality materials. Different vehicle models may react differently during tests. Vehicle weight is a critical factor that influences crash test results. Despite significant attention to safety, low-speed crash tests are often overlooked, even though they are vital for real-world road safety.

Low-speed crash tests are essential for understanding the dynamics of collisions at speeds ranging from 10 km/h to 25 km/h. At these speeds, vehicle damage may be minimal, but human injuries can be severe; permanent health damage and even death can occur. Effective safety systems must address the risks associated with such collisions, ensuring protection for drivers and passengers. Rear-end collisions, the most common type of accident, can cause injuries and chronic pain associated with neck and spinal injuries, which can lead to high treatment costs.

The development of safety systems requires understanding human body behavior during such collisions and developing active and passive safety systems that reduce the risk of injury. Reducing such collisions requires not only advanced knowledge of human body biomechanics but also the continuous improvement of the technologies used in vehicles.

As the number of vehicles on public roads increases, the frequency of low-speed accidents rises, emphasizing the need for targeted safety measures. Understanding the exact movement of individual human body parts during low-speed collisions is crucial for developing safety systems that provide effective protection in such situations.

2. EXPERIMENTAL

This article details the findings from experimental research conducted at Kielce University of Technology. The study involved 150 volunteers aged between 18 and 45, each of whom participated in a single crash test. Prior to testing, each participant was measured, weighed, and categorized into a specific percentile group. Five attempts were made to accelerate the platform during a collision at a speed of 20 km/h to ensure consistent platform acceleration impulses. The average platform deceleration across the five volunteer crash tests was 69.68 m/s². Following this, platform acceleration during the crash test was modeled using ADAMS simulation software.

The results of the simulated platform accelerations with volunteers in ADAMS were satisfactory and enabled the verification of the simulation model of the C50 dummy against real-world crash tests of the C50 dummy. Fig. 1 displays the differences in head movement along the X and Z axes between the physical C50 dummy and the simulation dummy during a frontal collision. In the initial impact phase (0.14 s), the head movement of the physical C50 dummy along the X-axis was slightly greater than that of the simulation dummy (0.44 m vs. 0.43 m). This difference did not exceed 15%. Conversely, along the Z-axis, the head movement of the physical C50 dummy was less than that of the simulation dummy (0.17 m vs. 0.20 m). Again, this difference was within 15%. The satisfactory results of this comparison allowed us to conduct a series of crash tests with volunteers, as well as additional testing using the validated C50 dummy. The simulation dummy was also compared with the physical HYBRID III dummy, as described in the authors' publication [9].

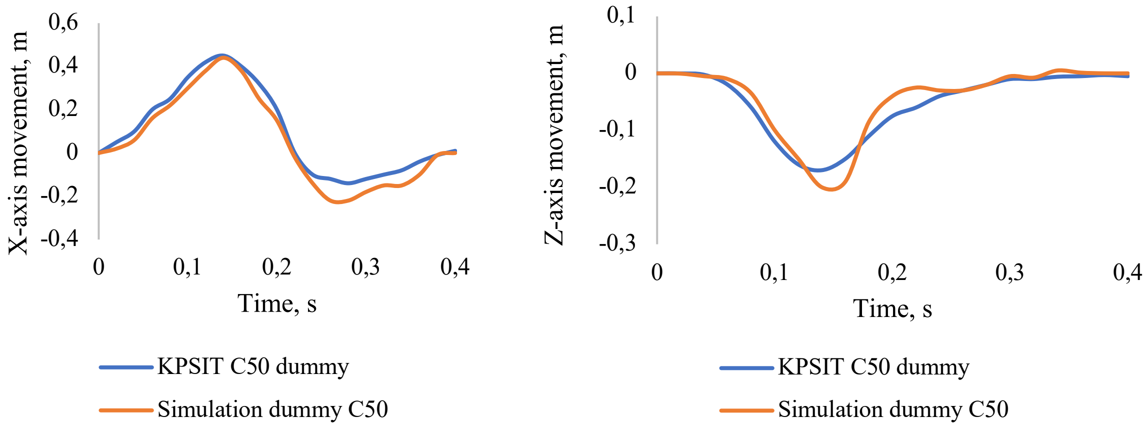

Fig. 1. Illustration of head movement along the X and Z axes for the physical and the simulation dummy during a frontal collision

The remainder of this article is structured as follows. Chapter Two describes the KPSIT C50 dummy, which represents a male at the 50th percentile. This dummy had been previously validated through simulations using a model based on the Hybrid III dummy. The research commenced with crash tests involving participants, followed by tests with the KPSIT C50 dummy. These tests were performed on two vehicle seats with a fixed backrest angle of 110° and two different types of seat belts.

Chapter Three details the findings from the experimental research. It outlines the head movement of participants during low-speed collisions and compares it with the head movement of the KPSIT C50 dummy. All crash tests were recorded using a high-speed Digital Fantom V310 camera, which operated at 2500 frames per second. The footage was analyzed with THEMA software.

Chapter Four presents an analysis comparing the head movement of participants with that of the KPSIT dummy. The head movements were evaluated in three phases of the collision: from the impact to the maximum forward head tilt; from the maximum forward tilt to the maximum backward tilt; and the stabilization phase, in which the dummy's head stabilizes after the displacement.

4. CRASH TEST

The KPSIT C50 physical dummy, designed to reflect human body characteristics based on age and weight, was utilized for low-speed crash testing. This dummy offers insights into the effects of low-speed collisions on various body parts. Its design ensures that each component mirrors the dimensions and mass of the human body. A key goal in constructing the dummy was to replicate the dynamics of joint resistance typical of the human body. Another important design feature was the ease of replacing damaged components to reduce downtime. The dummy's joints are detachable and can be swapped out quickly, and each joint features adjustable resistance, making it adaptable for different anthropometric models.

Fig. 2 illustrates the masses of the KPSIT C50 dummy's body parts, while Fig. 3 displays their dimensions. The dummy's structure includes separate elements for the head and neck, as well as upper limbs (shoulder, forearm, and hand) and lower limbs (thigh, lower leg, and foot), each divided into three sections similar to human anatomy. The torso is composed of two sections: an upper torso and a lower torso, with the abdominal region integrated into the lower torso. The KPSIT C50 dummy has a total mass of 78.6 kg, which approximates the mass of the 50th percentile of the mass of a male and aligns with the mass of the Hybrid III C50 dummy commonly used in crash tests. The masses and dimensions of the dummy's components are designed to match those of the Hybrid III dummy. The dummy was constructed using steel profiles measuring 25x25 mm and steel flat bars that were 50 mm wide. It was covered with leather and filled with a biodegradable material; each part was weighed before and after the filler was added.

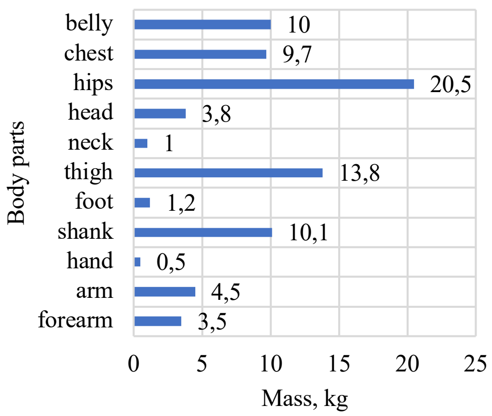

Fig. 2. Mass of the components of the physical KPSIT dummy C50

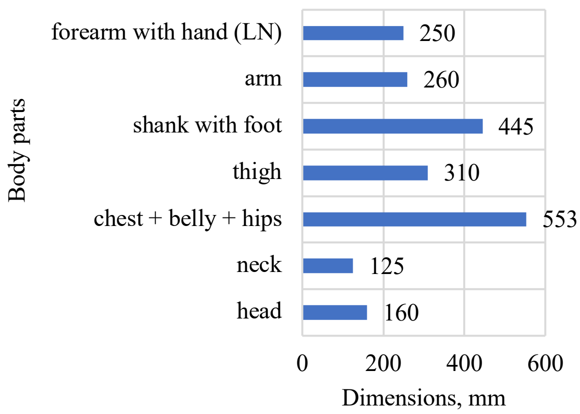

Fig. 3. Dimensions of the elements of the physical KPSIT dummy C50

The KPSIT C50 dummy was developed to evaluate the movements of its various components during impact and to assess the effectiveness of seat belts in collisions with stationary objects. This dummy allows for precise measurements of how different body parts react during low-speed crashes. The design incorporates joints that closely mimic those of the 50th percentile male Hybrid III dummy. The range of motion in these joints was gauged using a protractor positioned at the midpoint of each joint axis to measure flexion and extension angles. This method was also applied to the Hybrid III dummy for comparative analysis.

The testing process began with experiments involving human participants, followed by tests with the KPSIT C50 dummy using a specialized low-speed crash test rig. This test setup features a 10-m-long track on which collisions were simulated with the aid of two shock absorbers positioned at the end of the track. The vehicle seat, mounted on a platform, traveled along this track with the help of ball-bearing rollers. The height of the platform was controlled by a solenoid valve to maintain consistency throughout the tests. High-speed recordings of the tests were captured by a Phantom V310 camera operating at 2,500 frames per second to provide detailed data.

The test rig, detailed in Fig. 4, is capable of conducting crash tests at speeds ranging from 5–25 km/h. The desired speed is achieved by positioning the trolley and seat at the appropriate height. The maximum height of the test track is 2.4 m, allowing for the full range of speeds. The trolley, which carries the vehicle seat, moves along the track on precision rollers. The system includes upper and lower rollers that ensure the seat remains aligned with the track and prevent lateral movement. A steel plate separates the vehicle seat from the trolley, allowing the seat to be adjusted forward, backward, or sideways (at 45° or 90° angles) relative to the direction of movement. This configuration facilitates flexible testing and the accurate simulation of various collision scenarios.

Fig. 4. Crash test bench

The experiments were carried out in a controlled environment to ensure the safety and well-being of all participants. The study involved 150 volunteers (90 men and 60 women aged 18–45 years). Forty-five participants were categorized as 50th percentile males. Volunteers were segmented into three distinct percentile categories based on 15 different anthropometric measurements. Both human participants and physical dummies were subjected to frontal crash tests at a velocity of 20 km/h. The tests utilized two types of vehicle seats: a sports bucket seat and a standard passenger seat (see Figs. 5 and 6). The angle of the backrest was fixed at 110° for both types of seats. A four-point harness was employed for the sports bucket seat, whereas a three-point seat belt was used for the passenger seat. In the testing protocol, 15 male participants from the 50th percentile group were assessed using the sports bucket seat, and 30 male participants from the same group were tested with the passenger seat. Each test with the KPSIT physical dummy was conducted with five repetitions to ensure the recorded data were consistent and reliable. Additionally, to broaden the scope of the research, tests included variations in seating positions and belt configurations to simulate a range of real-world scenarios. The collected data provided valuable insights into the effectiveness of different seat types and safety belts in mitigating injury during frontal collisions.

Fig. 5. Sports bucket seat

Fig. 6. Passenger vehicle

Testing at low speeds with human participants yields essential insights into how the human body responds during frontal collisions with stationary objects. These tests are crucial for understanding the dynamics of the cervical spine and head, which are especially susceptible to injury in low-speed impacts. In a controlled lab environment, the risk of serious injury is significantly reduced because participants are not exposed to hazards such as steering wheels or dashboards, which are present in real-world crashes and can cause injuries if airbags do not deploy.

Analyzing the movement of various body parts in these tests is crucial for enhancing vehicle safety features. This data aids in refining seat designs, choosing suitable seat belts, and adjusting headrests to improve protection during minor accidents. By optimizing these elements based on crash test results, we can better protect drivers and passengers in everyday low-speed collisions.

It is important to note that many rear-end collisions in traffic jams occur due to the leading vehicle failing to brake. Such accidents typically involve both a frontal impact and a rear impact. During a frontal collision, the head initially moves forward, posing a risk that the person's body will strike objects in front of them. In contrast, during a rear-end collision, the head moves backward, potentially impacting the headrest. Incorrectly adjusted headrests or those that are at an insufficient distance from the head can lead to serious injuries or fatalities.

Due to safety concerns, conducting low-speed crash tests with human volunteers at a speed of 20 km/h is impractical. Thus, there is a need for a specialized anthropometric dummy that can accurately simulate these collisions. Such a dummy could replicate the human body's response to both frontal and rear impacts, offering a safe testing alternative.

The results from the crash tests performed in the present study were analyzed using TEMA software, which processes footage captured by a high-speed Digital Fantom V310 camera. This camera records at 2,500 frames per second, enabling the precise tracking of head position shifts. By marking the KPSIT C50 dummy and volunteers, researchers were able to assess displacement characteristics. Figs. 7 and 8 illustrate the head position shifts along the X and Z axes during a crash test involving a sports bucket seat. In the initial impact phase (0.14 s), head position shifts along the X-axis ranged from 0.18 to 0.22 m. This movement decreased to between 0.08 and 0.11 m in the subsequent phase (0.26 s), while head position shifts along the Z-axis ranged from 0.032 to 0.038 m.

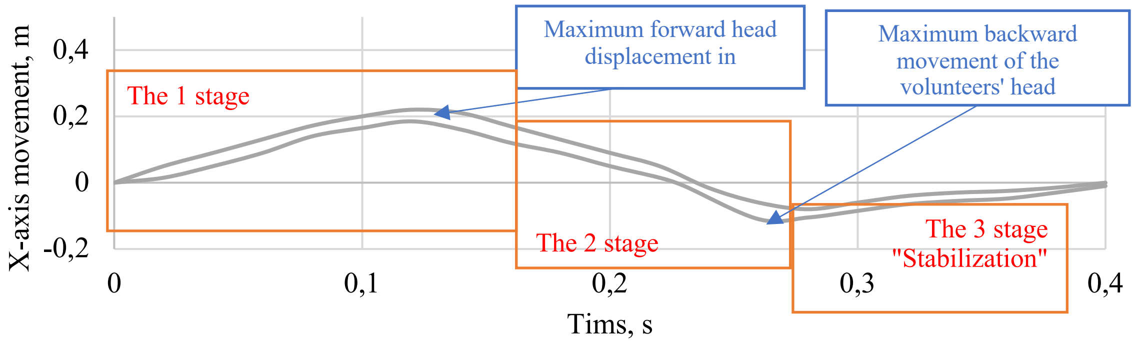

Fig. 7. Head Position Shift (X-axis) for C50 Volunteers - Sports Bucket Seat

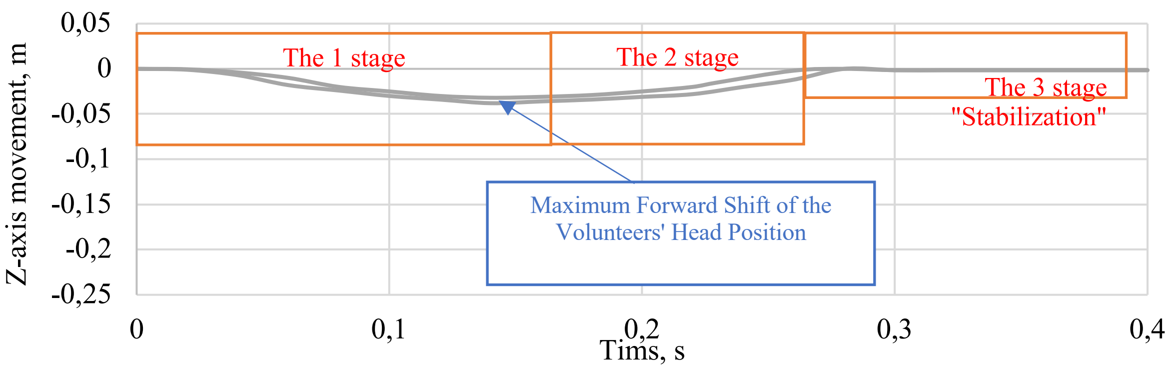

Fig. 8. Head Position Shift (Z-axis) for C50 Volunteers - Sports Bucket Seat

Figs. 8 and 10 illustrate the head position shifts along the X and Z axes for C50 volunteers during a crash test involving a passenger car seat. During the initial phase of the collision (0.14 s), the volunteers' heads shifted between 0.37 and 0.44 m along the X-axis. In the later phase of the collision (0.26 s), this movement decreased to a range of 0.13 to 0.15 m. During the first phase of the impact, the head movements observed along the Z-axis varied from 0.16 to 0.22 m.

Figs. 11 and 12 display the head position shifts in the X and Z directions for the KPSIT C50 dummy during a frontal impact involving a sports bucket seat. In the initial impact phase (0.14 s), the head position of the KPSIT C50 dummy shifted by 0.19 m along the X-axis, which decreased to 0.093 m in the subsequent phase (0.26 s). During the same initial phase, the head position shift along the Z-axis was recorded at 0.035 m. Figs. 13 and 14 illustrate the head position shift in both the X and Z directions for the KPSIT C50 dummy during a frontal collision when seated in a passenger vehicle seat. At the start of the collision (0.14 s), the head position shift along the X-axis was 0.367 m, which was reduced to 0.128 m by 0.26 s. The head position shift along the Z-axis during the first stage of the collision was 0.193 m.

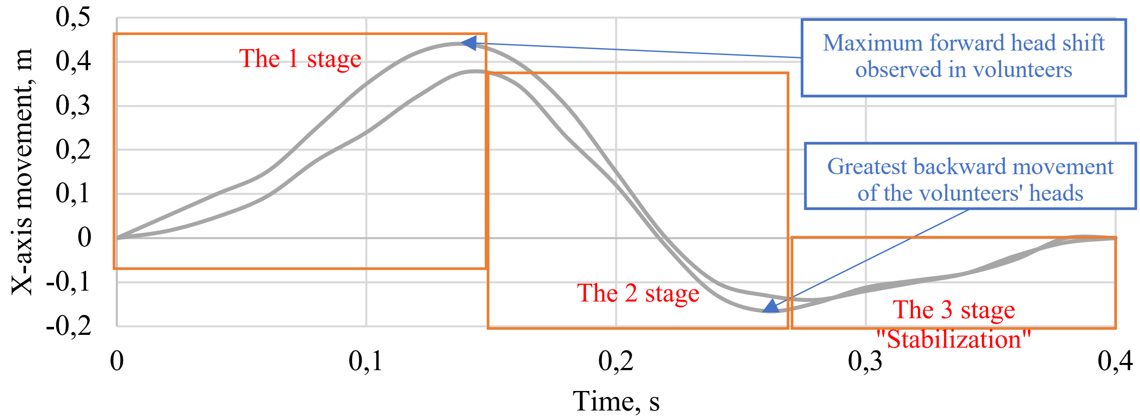

Fig. 9. Head Position Shift (X-axis) for C50 Volunteers - Passenger Vehicle Seat

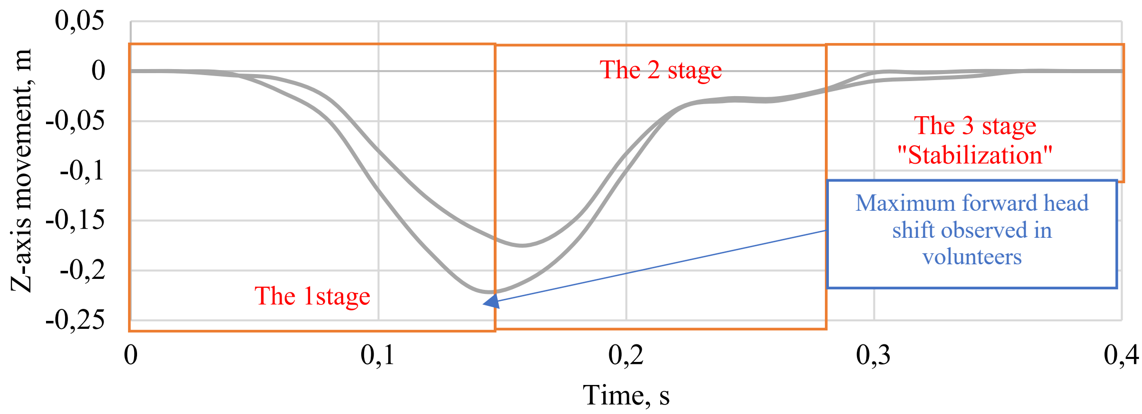

Fig. 10. Head Position Shift (Z-axis) for C50 Volunteers - Passenger Vehicle Seat

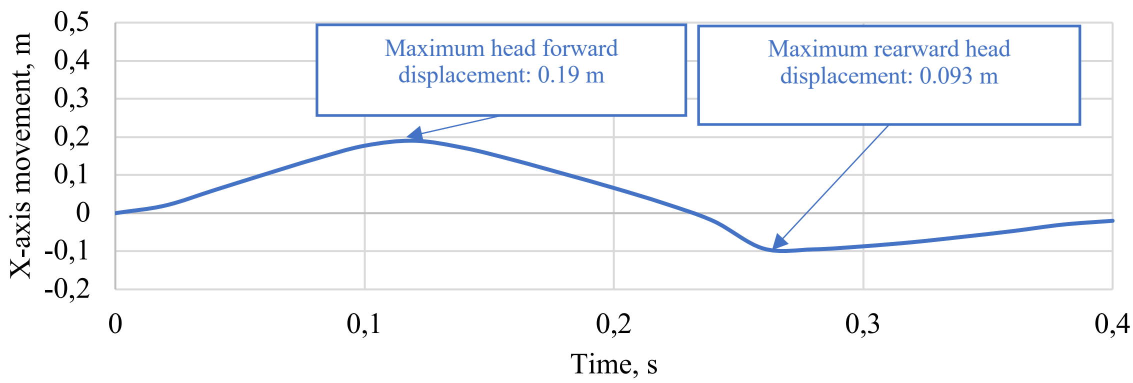

Fig. 11. Head Position Shift (X-axis) for C50 Volunteers - Four-point Belts Sports Bucket Seat

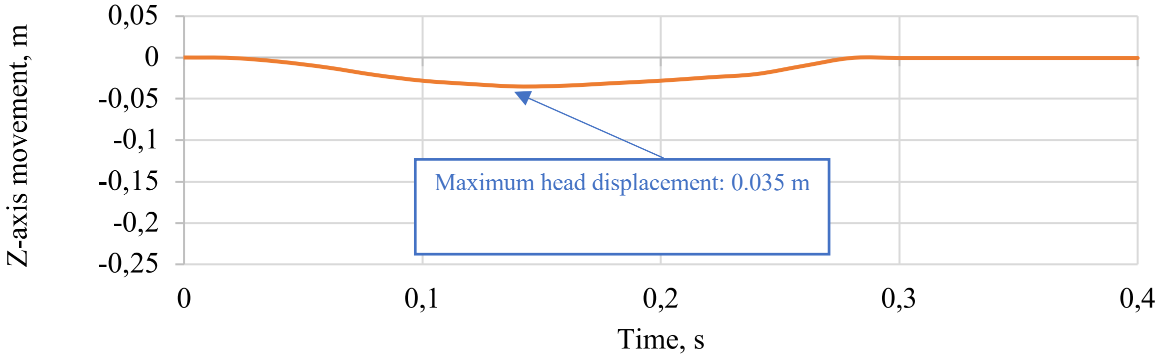

Fig. 12. Head Position Shift (Z-axis) for C50 Volunteers - Four-point Belts Sports Bucket Seat

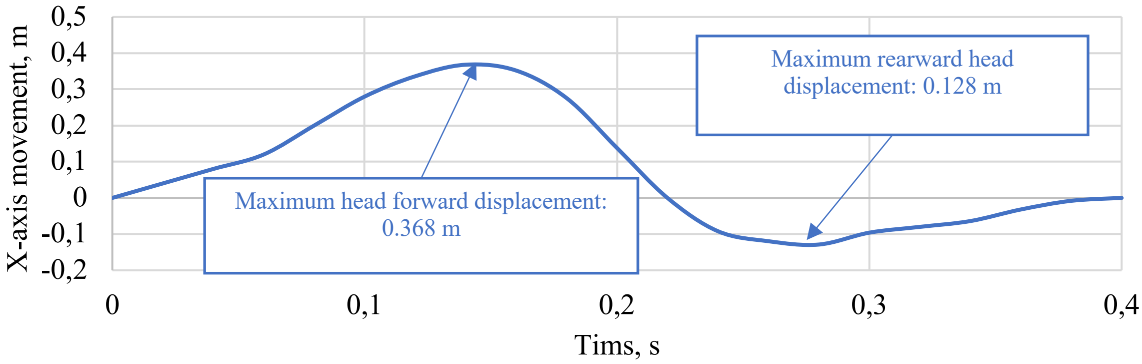

Fig. 13. Head Position Shift (X-axis) for C50 Volunteers - Three-point Belts Passenger vehicle seat

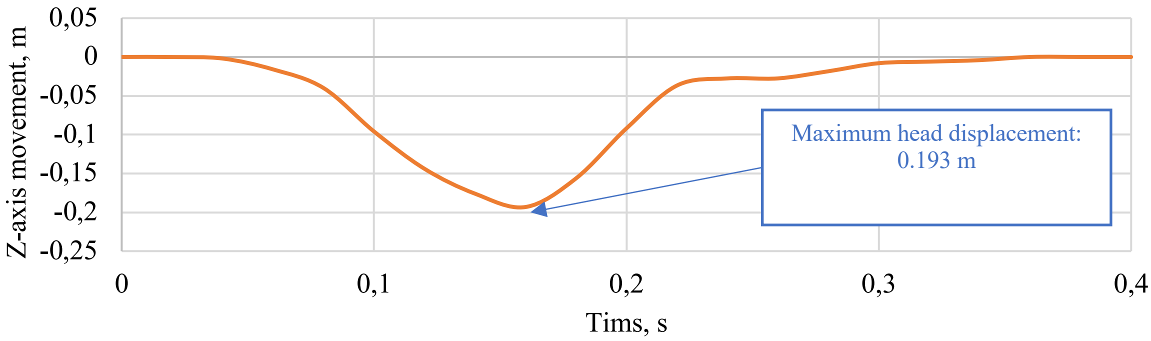

Fig. 14. Head Position Shift (X-axis) for C50 Volunteers - Three-point Belts Passenger Vehicle Seat

5. RESULTS

Figs. 15 and 16 illustrate the variations in head position along the X and Z axes for both the KPSIT C50 dummy and human volunteers during frontal collisions using a sports bucket seat with four-point seat belts. In the early phase of the impact (0.14 s), the head movement of the KPSIT C50 dummy along the X-axis closely aligned with the range observed in human participants. However, 0.28–0.35 s into the collision, the dummy demonstrated increased displacement compared to the volunteers. This suggests that the dummy experienced a slightly more pronounced forward movement than the average human response during this period. For the Z-axis displacement, the KPSIT C50 dummy's head position remained within the range of the volunteers throughout the collision event, indicating a similar pattern of vertical movement. The use of four-point seat belts was particularly effective in constraining head movements along both axes, with no maximum displacements exceeding 0.05 m, highlighting these seat belts' role in enhancing occupant protection during frontal impacts.

Figs. 17 and 18 present comparable data for frontal collisions involving a passenger vehicle seat equipped with three-point seat belts. In the initial impact stage, the X-axis displacement of the KPSIT C50 dummy's head was again within the range observed among the volunteers, though the dummy exhibited less displacement than the human participants at the 0.14-s mark. This discrepancy may reflect differences in the dynamic responses of the dummy and human volunteers. The dummy's head movement along the Z-axis remained consistent with that of the volunteers throughout the crash. However, the data reveals that three-point seat belts resulted in greater head displacement than the four-point belts and sports bucket seat configuration. This difference underscores the importance of seat belt design and seat type in managing head movement and improving safety outcomes during frontal collisions.

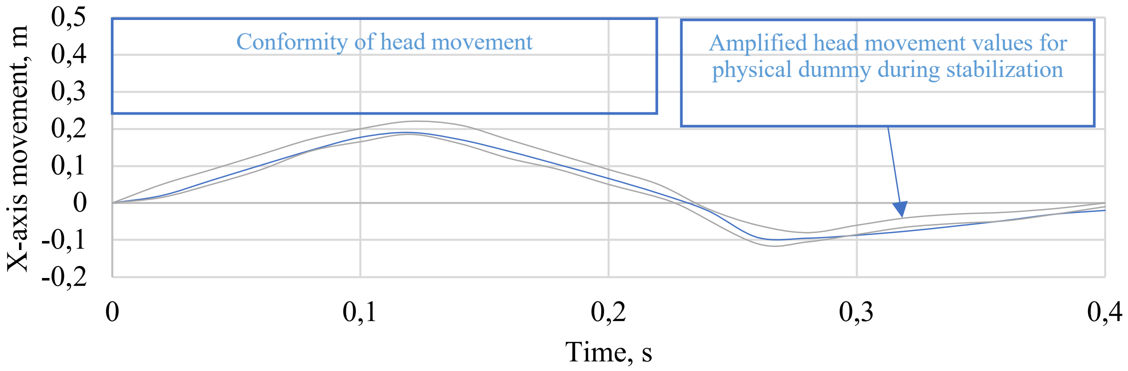

Fig. 15. Head Position Changes (X-axis) for Dummy and Volunteers - Frontal Crash with Four-point Belts Sports Bucket Seat

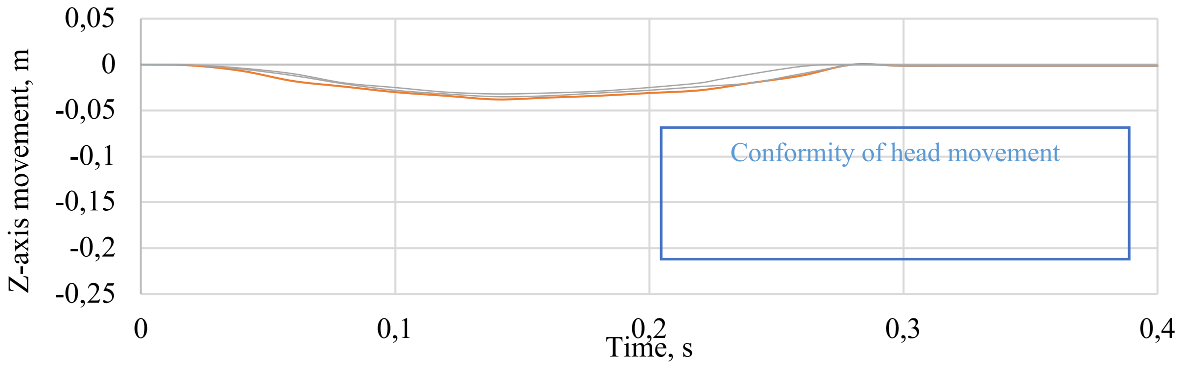

Fig. 16. Head Position Changes (Z-axis) for Dummy and Volunteers - Frontal Crash with Four-point Belts Sports Bucket Seat

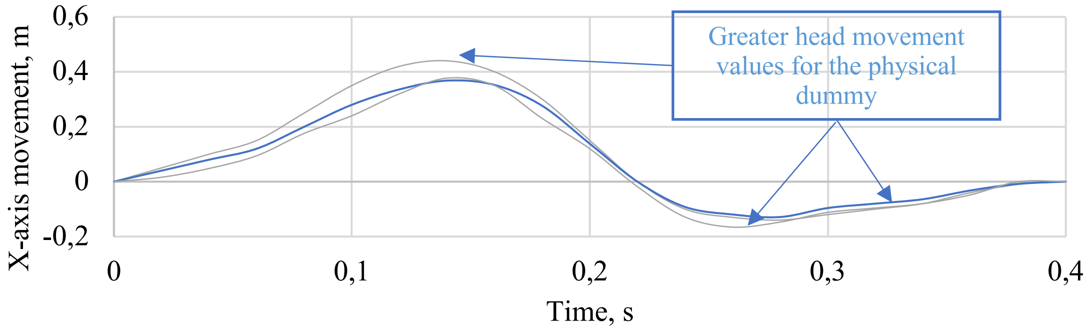

Fig. 17. Head Position Changes (X-axis) for Dummy and Volunteers - frontal crash with three-point seat belts passenger vehicle seat

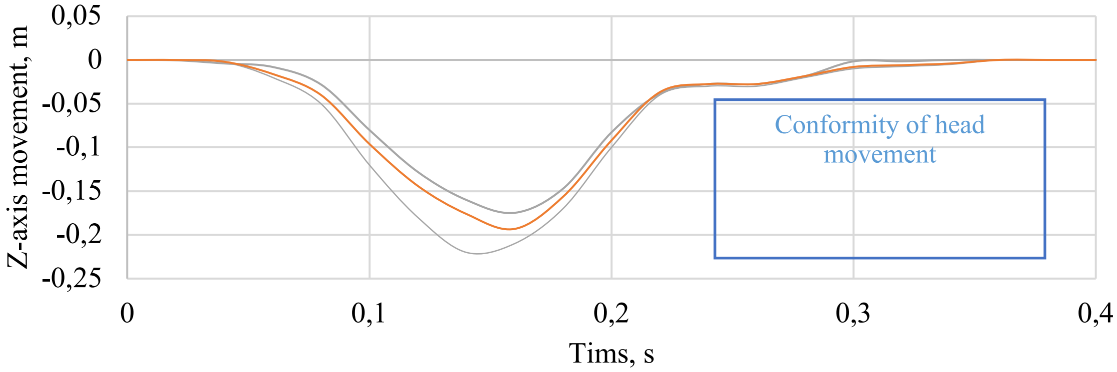

Fig. 18. Head Position Changes (Z-axis) for Dummy and Volunteers - Frontal Crash with Three-point Seat Belts Passenger Vehicle Seat

5. CONCLUSIONS

Low-speed crash tests are not typically part of standard safety assessments for vehicles entering the European market. This is partly due to the lack of specialized anthropometric dummies that can accurately simulate human responses at low collision speeds, as these dummies are not equipped with the necessary sensors for such detailed analysis. Traditional crash test dummies, like the BioRid II and Hybrid III, are optimized for specific types of impacts – rear and frontal, respectively – and can be used to collect only data that are relevant to those scenarios.

Historically, research involving human volunteers in low-speed impacts has been conducted with utmost care to ensure participant safety. These experiments are crucial for understanding human biomechanics during minor collisions, such as those occurring at approximately 20 km/h. This speed is typical of incidents in traffic jams or low-speed urban accidents in which vehicle airbags may not activate due to the collision's relatively low severity. Nevertheless, these minor impacts can result in significant head movements, and studies have shown that displacements of up to 0.44 m are possible. Such movements can cause occupants to strike their heads on interior surfaces, underscoring the importance of seat belts, even at low speeds.

Experimental studies are fundamental in advancing our knowledge of passenger safety in low-speed crashes. These studies provide vital data that inform the development of new dummies, such as the KPSIT C50 model, which is specifically designed to accurately reflect human motion. This new dummy represents the male population and incorporates joints that mimic natural human movement. It is engineered with adjustable resistance, making it adaptable for different demographic profiles, including various percentiles of males and females.

The KPSIT C50 is versatile and can be used in frontal, side, and rear crash tests at low speeds. This multi-functional capability allows researchers to assess human responses across different types of collisions without the need to use different dummies for each scenario. This approach provides a comprehensive understanding of potential injuries in low-speed accidents, especially in situations where airbags might not deploy.

Current dummy designs are often restricted to specific types of crash tests, necessitating the use of different models for each test type. For instance, BioRid II is primarily used for rear impacts due to its extensive spinal structure, while Hybrid III and THOR are dedicated to frontal impact testing. These limitations highlight the need for more adaptable testing equipment.

The development of the KPSIT C50 dummy addresses this gap by offering a single dummy that can be used in multiple test scenarios. This dummy can simulate human responses in both frontal and rear crashes, which is invaluable for understanding the dynamics of low-speed impacts. Such versatility not only reduces the need for multiple dummies but also enhances the accuracy of safety assessments by providing consistent data across various crash scenarios.

The integration of innovative dummies like the KPSIT C50 into crash testing protocols represents a significant advancement in vehicle safety research. These dummies provide a more nuanced understanding of human responses in low-speed collisions, thereby helping engineers design safer vehicles that can better protect occupants during everyday driving situations. As automotive safety continues to evolve, such advancements in crash test methodology will play a critical role in reducing injury risks and enhancing overall road safety.

Acknowledgments

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