SHORT COMMUNICATION: STAPP CAR CRASH CONFERENCE

Preliminary Evaluation of OpenSim as a Tool for Simulating Occupant Kinematics in Low-Speed Rear-End Collisions

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ABSTRACT – This study explored the feasibility of using OpenSim's forward dynamics tool to model occupant kinematics in low-speed rear-end collisions. The crash pulse characteristics and comparison kinematic data were obtained from an Insurance Institute for Highway Safety (IIHS) dynamic rear seat test. Given the exploratory nature of this phase of the study, certain assumptions and methodological simplifications were necessary to prioritize feasibility. Using the forward dynamics tool, a combined whole-body musculoskeletal model representing a 50^{th} percentile male was positioned on a simplified vehicle seat model and simulated in a 16 km/h low-speed rear impact subjected to an IIHS 10 g crash pulse. The simulation produced realistic acceleration magnitudes and patterns at the head, T1, and pelvis. The results suggest that OpenSim offers a promising, computationally efficient, open-source approach for studying occupant kinematics. This proof-of-concept study indicates that with further refinement and comprehensive validation against human subject test data, OpenSim's forward dynamics tool could be optimized for future applications in rear-impact simulations.

INTRODUCTION

In the National Highway Traffic Safety Administration Traffic Safety Facts 2020, rear-end collisions accounted for 26.2% of all injury-producing collisions with another motor vehicle in transport (National Center for Statistics and Analysis, 2022). This statistic highlights the importance and need for tools to model occupant kinematics in rear impacts. While many finite element analysis software or Mathematical Dynamic Models (MADYMO) (Simcenter Madymo, 2024) software are widely used for crash simulations, they can be very expensive, computationally intensive, and challenging to use. OpenSim is an open-source, multibody dynamics software developed by Stanford University that offers the ability to simulate musculoskeletal dynamics, including muscle activations, and allows for a high degree of customizability, which can be particularly useful for developing subject-specific musculoskeletal models (Akhundov et al., 2022; Delp et al., 2007; Seth et al., 2018).

The purpose of this research is to evaluate the feasibility of using OpenSim's forward dynamics simulation tool to model occupant kinematics in low speed rear-end collisions. The authors are aware of only one previous study using OpenSim for modeling occupant kinematics (Indrani et al., 2019). In this work, they validated OpenSim for simulating frontal impacts and explored the differences in muscle activations on occupant kinematics. There are several differences between this study's methodology and those employed by that study. First, this study implements a rear-end crash pulse, which produces significantly different occupant kinematics in comparison to a frontal impact. Additionally, this research incorporates improved seat geometry and contact force parameters. As this is a proof-of-concept, the focus is on feasibility rather than providing an optimized methodology or comprehensive validation. Certain assumptions and simplifications were necessary to prioritize feasibility.

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METHODS

Test data from an Insurance Institute for Highway Safety (IIHS) dynamic vehicle seat/head restraint evaluation (IIHS, 2020) utilizing a BioRID-II anthropomorphic test device (ATD) was obtained as reference data. The selected IIHS test of a 2018 Toyota Camry seat is identified by #SER17016 (IIHS TechData, 2017). This seat obtained a "Good" overall rating during the IIHS testing. The musculoskeletal model in this research utilized a combination of previously published models to form a full body model that contained musculature at the neck, upper body, and lower body (Barrett et al., 2021; Holzbaur et al., 2005; Rajagopal et al., 2016; Saul et al., 2015). To promote faster simulation processing times for this initial evaluation, muscles not critical to rear-impact kinematics, particularly in the lower body, were excluded. The combined model included 130 muscles across the body. The default muscle parameters were maintained as defined by the published models. The mass, however, was scaled using OpenSim's built-in scale tool from 71 kg to approximately 77.3 kg to match that of the 50^{th} percentile male.

For the seat geometry, OpenSim requires meshes to be watertight with properly oriented normals. Initially, an exemplar 2019 Toyota Camry seat was 3D scanned, but the resulting mesh was too complex for immediate use in OpenSim, prompting the use of a pre-existing, simplified generic surface mesh. The mesh's upper backrest and bottom seat sections were treated as separate bodies and joined together via a gimbal joint to allow for reclination. The gimbal joint was permitted one degree of freedom in rotation about the Z axis. OpenSim does not follow SAE J211 coordinate systems. Instead, they utilize the right-hand orientation of X-forward (red), Y-upward (green), and Z-lateral (blue). A 46 mm wide lap-belt mesh was modeled within the seat, and a “sled” buck , shown in gray, was added to represent the sled. Figure 1 shows the completed model, seat geometry, and coordinate axis.

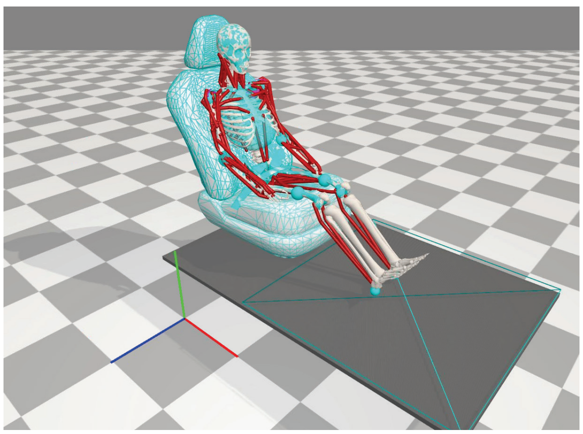

Figure 1: Initial position of the complete model of the seat and occupant on the sled.

The seatback joint was assigned a coordinate limit force defined to be 35 Nm/deg (Molino, 1998). This coordinate limit force enabled us to model the elastic deformation of the seat but did not model any plastic deformation. To allow the seat to contact the musculoskeletal model, separate contact meshes that are bound to specific body parts within the model must be defined to allow for these meshes to interact. Contact meshes were generated for specific areas of the body model that we expected would interact with the seat, such as the skull, scapula, glenohumeral joint, torso, elbow, pelvis, femur, and heel. Finally, we added a half space contact to model the floorboard where the heel’s rest. The contact meshes are shown by the light blue outlines in Figure 1. OpenSim has two main methods for calculating contacts: Hunt-Crossley, which is intended for use between contact spheres and/or contact half spaces, and Elastic Foundations, which is intended for use with custom contact meshes. Based on the work by Hast et al. (2019), a stiffness constant of 2.3e6 N/m was defined for the seatback’s elastic foundation force .

The prescribed crash pulse used in the IIHS low speed rear impact test produces a peak acceleration of 10 g, a mean acceleration of 5 g over a 91 ms duration meant to simulate a rear-end collision with a 16 km/h change in velocity (ΔV). The crash pulse was converted to a force versus time function in one-millisecond increments. This force-time data was defined as a prescribed force in OpenSim using a “SimmSpline” curve acting on the lower sled body. The musculoskeletal model was positioned on the seat according to the IIHS positioning protocol, including backset, pelvis angle, and torso angle. Figure 2 shows an approximate visual alignment comparison between the OpenSim simulation start position and the IIHS BioRID-II start position.

Figure 2: Overlay comparison of OpenSim starting position and IIHS.

RESULTS

The initial simulation was run for 150 milliseconds, and acceleration data was collected using OpenSim’s built-in analysis tool. The acceleration pulse of the seat in OpenSim matched the IIHS peak acceleration of 10 g. The model kinematic data was compared with the filtered IIHS data to determine if OpenSim’s forward dynamics simulation was producing reasonable results. The maximum IIHS head X-acceleration was measured to be 21.1 g at 108 ms. In OpenSim, peak skull X-acceleration measured 19.9 g at 63 ms. The peak IIHS T1 X-acceleration was measured to be 13.8 g at 108 ms, and the OpenSim was 13.7 g at 67 ms. The peak pelvis X-acceleration measured 11.4 g by IIHS at 77 ms and 13.3 g at 63 ms in OpenSim. The IIHS head contact time (HCT) is 63 ms total, and OpenSim measured roughly 45 ms. Figure 3 shows a graph comparing these measured variables to those of the IIHS over a 150ms duration.

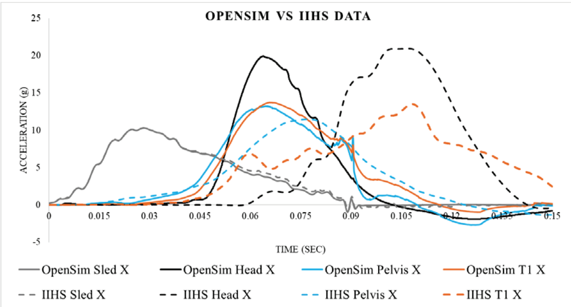

Figure 3: OpenSim Acceleration Data versus IIHS Data

DISCUSSION

The results showed similar peak accelerations at the head, T1, and pelvis. Additionally, the acceleration patterns were similar, although with a visible time-shift. The OpenSim data exhibited earlier onsets in comparison to the IIHS data. This time shift is likely a result of both limitations in the OpenSim musculoskeletal model and simplifications made in the initial methodology. Namely, the musculoskeletal model and contact meshes do not incorporate skin or fatty tissue interactions with the seat, leading to less accurate interactions of the model with the seat compared to human subjects. Simplified seat geometry further contributed to discrepancies between this simulation and the IIHS results. Additionally, there were limitations in modeling the seat and restraint system parameters. For instance, the gimbal joint's coordinate limit force was defined to model purely elastic deformation rather than plastic deformation, which is less realistic for rear-impact scenarios. Future work should include direct comparisons to human subject data to improve model accuracy and validation.

While the current methodology still needs to be improved for a comprehensive validation of OpenSim, this phase successfully demonstrates a proof-of-concept for using the forward dynamics tool to model occupant kinematics during rear-end collisions. Critical areas for future refinement include incorporating more realistic tissue interactions, enhancing seat geometry, and implementing seat and restraint models that account for both elastic and plastic deformations. Future work should aim to address these gaps and directly compare the OpenSim data to human subject corridor data to enhance validation.

OpenSim is rapidly improving. The integration of more sophisticated full-body musculoskeletal models has the potential to improve OpenSim's simulation accuracy. By enabling a more detailed analysis of cervical spine forces and moments, the model may prove useful for studying occupant kinematics and whiplash injuries in low-speed rear impacts.

CONCLUSION

This research aimed to demonstrate the feasibility of modeling low speed rear-end collisions using OpenSim's forward dynamics tool. The preliminary results showed promising alignment with reference IIHS test data, suggesting that OpenSim could serve as a viable open-source platform for studying occupant kinematics. While initial findings revealed some discrepancies, likely due to simplifications in the methodology, future work can address these gaps. Continued development and validation against human subject data will be essential for refining OpenSim's application in rear-impact simulations, ultimately enhancing the accessibility of occupant safety research.

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