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TITLE: Can Visual Feedback Improve Young Drivers' Accelerator Use? A proof-of-concept Study

INTRODUCTION

Young drivers are at heightened risk of road traffic collisions due to their tendency for riskier driving behaviors, such as excessive acceleration and speeding (Twisk & Stacey, 2007). Evidence from numerous studies in driving and aviation has shown that feedback can reduce risk-taking behavior of young operatives (Molesworth et al., 2006, Molesworth et al., 2011, Krasnova et al., 2016). Specifically, for driving, in-vehicle feedback systems offer a potential intervention by providing real-time behavioral cues to promote safer driving (Ouimet et al., 2015). For example, when vehicle speed exceeded the posted limit, visual feedback (change in colour of the vehicle's speed) has been shown to reduce the percentage of time speeding in a driving simulator (Brookhuis & de Waard, 1999) and reduce mean speed on the road (Molloy et al., 2021). Modern cars have a plethora of driver feedback systems (out of lane detection, speed limit, need to brake detection) which are not always explained at point of sale to the owner, and in any case, the evidence of their effectiveness in improving driver safety is unclear. Previous research has shown that if feedback is removed the learned effects disappear (Adell, 2010). The aims of this study were two-fold 1) can visual feedback moderate use of the accelerator in healthy young drivers, and 2) to discover whether for feedback to be effective, drivers must know the meaning of the feedback and what the appropriate response is.

METHODS

A driving simulator was used to assess the two aims of this study. Thirty-eight healthy young (age range 18-25 years, 22 male, 16 female) participants with a full driver's licence held for at least 1 year, and who drove at least twice a week for over 30 minutes or more, were recruited to this study. At the start of each session participants signed informed consent and then reported their age and sex. The driving simulator consisted of a 106cm plasma screen, steering wheel giving realistic feedback when turned, an accelerator and brake pedal (automatic gear change) and an adjustable car seat. Participants were instructed to drive safely as they would in a real car on the road. Each participant completed five identical simulator drives on a 3.1-mile winding country road taken from Colin McRea Rally 2 (Codemaster, Leamington Spa, UK). There were no other road users. The view of the road was through the windscreen with the speedometer in the bottom right-hand corner with the feedback symbol placed just above it. During each drive, pedal depression and steering wheel angle were recorded as well as the time it took to complete each drive and the number of times a driver went out of lane or crashed into the side of the road. Drive 1 and 2 were practice and baseline assessment respectively. During Drive 3 and 4 the feedback symbol which was a red circle with a black icon of a foot just above an accelerator pedal on a white background (Figure 1) would light up, providing visual feedback (no audio feedback), if the accelerator was pressed down more than halfway (12 degrees). Before Drive 3 participants were told this would happen but were not told what this symbol meant or how they should respond. Before Drive 4 participants were specifically instructed that if they saw the symbol light up, they should back off the accelerator until the light turned off. During the fifth and last Drive, the feedback was removed again. Ethical approval was granted by the local research ethical committee. All five drives happened in the same session and there was a 5 minute break between each of the drives.

Figure 1 Accelerator feedback symbol

RESULTS

As this work is still ongoing this abstract will present and discuss preliminary data on journey time (drive time), and the number of times a driver went out of lane or crashed into an obstacle by the side of the road. Full pedal and steering wheel angle data will be ready to be presented and discussed at the conference, an example of pedal use is shown at the end of the results.

The Shapiro-Wilk test showed that all data was non-normally distributed ($p<0.05$) therefore non-parametric tests were used to assess differences in drive time, out of lane excursions and number of crashes. For differences between those who triggered the feedback vs those who did not, the Mann-Whitney U test was used. For differences over the drives the Related-Samples Friedman's Two-Way Analysis was used. A Bonferroni correction was applied for multiple comparisons. Data are presented as median score, and interquartile range IQR (Q3-Q1).

Of the 38 participants, 23 (~60%) pushed the accelerator pedal down more than 12 degrees and so triggered the feedback in either Drive 3 or Drive 4. Of the 23 who triggered feedbackth,17 were male drivers (~74%). Drivers who triggered the feedback were significantly faster across all drives compared to those who did not trigger the feedback (Figure 2).

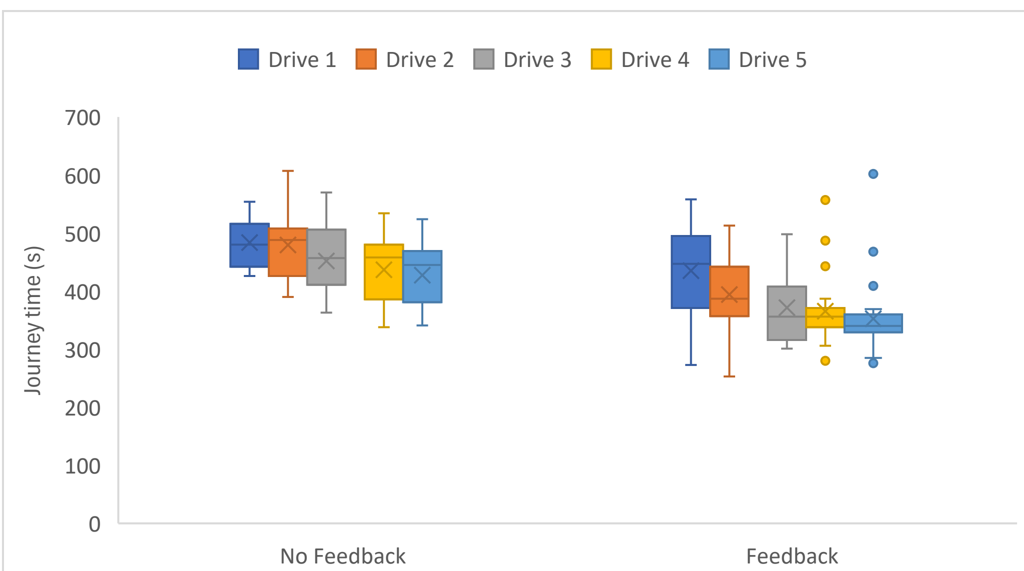

Figure 2 Median journey time in seconds per group. error bars represent IQR (Q3-Q1).

Furthermore, drivers who triggered the feedback also made more out of lane excursions in the practice drive (Drive 1), the baseline assessment drive (Drive 2), the feedback but no instruction drive (Drive 3), and during the last drive when feedback had been turned off (Drive 5); Figure 3. Interestingly, during the drive where drivers were told what the feedback light meant and how they should respond (Drive 4), there was no significant difference between the two groups; Figure 3, Drive 4.

There was no significant difference in the number of crashes between those that triggered the feedback (median 1, IQR 3) and those who did not trigger the feedback (median 0, IQR 0).

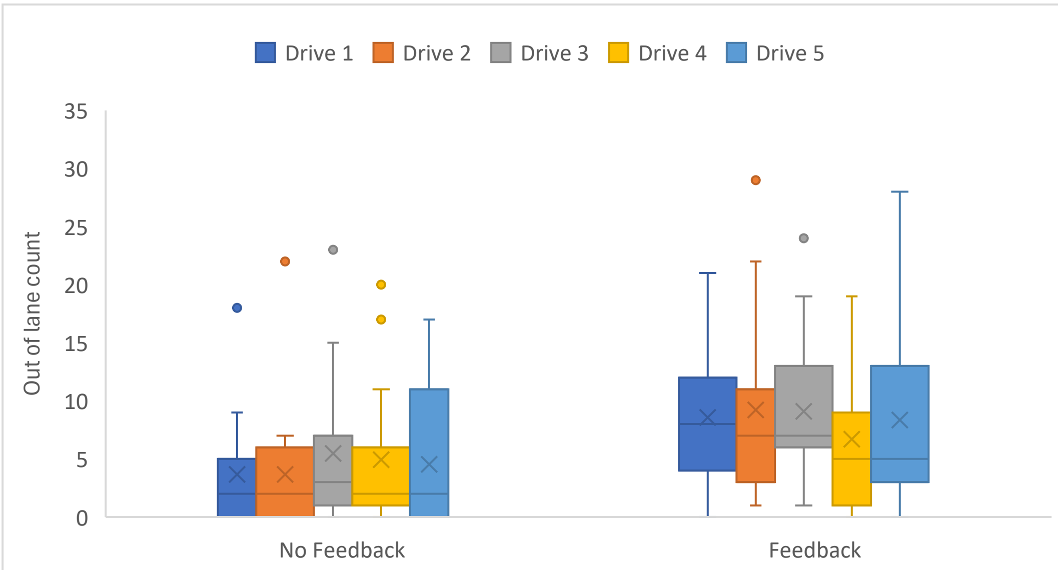

Figure 3 Median out of lane count per group. error bars represent IQR (Q3-Q1).

To assess whether the feedback had any effect on drive time, out of lane excursions, or crashes, we selected only those drivers who triggered the feedback (n=23) and used Drive 2 as the baseline assessment of their driving. This was compared to Drive 3 (feedback but no instruction), Drive 4 (feedback and instruction) and Drive 5 (final drive, no feedback). Furthermore, we compared the same variables between Drive 3 and Drive 4 to see if adding the specific instruction, to ease back off the accelerator if the feedback symbol lit up, had any effect.

The feedback had no effect on the number of out of lane excursions nor the number of crashes.

There was a significant effect on drive time of Drive 2 (median 387s, IQR 81), Drive 3 (median 356s, IQR 78), Drive 4 (median 356s, IQR 29) and Drive 5 (median 340s, IQR 27): $\chi 2(3) = 27.157$, $p < .001$. Pair wise comparison revealed that Drive 2 (baseline) was significantly slower than Drive 4 ($p = .008$) and Drive 5 ($p < .001$).

In terms of moderating use of the accelerator, preliminary data shows that feedback could moderate pedal use but didn’t in every driver. As data analysis is still on going, results from two individual drivers are presented (Figure 4 and Figure 5). These two drivers reflect the two types of responses seen. The driver in Figure 4, did moderate their use of the accelerator in Drive 4 (feedback and instruction), effectively constraining the accelerator pedal depression to less than halfway down (the feedback threshold) and shifting it to the 10 – 7.5-degree range.

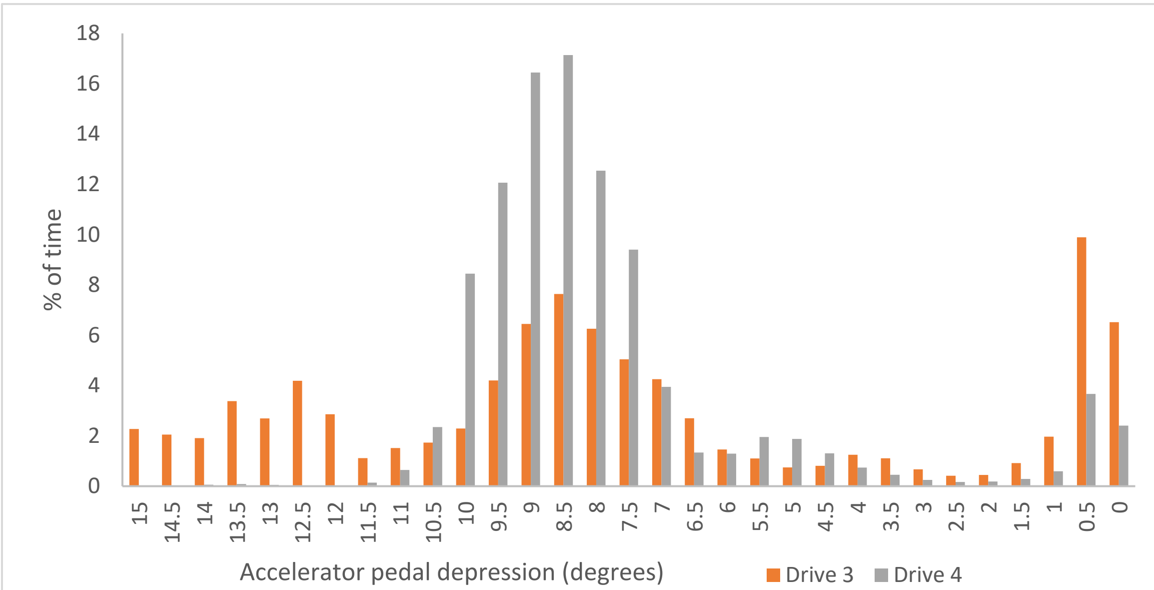

Figure 4 Example 1 of a frequency distribution of percentage of time a driver pressed down the accelerator pedal for Drive 3 (feedback but no instruction) Drive 4 (feedback and instruction)

The driver in Figure 5, did not show this shift and continued to push the accelerator beyond 12 degrees in Dive 4 even though they were instructed to back of the accelerator when the feedback light was activated.

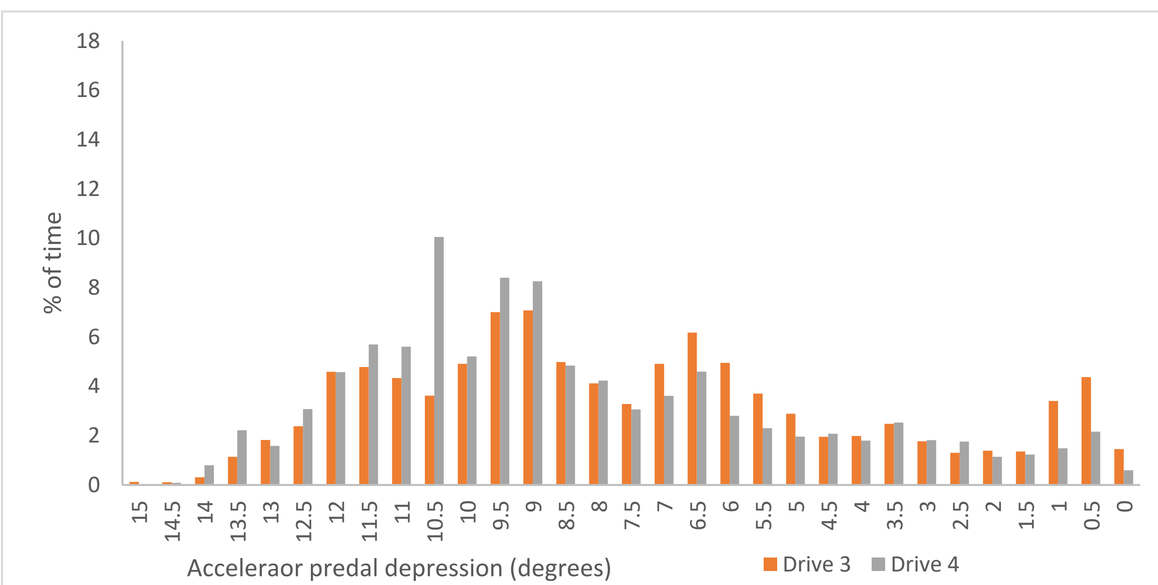

Figure 5 Example 2 of a frequency distribution of percentage of time a driver pressed down the accelerator pedal for Drive 3 (feedback but no instruction) Drive 4 (feedback and instruction)

DISCUSSION

The results show that those who triggered the feedback in Drive 3 or Drive 4 had significantly shorter drive times across all drives compared to those who did not trigger the feedback. Furthermore, those who triggered the feedback also made more out of lane excursions, but they did not have any more crashes (crashes were rare in all drives). The feedback (with or without instruction) did not change the number of out of lane excursions nor the number of crashes compared to the baseline drive. There was a significant effect of feedback on the drive time, however it is more likely that this is due to drivers learning the route rather than feedback leading to an increased speed. The group that did not trigger the feedback also become quicker over the five drives.

In terms pedal use, from the two examples presented, feedback without instruction does not seem to moderate pedal use to the range less than 12 degrees down. However, feedback with instruction did for some drivers effectively limit use of accelerator to less than 12 degrees down.

This study is not without limitations. Firstly, the driving situation is a simplified version of the real world. There are no other road users. Yet the route driven in the simulator is a realistic representation of winding country road in the UK. Furthermore, the pedal data is being analyzed and will be ready for the conference therefore only data of two individuals were presented as examples and should be treated as such.

To conclude, the preliminary data in this study lends evidence to the finding that intelligent driver assistance systems without explanation and instructions are unlikely to prove affective in terms of pedal use and consequent driver safety outcomes. Further research in more complicated driving situations and with different populations is needed.

ACKNOWLEDGEMENTS

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TITLE: A Finite Element Study of Interaction of Helmet and Head Surround Foam During Side Impact Events in Motorsport

INTRODUCTION

Head surround foams are compulsory safety components required in NASCAR (National Association for Stock Car Auto Racing, LLC) sanctioned races. The foams significantly mitigate the severity of head impacts during crashes, resulting in reduced head injury risks. The NASCAR rulebook mandates that the foam materials on both sides of the driver's helmet meet the SFI Foundation, Inc (SFI) 45.2 regulations (SFI 45.2). The rulebook required head surround foam dimensions are shown in Fig. 1 (NASCAR rule book).

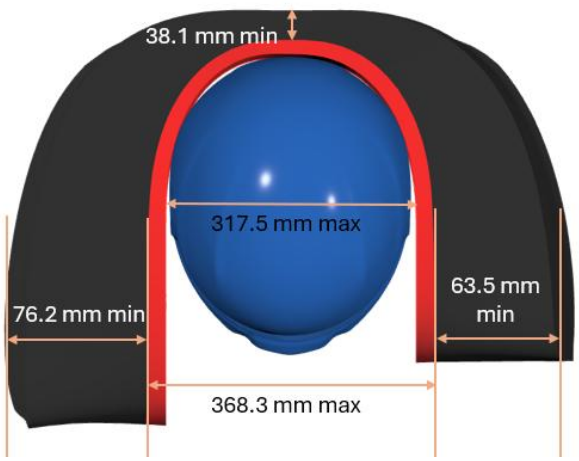


Figure 1: NASCAR rulebook required head surround foam dimensions (top view) with SFI 45.2 foam in grey and non-SFI 45.2 material shown in red.

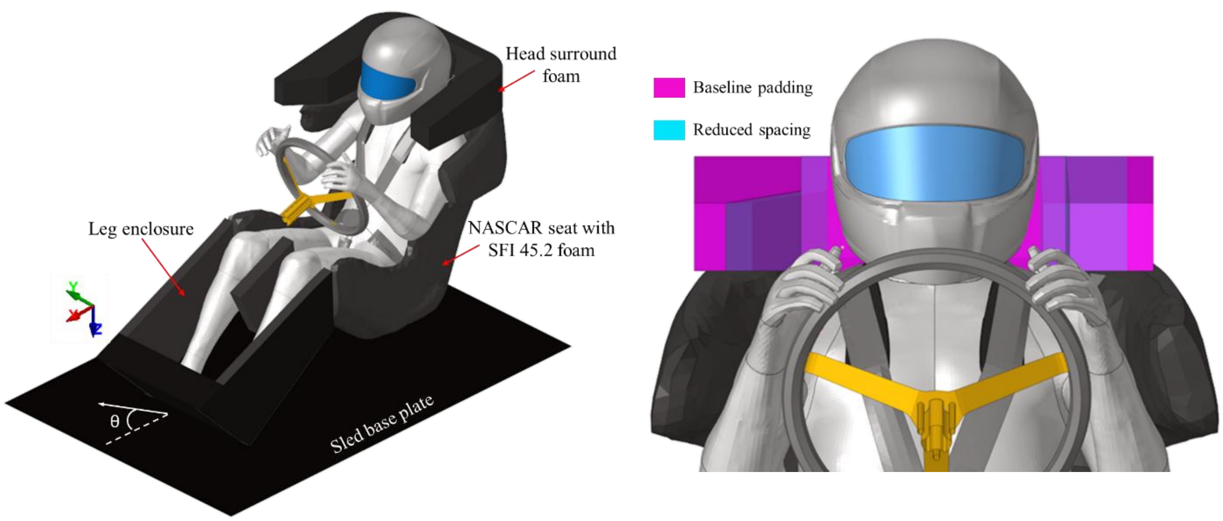
The grey foam in Fig. 1 must be SFI 45.2 compliant with a maximum gap of 368.3 mm (14.5mm) between the inner surfaces of the foam. Drivers may use an additional layer of comfort foam (shown in red in Fig. 1) and the resulting foam to foam distance must not exceed 317.5 mm (12.5"). Additionally, the foam to the rear of the helmet must have a minimum thickness of 38.1 mm (1.5") SFI 45.2 compliant material. Since 2024, an alternate NASCAR approved rear impact foam with a minimum thickness requirement of 76.2 mm (3") is also permissible for use behind the driver's helmet. The specifications of the alternate foam were established based on extensive drop tower testing and finite element simulations, demonstrating reduced head accelerations during lower-speed helmet to foam impacts (Gray et al., 2025). The head foam is asymmetrical because right-side impacts are more common. The left side remains more open to allow quick driver exit during emergencies (Patalak et al., 2011, 2020).

A finite element (FE) study was performed to evaluate the contribution of the head surround foam geometry and the SFI 45.2 material on the head injury risks during side impacts. The Total HUman Model for Safety (THUMS) human body model (HBM) was used in a NASCAR seating environment (Patalak et al., 2013; Decker et al., 2020) to assess the effectiveness of head surround foam in mitigating injury risks to the drivers. Specific attention was given to the effects of the head foam left-to-right gap and the effects of the NASCAR alternate rear impact foam model.

METHODS

FE Model Setup

A 50th percentile male THUMS v7 occupant model (henceforth called THUMS in this document) was used for this study. THUMS was settled into a NASCAR environment consisting of a 7-point seatbelt, head and neck restraint (HNR), helmet, and leg enclosure (Patalak et al., 2013; Decker et al., 2020) (Fig. 2a). The THUMS model was seated through prescribed motion, aligning with the pelvis position established in previous research by Decker et al. (2020). The helmet was carefully positioned onto the THUMS head using a simulation-based fitting process. Additional adjustments were performed to ensure accurate positioning of the HNR device, seatbelt pre-tension, and the hand placement on the steering wheel (Patalak et al., 2013 Decker et al., 2020).



(a) (b)

Figure 2: (a) THUMS settled in the NASCAR environment (b) Comparison of baseline foam and reduced spacing head surround (the reduced spacing foam is transparent).

The head surround foam was incorporated into the finite element (FE) model setup with a baseline spacing of 330 mm (~13") between the inner left and right surfaces of the foam. The right-side thickness was 130 mm (~5") and the left-side thickness was 105 mm (~4"). This head surround geometry was derived from CAD models provided by foam manufacturers as well as measurement data gathered through field surveys of existing head surround foam installations. The SFI 45.2 material properties were characterized through a combination of quasi-static compression tests and dynamic drop tower experiments (Gray et al., 2025; Mukherjee et al., 2024). These properties were then assigned to the head surround foam components in the FE model.

The sled base plate shown in Fig. 2 was constrained in the vertical (Z) direction and for all rotational degrees of freedom (DOFs). Acceleration pulses were applied in the X-Y plane to simulate right-frontal and left-frontal collisions, resulting in helmet contact with the head surround foam on the right and left sides, respectively. Three different acceleration pulses were applied as boundary conditions at the sled base plate. For right-side impacts, low severity (20

G peak, 43.2 kph) and medium severity (40 G peak, 43.2 kph) pulses were used, both applied at a 60° angle in the X-Y plane (θ in Fig. 2). These low and medium severity pulses were derived from analyses of crash data collected from the NASCAR racing series between 2011 and 2018 (Patalak et al., 2011, 2020). For the left-side impact, a sled pulse with a peak acceleration of 50 G (30 kph) was used. This pulse was based on chassis data recorded from an incident during the 2024 NASCAR Cup Series race season. This configuration allowed comparison of the head acceleration data under high acceleration but low velocity change (ΔV) conditions.

In this study, the effects of head surround foam spacing and material properties on head kinematics were analyzed. Apart from the baseline foam configuration (called "Baseline Foam"), two other head surround setups were simulated. First, spacing between the inner surfaces of the foam was reduced (from baseline) to 260 mm (10.2"), leaving a clearance of 8 mm (~1/3") on either side of the helmet (called "Reduced Spacing"). This setup represented a tighter fit and was intended to explore the influence of reduced lateral space on helmet-to-foam interaction. Secondly, but separately from the 'Reduce Spacing' configuration, the SFI 45.2 material in the baseline geometry of the head surround foam was replaced with the NASCAR alternate foam material (Gray et al., 2025; Mukherjee et al., 2024), to evaluate the material's influence on impact mitigation (called "Alternate material") with the Baseline Foam spacing. Both alternative configurations were simulated under the same three acceleration cases as the baseline padding to assess differences in driver head kinematics.

All simulations were performed in LS dyna v13. The simulations were run across 90 cores hosted on a high-performance cluster (HPC). The simulations were run for 145 ms with the acceleration pulse initiating 25 ms after the start of the simulation, permitting the seat belts to reach the desired preloads (Patalak et al., 2013).

FE Model Response and Injury Investigation

The THUMS model by default is instrumented to capture the head accelerations and rotational kinematics. Head Injury Criterion (HIC) (King et al., 2003) values and Diffuse Axonal Multi-Axis General Evaluation (DAMAGE) (Gabler et al., 2018, 2019) were calculated for each simulation case and used to compare injury risk across the head surround foam configurations. Linear accelerations and rotational velocities in the X, Y, and Z axes were extracted from binout result files. The resultant acceleration was used for HIC calculations, and rotational velocities were differentiated by processing the velocity history to compute rotational accelerations. The use of both head linear and rotational kinematics allowed for consistent comparison with the real-world injury data measured through mouth-sensors across the NASCAR racing series (Miller et al., 2023).

RESULTS

The head accelerations and rotations were output for each head foam configuration for all the impact conditions. The resultant acceleration and resultant rotational velocity for the medium severity right impact case is shown in Fig. 3.

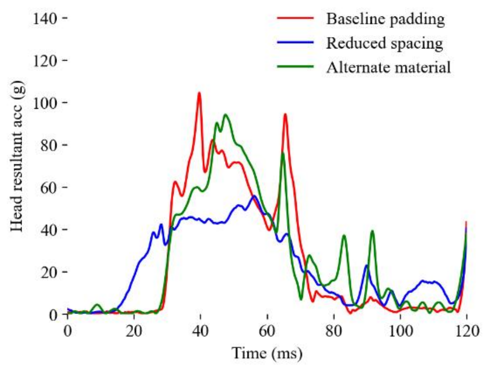


Figure 3: Medium severity right frontal impact - Head resultant acceleration (25 ms after the simulation start).

The simulation results indicated that the alternate material reduced both the peak linear acceleration (Fig. 3) and peak rotational velocity of the head. Among the three configurations, the reduced spacing foam scenario resulted in the lowest head resultant acceleration. Furthermore, this configuration demonstrated a substantial reduction in peak resultant rotational velocity—nearly half compared to the baseline and alternate foam cases. In the mid severity left impacts, a secondary peak in the resultant acceleration trace was observed, which was primarily driven by vertical (Z-direction) acceleration, due to a secondary impact of the helmet with the foam. Similar trends were observed in the low severity right-side impact and the left-side impact cases as well. In both these scenarios, the second acceleration peak was less pronounced compared to the mid severity left impact. The only aberration occurred in the left-side impact, where the initial peak acceleration was higher in the reduced spacing configuration.

The injury risks for each head foam setup are compiled in Table 1.

Table 1

Simulation case		HIC15	HIC36	DAMAGE
Mid severity right side impact	Baseline foam	898.84	1331.83	0.494
	Reduced spacing	257.95	505.068	0.267
	Alternate material	848.39	1167.89	0.464
Low severity right side impact	Baseline foam	192.64	209.059	0.306
	Reduced spacing	57.94	88.20	0.130
	Alternate material	197.910	228.84	0.282
Left side impact	Baseline foam	524.21	343.13	0.380
	Reduced spacing	348.04	247.96	0.259
	Alternate material	343.20	251.61	0.398

The alternate material was found to be effective in reducing Head Injury Criterion (HIC) value in the medium severity right-side impact scenario. The reduced spacing configuration resulted in the lowest HIC values across most cases, except for the HIC15 metric during the left-side impact, where it was slightly higher than that observed in the alternate material case. Notably, the reduced spacing configuration substantially decreased DAMAGE values—by approximately 40% to 50%—in all three impact cases. On the other hand, while the NASCAR-approved foam effectively reduced peak resultant rotational velocities, it had minimal influence on DAMAGE values.

DISCUSSION

The current study evaluated the effect of foam geometry and material type in mitigating head injury risks in a belted NASCAR driver. Three different foam configurations were assessed across three distinct impact scenarios representing a range of severities and impact directions. Overall, the simulation results suggest that the reduced spacing foam configuration consistently lowered head injury metrics across the conditions examined (Table 1).
The foam with alternate material configuration was most effective in the high acceleration low velocity left side impact case (Table 1) while in the two right side impact conditions, the effect of material change was minimal. This result can be attributed to differences in the acceleration pulse characteristics used to drive the sled —specifically the change in velocity (ΔV) was lower for the left side impacts. A similar trend was observed in a previous study of rear impact scenarios where the alternate material reduced the peak head acceleration in low speed impacts (Gray et al., 2025).

The result plots (Fig. 3) indicate that both acceleration and rotational velocity begin to rise earlier in the reduced spacing configuration compared to the other two setups. This earlier onset suggests that contact between the helmet and foam occurs sooner, potentially contributing to the observed reductions in injury metrics across all load cases. Early engagement with the foam helps attenuate peak forces, with the only notable deviation in the left-side impact, where the peak resultant acceleration magnitude was higher in the reduced spacing configuration. This suggests that the alternate material foam was as effective as reduced spacing in this lower ΔV scenario. While reduced spacing generally lowers peak kinematic outputs, specific impact orientations may momentarily amplify the measured responses. The peak accelerations and HIC values measured for the medium right-side impacts were notably high for both the baseline foam and the alternate material configurations. The high peak head acceleration is driven by the severity of the 40 g input pulse. Moreover, fitting a helmet adds mass to the headform, which can also affect the peak linear accelerations under these conditions. However, these severities have been observed in actual race incidents and therefore must be considered when assessing head foam performance.

Future studies will explore the combined effects of foam geometry and material modifications on head injury mitigation. Further investigation will assess how simultaneous changes in spacing and material properties influence both linear and rotational head kinematics. Boundary conditions that induce multiple head-foam interactions will also be analyzed to assess repeated loading effects. Additionally, the current minimum dimensional requirements for head surround foam will be reviewed, along with the vertical positioning of the foam relative to the helmet. These efforts aim to refine the design guidelines and inform safety improvements that can enhance injury mitigation in motorsport environments.

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