AAAM 67th Annual Conference Student Symposium Abstracts

Modeling Driver Behaviors in Intersections Based on Real-World Intersection Traversals from Large-Scale Naturalistic Driving Data in the U.S.

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INTRODUCTION

From 2019 to 2020, 25% of all traffic fatalities occurred at an intersection [1]. The three most common crossing path pre-crash scenarios are straight crossing path (SCP), left turn across path lateral direction (LTAP/LD), and left turn across path opposite direction (LTAP/OD) [2] (Figure 1). Crossing path crashes are the most common intersection crash type, comprising 33% of intersection crashes [2].

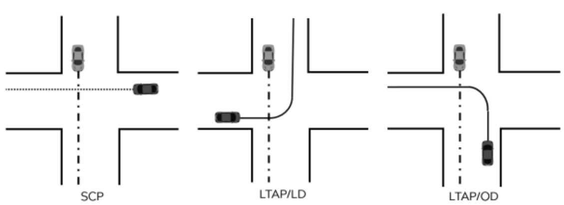

Figure 1. Three most common crossing path pre-crash scenarios.

Intersection advanced driver assist systems (I-ADAS) can assist drivers in preventing or mitigating intersection crashes. One common way I-ADAS assists in crash prevention and mitigation is with automatic emergency braking, which automatically applies braking without driver input, when a crash is imminent. However, drivers can perform evasive actions that could alter the encounter outcome even with I-ADAS equipped. To increase I-ADAS effectiveness for crossing path crashes, it is helpful to understand how drivers behave in intersections.

RESEARCH QUESTION/OBJECTIVE

The purpose of this study was to use real-world driving data to construct a driver behavior model to predict how drivers behaves when an SCP, LTAP/LD, or LTAP/OD crash is imminent. The time-varying Markov chain model constructed was used to provide insight on how drivers behave in intersections.

METHODS

Data sources

Data was extracted from two real-world driving databases for this study: The Second Strategic Highway Research Program (SHRP 2) database and the Virginia Traffic Camera for Advanced Safety Technologies (VT-CAST) database. The SHRP 2 roadway information database is a comprehensive database. The participant vehicles were equipped with video and radar to capture the trajectories and behaviors of other vehicles [3]. VT-CAST data is sourced from the VT-CAST Virginia Traffic Information System which provides livestream video to the public throughout the state of Virginia. VT-CAST is comprised of trajectory data from 1,263 cameras recorded from December 17th, 2019 to December 31st, 2020.

Preparing the Training and Test Data

Vehicle encounters from SHRP 2 and VT-CAST were combined to create the training and test datasets. This dataset encompassed normal driving encounters, as well as crashes and near-crashes (Table 1). The training data encompassed 70% of the randomly selected vehicles from each encounter type. The remaining 30% of the vehicles from each encounter type was used to test the model. The state probabilities are based on the vehicles' velocity, estimated time to collision (eTTC), acceleration, type of encounter (normal driving, crash, or near crash), and the role in the encounter (travelling straight or turning left).

Table 1. Total training data case counts.

Encounter Type	SCP	LTAP/LD	LTAP/OD
Crash (SHRP 2)	7	4	8
Near-Crash (SHRP 2)	57	90	135
Encounter (VT-CAST)	35,879	52,957	54,506
TOTAL	35,943	53,051	54,649

At every timepoint, each vehicle in the training dataset in one of four potential states: accelerating, braking, waiting, or constant velocity. The vehicle was determined to be accelerating if the instantaneous acceleration was greater than 0.1 m/s^2. The vehicle was determined to be braking if the vehicle had an instantaneous acceleration of less than -0.1 m/s^2. The vehicle was determined to be waiting if there was no acceleration and the velocity was less than 1 m/s. The vehicle was determined to be at a constant velocity if there was no acceleration and the velocity was greater than 1 m/s.

Building the Markov Model

A Markov chain model was used to determine the probability of a vehicle transitioning to a different state or staying in the same state between time steps. Based on the current vehicle state, there up to 4 different probabilities to transition to (Figure 2).

To predict the probability of a vehicle transitioning from the current state to any of the four potential states at the next time step, the Markov chain looked at the current state for each vehicle. This means the Markov model assumes the current state will help predict the next state. Five predictive variables were used to determine the probability of a vehicle transition: velocity, estimated time to collision, acceleration, encounter type, and the role the vehicle was in the encounter (turning left or going straight).

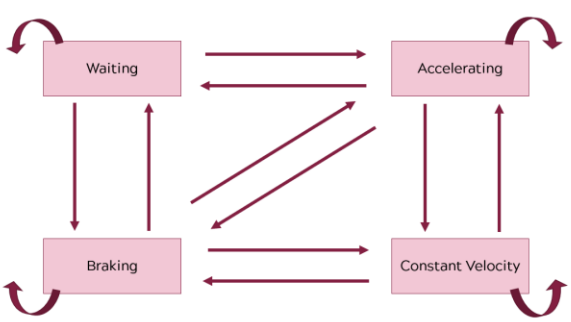

Figure 2. States and Transitions

The probability of transitioning is constantly changing and can be expressed as a multinomial logistic equation based on the current state and the predictive variables (Equation 1). The model was trained on training dataset and assigned weights to each of the parameters (β) using the R multinom function. The model accuracy was calculated by comparing the actual next state to the next state predicted by the model. The model was run on the training data and the test data.

$$\ln\left(\frac{\mathbf{P}}{\mathbf{1-P}}\right) = \beta_0 + \beta_1(\text{Velocity}) + \beta_2(\text{eTTC}) + \beta_3(\text{Acceleration}) + \beta_4(\text{Encounter}) + \beta_5(\text{Near Crash}) + \beta_6(\text{Crash}) + \beta_7(\text{Role}) \quad (1)$$

RESULTS

Transition Probabilities

Each timestep for each vehicle is associated with a set of probabilities that predict what the next state will be based on the current state (Table 2). The probabilities from the training set range, but the average probability gives insight to where most of the vehicles will transition.

It was not possible for a vehicle to transition from a constant velocity to waiting, as a braking period must occur between these two states. The most probable next state for a vehicle at a constant velocity, in any of the encounters, was to stay at a constant velocity. For the LTAP/LD and LTAP/OD encounter types the next highest probable state was accelerating, which was most likely the vehicle accelerating out of a turn. If a vehicle's current state was braking the model predicts a probability of the next state being the vehicle at constant velocity as 3.2%, regardless of encounter type. When the vehicle was accelerating, it was most likely to remain accelerating or transition to travelling at a constant velocity. A vehicle was not able to transition from waiting to constant velocity, as an acceleration period must occur between these two states. Second to the vehicle continuing to wait, the vehicle was most likely to accelerate. The vehicles in the dataset considered to be in the waiting state did not necessarily have exactly zero velocity, so transitioning to braking was possible.

Table 2. Average transition probabilities.

Current State	Encounter	Probability for Next State (%)			
		Const. Vel.	Brake	Accel.	Wait
Const. Vel.	SCP	92.1	5.7	2.2	NA
	LTAP/LD	77.3	7.9	14.7	
	LTAP/OD	78.1	8.1	13.6	
Brake	SCP	3.2	94.8	0.3	1.7
	LTAP/LD	3.3	87.0	5.4	4.3
	LTAP/OD	3.2	87.9	4.8	4.1
Accel.	SCP	4.7	0.1	94.6	0.6
	LTAP/LD	5.4	1.9	91.1	1.5
	LTAP/OD	5.6	1.9	91.1	1.4
Wait	SCP	NA	3.0	4.6	92.2
	LTAP/LD		5.4	6.7	87.8
	LTAP/OD		5.8	6.4	87.7

Model Accuracy for Each State

Performance was better on training data than the test data. The LTAP/LD with the constant velocity being the current state model yielded lowest accuracy. The models were the most accurate for the SCP encounter. The model for the constant velocity being the current state was the least accurate for LTAP/LD. The model for predicting the next state while the current state was braking was found to be more accurate than the constant velocity. The model accuracy for the transition state from accelerating was the highest model accuracy compared to the other three state's models. The model for the vehicles in the waiting state ran on the test data averaged 85% accuracy for predicting the next state.

Table 3. Model accuracies for training and test data.

Current State	Encounter	Training	Test
Constant Velocity	SCP	92.11%	91.48%
	LTAP/LD	77.33%	61.41%
	LTAP/OD	78.19%	62.46%
Braking	SCP	94.74%	95.04%
	LTAP/LD	87.05%	79.15%
	LTAP/OD	87.93%	80.53%
Accelerating	SCP	96.0%	96.1%
	LTAP/LD	91.1%	86.93%
	LTAP/OD	91.09%	86.88%
Waiting	SCP	92.37%	90.49%
	LTAP/LD	87.78%	82.46%
	LTAP/OD	87.66%	82.58%

DISCUSSION

The Markov chain with the multinomial logistic regression model performed well in predicting the next state for each of the current states in the model. SCP preformed the best, likely because the two vehicles behave similarly. The acceleration and velocity consistently had the highest weights in the model while the other predictors fluctuated based on the state and next state in the equation. In future work, the model will be trained after separating the LTAP cases by whether the vehicle is turning or travelling straight. Furthermore, information about the other vehicle in the encounter (velocity, eTTC, acceleration, etc.) will be taken into consideration in the model.

CONCLUSION

The model used over 124,000 total intersection encounters including 301 crash and near-crash scenarios. The driver behavior model created in this study has shown that it can be a good predictor of real-world driving in normal driving scenarios, and in crash and near-crash scenarios.

NOVELTY/TRAFFIC SAFEY IMPLICATIONS

This study used a novel dataset (VT-CAST) accompanied by SHRP 2 data to create a unique predictive driver behavior model in intersections.

ACKNOWLEDGEMENTS

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COMPUTATIONAL LITERATURE REVIEW OF NATURALISTIC DRIVING STUDIES: IDENTIFYING RESEARCH PRIORITIES

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INTRODUCTION

Naturalistic driving studies (NDS) are a method of data collection by instrumented vehicles undertaking everyday journeys without experimental direction. A combination of sensors, trackers, and cameras collect information about drivers, their vehicles, and the road environment [1]. NDS data vary in scope and scale and have the potential to inform all aspects of a systems-based approach to road safety [2].

The identification of a priority area for the innovative application of NDS data relies on an understanding of the NDS research already conducted, and an awareness of regional road safety priorities.

RESEARCH QUESTION / OBJECTIVE

1. To describe the NDS research domain in terms of:
   a. Descriptive structure: leading authors, institutions, nations, and their relationships; and,
   b. Conceptual structure: prominent topics and applications of NDS data.
2. To identify a target road safety priority to guide the development of a novel NDS data analysis methodology.

METHODS

Computational processes are an emerging mechanism to scope and summarise large collections of literature [3]. Descriptive analysis that does not require judgement of the quality or impact of a paper is suited to well-written algorithms that provide significant time savings over manual processing [4]. The rigorous, comprehensive, and replicable protocol for a 'Computational Literature Review' (CLR) [5] encompasses the following steps:

1. Defining a conceptual goal (scoping).
2. Operationalising the review: defining the research domain (NDS), refining search keywords, extracting metadata from academic databases (Web of Science and Scopus), and cleaning the data export.
3. Performing content analysis: identifying units of analysis (descriptive and conceptual structure), choosing computational techniques (scientometrics, text mining), selecting software tools (*bibliometrix* and *biblioshiny*), and visualising the data (*R* and *python3*).

RESULTS AND DISCUSSION

NDS Research Domain – Descriptive Structure

Exported on 4 November 2022, the NDS research corpus contained 1,120 journal articles and conference proceedings published in 349 sources, as written by 2,465 authors from 336 institutions in 39 countries.

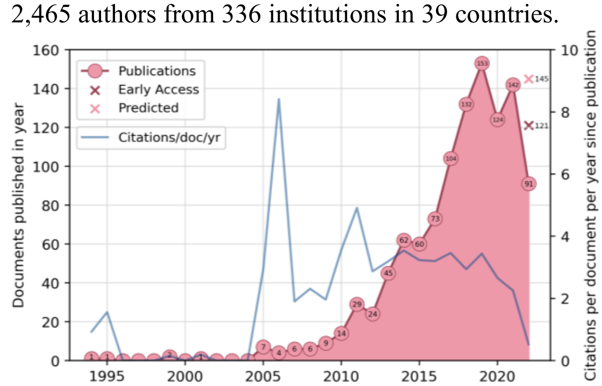

Figure 1: Annual Production and Citations of NDS research – *the number of documents published (red) and their citations (blue) per year.*

The production of NDS research (Figure 1) first saw meaningful growth in 2006, coinciding with the publication of results from the first large-scale NDS project, the 100-car naturalistic driving study [6].

The 10-fold growth in NDS research since 2012 has been driven by publications addressing the research aims of subsequent large-scale NDS studies including UDRIVE in 2014 [7], and SHRP 2 NDS in 2016 [8]. Growth can also be attributed to the wide availability of data from these studies and their contribution to broadening the awareness of the NDS method.

Prolonged growth ceased in 2020, likely due to the effects of the COVID-19 pandemic on conducting real-world research. The analysis of existing data during this period may have limited the reduction in ongoing NDS publication rates. It is difficult to conclude on the basis of this data whether NDS research has reached a limit or will continue to grow.

NDS Research Domain – Conceptual Structure

An insight into the topical structure of NDS research is derived from the analysis of author keywords. The 37 most prominent author keywords are related in a co-occurrence network (Figure 2), with edges linking pairs of keywords that appear together in at least one document.

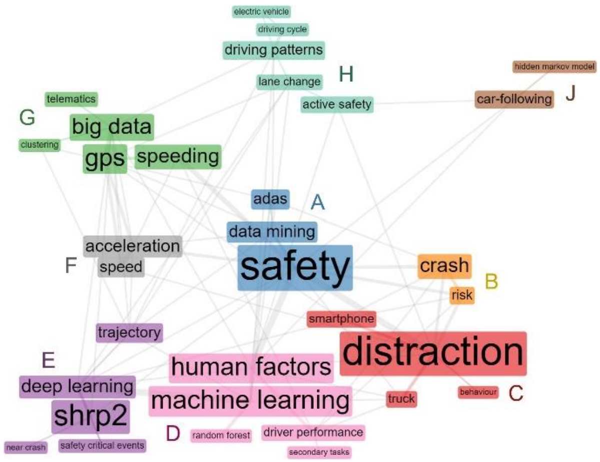

Figure 2: Author keyword co-occurrence network *– edges (lines) link nodes (author keywords with >10 instances in the corpus) that appear together in the keywords of at least one document.*

The central node in the network is 'safety', a broad term with many links given the focus of most NDS research on improving various aspects of road safety. The most prevalent application of NDS data is to questions of driver behaviours, such as distraction, risk, performance, and car-following.

The network visually maps a circle of communities around Community A, with applications (C, H, J) and data sources (E, G) bridged by data types (B, F) and analysis methods (D, E). Despite being arranged in a circular structure, the network exhibits wide-scale interconnectivity. The data types and methods of NDS research see application across all aspects of NDS study and are widely interchangeable.

Road Safety Priorities and Impact

Road safety priorities are determined by various levels of government to guide investment and policy decisions over time. These priorities describe problems for which there is identified public need for evidence-based improvement of safety outcomes. Of relevance in Victoria, Australia are the local priorities of the State Road Safety Strategy [9], the broader priorities of the Australian Road Safety Strategy [10], and the international priorities of the Global Plan for the Decade of Action for Road Safety [11].

The relative importance of each priority in terms of the impact on road trauma is a useful measure to identify the priorities for which finding a solution will have the greatest impact. The in-depth Enhanced Crash Investigation Study (ECIS) [12] performed detailed crash analysis for 400 seriously injured passenger vehicle drivers. Each priority was aligned with a corresponding 'factor', and their impact described in terms of the proportion of crashes for which the factor "not only was present but was assessed to have played a contributing role to the crash and/or type and severity of injuries sustained" (p. 17). Impact was presented both as a proportion of all 400 injured drivers at maximum abbreviated injury scale (MAIS) Level 1+ (minor and above), and for the subset of 188 participants with MAIS Level 3+ (serious and above).

The list of combined priorities was then compared to the key themes identified from NDS research with the aim of identifying road safety problems to which NDS data are applicable, but to date have been underexplored. (Figure 3).

	Impact		NDS Literature			Impact		NDS Literature	
Theme	ECIS MAIS 1+ (%)	ECIS MAIS 3+ (%)	Key Topics	KWs	Theme	ECIS MAIS 1+ (%)	ECIS MAIS 3+ (%)	Key Topics	KWs
vulnerable road users					**unsafe vehicles**				
- older drivers (60+)	35	35		69	- older vehicles	58	66		0
- young drivers (<25)	18	20		16	- light commercial vehicles	13	14		1
- cyclists	-	-		9	- heavy vehicles	2	1		22
- pedestrians	-	-		17	**roads as a workplace**				
- motorcyclists	-	-		1	- career drivers	6	-		9
risky road use					- roadworks	3	4		0
- distraction	45	45		126	**road infrastructure**				
- speeding	27	36		30	- intersection risk	38	34		11
- fatigue	25	27		18	- remote/rural roads	37	50		1
- drugs/alcohol	23	30		0	- supportive road system	22	21		4
- red light running	8	7		0	**post-crash response**	-	-		0
- seatbelts	7	7		3	**automated vehicles**	-	-		16
- phone use	4	5		51	**first nations drivers**	-	-		0
- child restraints	-	-		4					

Table 1: Impact of Road Safety Priorities and Existing Coverage of Road Safety Priorities in NDS Literature – impact is measured as the proportion of injuries for which a given priority was a contributing factor. Green shading corresponds to priorities identified as a leading topic of NDS research by at least two computational methods. KWs refers to the number of documents in the NDS corpus for which that priority (or its synonym) was an author keyword.

Identification of a Target Road Safety Priority

Despite the potential for NDS data to inform all aspects of the road safety system, vehicular and environmental factors are under-represented. Road infrastructure has substantial potential to be explored by NDS data. Specifically, the topic of intersections stands out as a promising target for three key reasons:

- Intersections have the second largest injury contribution of the themes for which existing data can be repurposed.
- Given the dominance of driver-related factors, exploration of road infrastructure will address a systematic gap in NDS data application.
- Topics such as speed, car-following, and distraction see application at intersections. Existing methods to isolate intersection traversals from NDS data can potentially be adapted to questions of road environment and design.

CONCLUSION

NDS research is growing and has the capacity to inform a broad range of road safety, driver behaviour, and vehicle performance applications. From consideration of the impact of road safety priorities, intersections emerge as a relevant focus area to target the development of a NDS data analysis methodology.

NOVELTY/TRAFFIC SAFETY IMPLICATIONS

A fundamental consideration of the CLR process is the relationship between human researchers and computational algorithms, and the need for the human to calibrate and interpret computational output considering their experience. The use of computational tools shifts the burden of the researcher from lengthy manual classification of documents to the interpretation of complex computational outputs. Caution should be taken in the use of computational tools without understanding the parameters and algorithms used, and in the interpretation of computational output without contextualisation with respect to existing field-specific knowledge.

The ultimate aim of my PhD program of research is to develop a robust and adaptable regime for the application of NDS data. Focusing on a problem related to intersections ensures that a meaningful contribution to road safety can be achieved within the time constraints of the PhD. The methodology will also be developed to enable straightforward modification to address a range of problem contexts.

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A Methodology to Determine Local Ankle Injury Tolerances

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INTRODUCTION

Ankle injuries remain common injury types, particularly for females [2][5]. The causes of these injuries remain unclear, and therefore further understanding of ankle fracture tolerance, and refinement of ankle injury prediction tools will be helpful. Human body models may be used to incorporate information on population-wide variability in the overall shape and injury tolerance in the affected tissues [1]. Where past research efforts have focused on *in situ* testing of whole ankles under combined loading [3][4], localized testing of isolated distal tibiae and fibulae remains an unexplored avenue for examination of ankle fracture.

RESEARCH QUESTION/ OBJECTIVE

The goal of this study was to develop a methodology to determine localized injury tolerances for the distal tibia and fibula targeting fracture types common in automobile collisions.

METHODS

Identification of Fracture Types to Target

To identify which injury types to target, the relative frequency of various ankle injuries in the field data was examined. A query of the NASS and CISS datasets was performed. The query was limited to NASS-CDS collection years 2010-2015 and CISS collection years 2017-2019 with passenger vehicles less than ten years old at time of collection. The query was further reduced to frontal impact with belted occupants aged thirteen and older where rollovers, fires, and ejections were excluded. Of the 1433 reported AIS2+ injury cases in the resulting dataset, ankle injuries were present in 196 cases (13.6% of all AIS2+ injury cases). The distributions of AIS2+ ankle injuries among those cases are shown in Figure 1 (unweighted). For females, the most common types of AIS2+ ankle injuries were fractures to the distal tibia or fibula. For males, the injuries were more evenly distributed between tibia, fibula, talus, or calcaneus fracture, or severe ligament injury (e.g., dislocation).

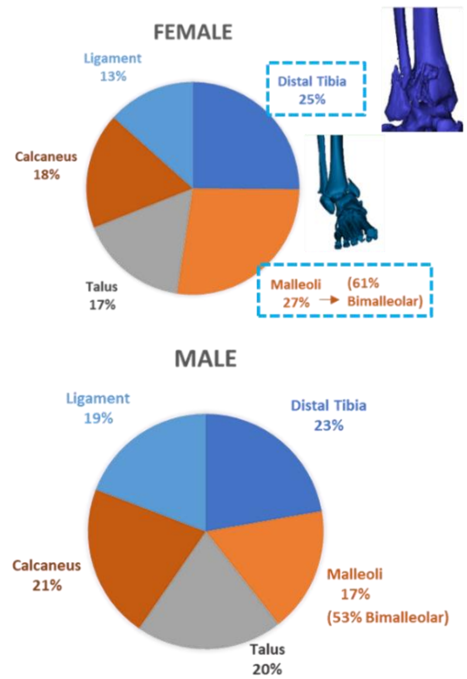

Figure 1: Distribution of AIS2+ ankle injuries from the NASS and CISS cases (unweighted).

To elucidate target fracture patterns of the tibia and fibula of AIS2+ injuries in the ankle, cases were examined from the Crash Injury Research Engineering Network (CIREN) of the National Highway Traffic Safety Administration (NHTSA). NHTSA's latest iteration of the CIREN case collection database (collection years 2017+, vehicle model years 2010+) was queried for cases resulting in distal tibia or fibula fracture. The search included all directions of impact.

The CIREN query identified 143 cases which resulted in various kinds of distal tibia or fibula fractures (Figure 2), many of which included radiology images of the injury. Most cases (89%) were drivers. Sixty percent of all cases exhibited fracture in the right ankle. Distal tibia fractures comprised approximately 34% of the observed fractures. Many tibia fractures were Pilon fractures with occasional inclusion of malleolar fracture. Among the cases of fibula fracture, the Weber C fracture type was the most common, with the fracture occurring proximal to the tibio-fibular syndesmosis.

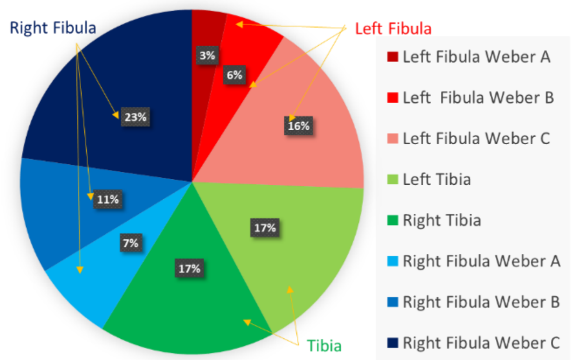

Figure 2: Distribution of tibia and fibula injury types among queried CIREN cases.

Based on these observations, we prioritized distal tibia and fibula fracture for experimental characterization, as together they represent the most common types of ankle injuries observed in this dataset (especially among females).

Mechanical Testing

Tibia Compression

Component-level test modes were designed targeting the fracture types described above. These test methods will be employed with 20 post-mortem human subject (PMHS) specimens (10 male and 10 female across a wide anthropometric range). To replicate tibial pilon and medial malleolar fractures, isolated distal tibia specimens will be subjected to inferomedial oblique loading by a custom 3D printed loader shaped as the talar dome of each specific specimen (Figure 3).

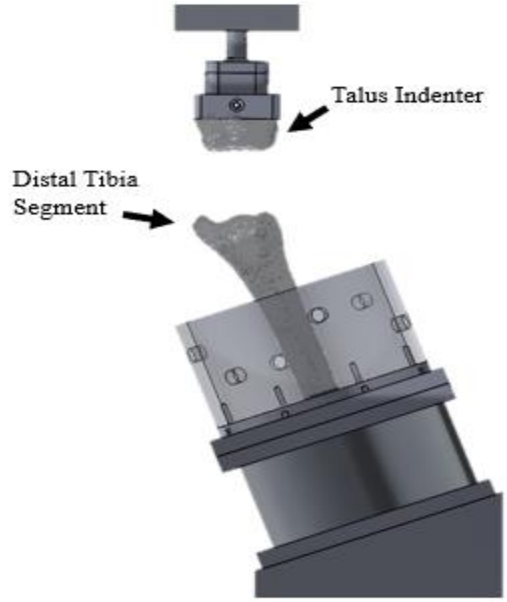

Figure 3: Tibia Loading Fixture to quantify the local tolerance of the tibia to oblique loading with subject-specific talar dome loading head.

Fibula Bending

To replicate fibular suprasyndesmotic (Weber C) fractures, isolated fibula specimens will be subjected to quasi-static-bending superimposed on axial pre-compression (Figure 4). For both the fibula and tibia testing, instrumentation will include 6-axis load cells mounted underneath the mounting base to measure applied loads applied to the specimen (which may be transformed via rigid-body transformation to calculate the local forces and moments occurring within the specimen at specified locations), measurement of the input displacement of the loading head, and (where possible) measurement of local strains via multi-axial bone mounted strain gages.

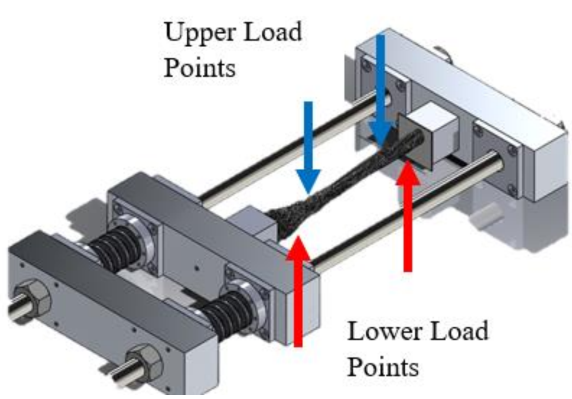

Figure 4: Test fixture to quantify the local tolerance of the fibula to combined compression and bending load.

The unique experimental setups were designed to collect key results of the tibial and fibular specimens, including the force and deformation at failure. Use of high-speed video, surface strain gages, and load time-histories provide capabilities for determination of fracture timing. Radiological documentation allows for pre- and post-test bone geometry comparison to failure modes with CIREN data. The load and deformation data may be applied via matched simulations to determine effective stress and deformation thresholds for tibial pilon or malleolar fracture, and lateral bending of the distal fibula.

DATA SOURCES

To estimate the frequency and distribution of ankle injury among AIS2+ injuries, the NASS-CDS (years 2010-2015) and CISS (years 2017-2019) databases were queried. 1433 cases of AIS2+ injury matched the query criteria, of which 196 (13.6%) cases were AIS2+ ankle injuries.

To further study injury patterns of the distal tibia and fibula, the CIREN database (years 2017-2022) was queried. 143 cases of AIS2+ distal tibia or fibula injury were identified.

To replicate the target fracture types experimentally, isolated tibiae and fibulae from 20 PMHS (10 male, 10 female, no matched pairs) will be tested.

ANALYSIS & DISCUSSION

This study resulted in a unique experimental setup designed to collect force and moment tolerance data with isolated tibia and fibula from male and female post-mortem human specimens. This unique approach will help to collect data necessary for the development and validation of computational models to further enhance understanding of the different ankle injury rates for males and females observes in crash data.

CONCLUSION

The implementation of the proposed methodology complements existing lower extremity experimental data in understanding the tolerance of the human ankle to injury [3][4]. Specifically, the data may be used to develop injury risk functions for localized ankle injury to enhance tissue-level injury prediction with human body models.

NOVELTY/TRAFFIC SAFEY IMPLICATIONS

AIS2+ ankle fractures represent a notable portion of all AIS2+ injuries. The inclusion of the local injury tolerances provided from this study may allow for enhancement of tissue-level injury prediction with human body models for use in the design and implementation of injury prevention countermeasures. This local injury tolerance information will also aid in the prediction of distal tibia and fibula fractures in other scenarios where ankle injury is of concern (e.g., sports and occupational safety).

ACKNOWLEDGEMENTS

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Injury Patterns in Motor Vehicle Collision-Youth Pedestrian Deaths

INTRODUCTION

In the United States, there were 6,634 youth (15 – 24 years) killed in 2020 in motor vehicle collisions (MVCs), and 8.9% (n=590) were pedestrians [1]. Road traffic injuries involving youth is recognized as a major health and safety issue also in Canada and around the world [2–4]. From 1999 to 2019, 11,418 youth pedestrians were fatally injured in Canada [5].

Medical literature focused on MVC – youth pedestrian fatal injury patterns based on postmortem data is sparse [6] even though the increasing shift to trauma as a cause of death in this age group is well recognized [4]. In 1965, "The Fatal Triad" of skull-pelvic-extremity fractures was described by Farley who observed that only a ¼ of his series of injured patients survived [7].

Compared to adults, youth pedestrians can be less aware of the potential risk of injury because they lack cognitive maturity and acquired appropriate behavior [8–13]. Risk-taking behaviors such as crossing without the right of way, checking traffic and jay-walking are higher for youth pedestrians [13]. Teenagers particularly are most at-risk [14].

The present study aimed to describe fatal youth pedestrian injury patterns and correlate them with MVC characteristics and pedestrian kinematics using data from medicolegal death investigations of MVCs occurring in the current Canadian motor vehicle (MV) fleet.

METHODS

Based on a systematic literature review [6], MVC-pedestrian injuries were collated in an Injury Data Collection Form (IDCF). The IDCF was coded using the Abbreviated Injury Scale (AIS) 2015 revision [15]. The AIS of the most frequent severe injury was noted for individual body regions. The Maximum AIS (MAIS) was used to define the most severe injury to the body overall and by body regions (MAISBR). This study focused on serious to maximal injuries (AIS 3–6), that had an increasing likelihood of causing death.

The study was approved by the Western University Health Science Research Ethics Board (Project ID: 113440; Lawson Health Research Institute approval number: R-19-066).

DATA SOURCES

The IDCF was used to extract collision and injury data from the Office of the Chief Coroner for Ontario (OCCO) database of postmortem examinations done at the Provincial Forensic Pathology Unit (PFPU) in Toronto, Canada and other provincial facilities between 2013 - 2019. Injury data was correlated with data about the MVs, and MV dynamics and pedestrian kinematics.

RESULTS

There were 88 cases: 54 (61.4%) males and 34 (38.6%) females. Youth pedestrians comprised 13.1% (88/670) of all autopsied pedestrians.

Cars (n=25/88, 28.4%) were the most frequent type of vehicle in single vehicle impacts, but collectively vehicles with high hood edges (i.e., greater distance between the ground and hood edge) were in the majority: SUV (n=16/88, 18.2%), pickup truck (n=15/88, 17.1%), heavy truck (n=11/88, 12.5%), minivan (n=8/88, 9.1%), van (n=4/88, 4.6%), and bus (n=1/88, 1.1%). In 6 cases (6.8%), multiple vehicles were involved. The vehicle type striking the youth was unknown in 2 cases. Vehicle model years ranged from 1997 to 2018.

Forward projection (n=34/88, 38.6%) was the most frequent type of pedestrian kinematics followed by wrap (n=21/88, 23.9%), roof vault (n=15/88, 17.1%), fender vault (n=2/88, 2.3%), sideswipe (n=2/88, 2.3%), and side impact projection (n=1/88, 1.1%).

The pedestrians were known to be either struck/not run-over (n=57/88, 64.7%), or struck/run-over (n=27/88, 30.7%). In all the struck/not run-over cases, impact speeds ranged from 50 km/h to 162 km/h [median (IQR) speed 80 km/h]. Of these, 51 (89.5%) resulted from forward-moving vehicles; 6 (10.5%) vehicles lost control. Over one-third (n=10/27) of the confirmed run-over cases (n= 27/88, 30.7%) occurred at low speed [≤30km/h, median (IQR) speed 15 km/h]. The remaining 17/27 cases occurred at speeds ≥35 km/h [median (IQR) speed 70 km/h].

The following frequencies of overall injuries (AIS 1–AIS 6), and the most frequent serious injury based on AIS ≥ 3 for each body region were observed:

•Craniocerebral injury: 84/88 (95.5%) - 23/84 (27.4%) AIS 6, 21/84 (25%) AIS 5. Most AIS 6 injuries – brainstem lacerations (n=16/23, 69.6%); 9/21 (42.9%) AIS 5 injuries – brainstem injuries (hemorrhage/contusion/infarction/compression). Skull fractures – 18/84 (21.4%). Intracranial hemorrhages – 17/84 (20.2%).

•Face injury: 81/88 (91.1%) – 3/81 (3.7%) AIS 4 crush injury (n=2); Le Fort III fracture with blood loss (n=1); 2 (2.5%) AIS 3 injuries [Le Fort III fracture (n=1); pan-facial fracture (n=1)].

•Neck injury: 49/88 (55.7%) - 9/49 (18.4%) AIS 6, all spinal cord trauma (C3 or above). One AIS 5 injury – spinal cord transection/C5 fracture. Three (6.1%) AIS 4 injuries – 2 tracheal transections; 1 common carotid artery laceration. Of 9 (18.4%) AIS 3 injuries – 6 atlanto-occipital fracture/dislocations, 1 odontoid fracture, 1 atlanto-axial dislocation, 1 thyroid cartilage fracture.

•Thorax injury: 85/88 (96.6%) - 18/85 (21.2%) AIS 6 injuries – 14/18 (77.8%) thoracic aorta; 11/85 (12.9%) AIS 5 injuries – pulmonary laceration (n=5), rib cage shattered/flail (n=3), pulmonary artery laceration (n=2), spinal cord injury/fracture (n=1). Twenty-four (28.2%) AIS 4 injuries – 16/24 (66.7%) pulmonary contusion or lacerations.

•Upper extremity: 84/88 (95.5%) - 1/84 (1.2%) AIS 4 i.e., amputation; 1 (1.2%) AIS 3 (compound radius and ulna fracture).

•Abdomen/retroperitoneum injury: 73/88 (82.9%) - 18/73 (24.7%) AIS 4 injuries of liver, spleen, kidney, colon, or inferior vena cava; 11/73 (15.1%) AIS 5 injuries of liver, spleen, or kidney; 4/73 (5.5%) AIS 6 injuries, all liver avulsions.

•Pelvic injury: 65/88 (73.9%) - pelvic fractures [4 (6.2%) AIS 5; 8 (12.3%) AIS 4 ; 6 (9.2%) AIS 3].

•Lower extremity injury: 83/88 (94.3%) – 1 (1.2%) AIS 4 injury (amputation); 24 (28.9%) AIS 3 injuries [fractures of femur (n=19), tibia (n=4, all compound fractures) or both (n=1)].

The median MAIS and ISS for the 57 pedestrians, struck/not run-over and the 27, struck/run-over, were 6 (IQR) and 75 (IQR), respectively. In 80 cases where the impact zone was frontal (center, right, left, not specified), the median MAIS and ISS were 6 (IQR) and 75 (IQR), respectively. For the 2 cases where the vehicle was backing up, the median MAIS and ISS was 5.5 (IQR) and 55 (IQR), respectively. For the 4 cases where the pedestrians were lying down and struck by the undercarriage of the vehicle, the median MAIS and ISS was 5.5 (IQR) and 55 (IQR), respectively. For the remaining 2 cases where the pedestrians were struck by the wheels of moving vehicles (front-1, front/rear-1), the median MAIS and ISS was 5.5 and 66, respectively.

Regardless of the type of vehicle, there was a tendency in the large majority of cases for the median MAISBR≥3 to involve the head and thorax. A similar trend was seen in the majority of the pedestrian kinematics involving the various frontal impacts.

Of the 88 cases, at least 63 (71.6%) were known to be engaged in risk-taking behaviours (e.g., activity on roadway). At least 11 deaths were non-accidental (7 suicides, 4 homicides, 1 altercation). Some activities may have been impairment-related, as 26/63 (41.3%) pedestrians undertaking risk-taking behaviour on the roadway were impaired.

Toxicological analyses revealed that over half of the cases (47/88, 53.4%) tested positive for a drug or drugs which could have affected their behaviour. Ethanol was the most common drug. Thirty-one had positive blood results. The median blood ethanol concentration was 175 mg/100ml (range 16 – 388 mg/100ml).

DISCUSSION

The present paper focuses on MVC-youth pedestrian injury patterns and correlates them with MVC dynamics and pedestrian kinematics.

The majority of the fatalities were caused by impacts from vehicles with higher hood edges compared to cars. The most frequent kinematic trajectory was forward projection. Except for ten run-over victims, all the victims were killed by vehicles travelling ≥ 35 km/h. Regardless of the type of vehicle and frontal impact kinematics, median MAISBR ≥3 head and thorax injuries characterized a fatal dyad. Compared to our previous study of pediatric cases [16] intracranial hemorrhages (19.3%) were more frequent in youth. Aortic injury was seen in the youth fatalities and in children 11-14 years in contrast to children (0 – 10 years) who did not have aortic trauma [16].

Children and youth pedestrians have a higher risk of involvement with MVCs due to their limited developmental capacity to perceive road and traffic threats [17]. Our results found nearly three-quarter of youth engaged in risk-taking behaviour on the roadway at the time of the crash. Alcohol and other drugs enhance the risk of injury [18]. In this study, we found that over half the individuals had evidence of drug use, particularly ethanol.

CONCLUSION

Head and thorax injuries were a fatal dyad in the youth pedestrians in this study.

Vehicles with high hood edges were involved in the majority of cases.

Most deaths occurred from frontal collisions and at speeds more than 35 km/h.

Risk-taking behaviours on the roadway accounted for nearly ¾ of fatalities. Alcohol and other drugs were found in over ½ of cases.

NOVELTY/TRAFFIC SAFEY IMPLICATIONS

1. Identification of an MVC-pedestrian fatal injury pattern ("dyad") for youth pedestrians aged 15 – 24 years.

2. Correlation of current types of vehicles in the North American fleet with injury patterns and potential for MVC reconstruction.

3. Determination that risk-taking behaviours and alcohol/drug consumption were significant factors in the fatalities studied.

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Redesigning an Anthropomorphic Test Device (ATD) Lumbar Spine to Better Model 'Submarining' in Motor Vehicle Crashes

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INTRODUCTION

Automobile crash injuries are a major cause of death and disability among children in most of developed countries and abdominal injuries are one common type of injury (Ben Beck, Brown, & Bilston, 2011; B. Beck, et al., 2011). The abdomen is the second most vulnerable body region (B. Beck, et al., 2011). In frontal car crashes, abdominal injuries are commonly attributed to *seat belt syndrome* (B. Beck, et al., 2011), where abdominal and lumbar spine injuries are caused by lap belt loading of the anterior abdomen (B. Beck, et al., 2011). Seat belt syndrome often occurs in conjunction with *submarining* (B. Beck, et al., 2011) and older children and small occupants are particularly vulnerable to submarining. Submarining occurs when the pelvis rotates under the lap belt, and seat belt webbing penetrates the abdomen and loads the intra-abdominal organs (B. Beck, et al., 2011). However, the *Hybrid III 5th percentile female anthropomorphic test device (ATD)* is unable to accurately mimic submarining and assess the risk of abdominal injury in frontal car crash tests because of the unbiofidelically high stiffness of the lumbar spine element (Benjamin Beck, Brown, & Bilston, 2014; Demetropoulos, 1999).

RESEARCH OBJECTIVE

This study aimed to develop a more biofidelic lumbar spine element for the Hybrid III 5th percentile female ATD to more accurately mimic submarining in frontal car crash tests.

METHODS

Lumbar spine prototype design development

The target stiffness (in N.m/degree) corridor of the redesigned lumbar spine element was based on cadaver lumbar spine experimental data (Demetropoulos, 1999) scaled to the 5th percentile female ATD, following the scaling procedure of the National Highway Traffic Safety Administration (Lee, 2020)**.** A 3D CAD model of the lumbar spine prototype was developed in Ansys LS-DYNA software for in silico evaluation of design prototypes through an iterative design process regarding the geometry and materials. Boundary conditions were matched to the cadaveric tests, and material properties for rubber components were based on mechanical testing to *ASTM D412-16* of rubber samples. The final prototype design mechanical response was within the target stiffness corridor.

Manufacturing and quasi-static testing of the lumbar spine prototype

Steel mold and and Aluminium and Steel components of the prototype were manufactured by Computer Numerical Control (CNC) machine and Electrical Discharge Machining (EDM), to which Natural rubber $60° \pm 5°$ shore A components were molded using a compression molding process. Quasi-static compressive and bending tests of the whole prototype at the 5, 10, 20, 30, and 40mm/min and 1.9, 3.7, 7.5, 11.3, and 15.1 degree/min were conducted respectively to assess the protoype strength and repeatability prior to dynamic testing. Low sensitivity to the strain rate demonstrated that mechanical behavior of the prototype is repeatable under similar test conditions. Importantly, there was no damage or permanent deformation to the prototype, indicating that the lumbar spine prototype potentially has an acceptable level of durability to proceed to dynamic testing.

Sled tests

Frontal impact sled tests were conducted at 24 g and ΔV=46 km/h on a deceleration sled with the Hybrid III 5th percentile female ATD using the original lumbar spine element and lumbar spine prototype. A semi rigid seat was used in these tests. The seat pan and seat back of the seat were angled at 5.5° and 110° from horizontal, respectively. Pre-impact pelvis angle of ATD for all tests measured 16° from horizontal. Two tests were performed in each condition. *Standard seat belt* was considered as a baseline condition, in which the lap and shoulder portion of 3-point seat belt were tightly placed below the Anterior Superior Iliac Spine (ASIS) and middle of chest and shoulder, respectively. In addition, three seat belt configurations were selected to specially vary the degree of submarining.

These configurations were used for sled tests replicating the conditions used by Rouhana et al. (Rouhana, 1990) : **1.** *no submarining*, where the lap belt was tightly placed below the ASIS of pelvis and 76mm slack was introduced into the shoulder belt; **2.** *pre-submarining*, where the lap belt was placed above the ASIS points of pelvis and was contacted abdomen and the shoulder belt was properly secured on shoulder; and **3.** *dynamic submarining*, where the lap belt was placed in an appropriate position below the ASIS of the pelvis, but with 76mm slack and the shoulder belt was tightly placed on shoulder. The ATD was seated in an upright posture and its measurements were recorded for the head center of gravity acceleration, chest acceleration, lumbar spine forces and moments and sternal deflection. All data was acquired and filtered in accordance with SAE J211. Dummy and restraint motion were captured using a high-speed digital camera, to determine whether or not the lap belt moved up into the abdomen during testing, and also to measure femur excursion and pelvis rotation.

RESULTS

The *pre-impact position* of the lap and shoulder portion of 3-point seat belt played a significant role on submarining. In the configuration of standard seat belt, femur excursion and pelvic rotation were significantly similar for both lumbar spines and no visible submarining was observed on the high speed video. For all three of the other configurations, the lumbar spine prototype resulted in greater femur excursion and greater pelvis rotation, although this difference was small in the pre-submarining configuration *(see Figure 1)*. The middle trunk (pelvis) and upper trunk (chest) of the ATD with original lumbar spine rebounded (clockwise rotation) sooner than the ATD with the new prototype spine. In the dynamic submarining configuration, the *ATD with lumbar spine prototype* demonstrated that the lap belt portion of 3-point seat belt slid up on the ASIS of the pelvis and penetrated into the abdomen, as shown in *Figure 2*. Dynamically, in the dynamic submarining configuration, lap belt force traces during submarining had a fluctuation at the peak force for the ATD with lumbar spine prototype. The ATD with the original lumbar spine did not demonstrate this behavior, with the lap belt portion of 3-point seat belt remaining on the ASIS points of the pelvis, as shown in *Figure 3*. Except for the No submarining configuration, the average resultant lumbar spine force and chest deflection was larger for the ATD with the lumbar spine prototype compared to the ATD with the original lumbar spine.

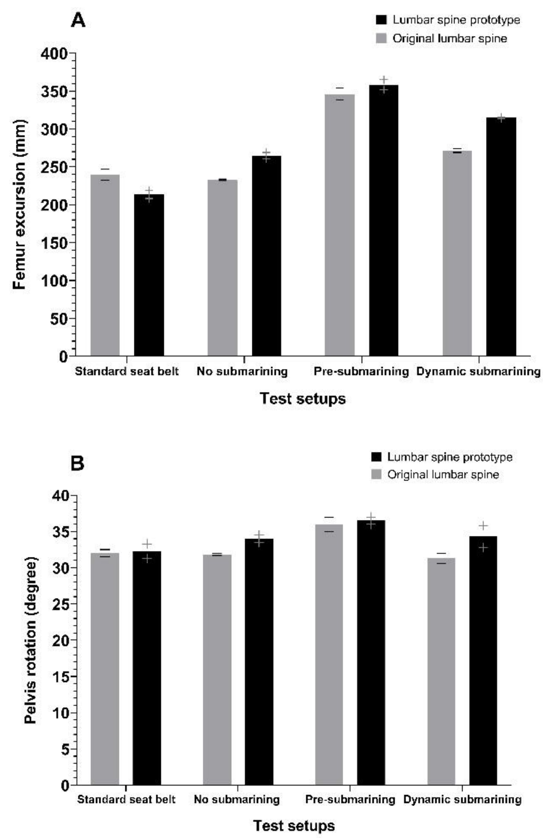

Figure 1: Average femur excursion (A) and Pelvis rotation (B) with the original lumbar spine (gray bars) and lumbar spine prototype (black bars) in frontal sled tests. Individual test data are shown as symbols on the bars.

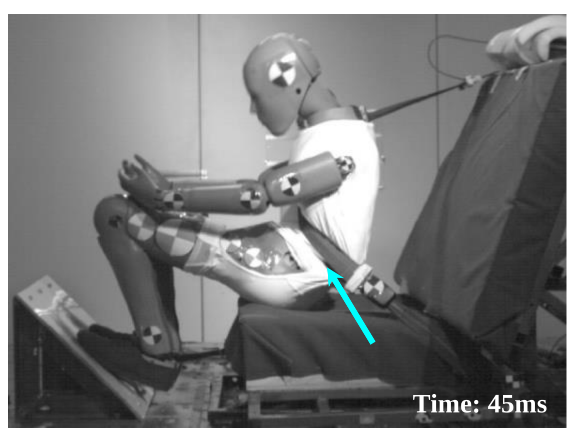

Figure 2: Still images of maximum knee excursion with lumbar spine prototype in the dynamic submarining test.

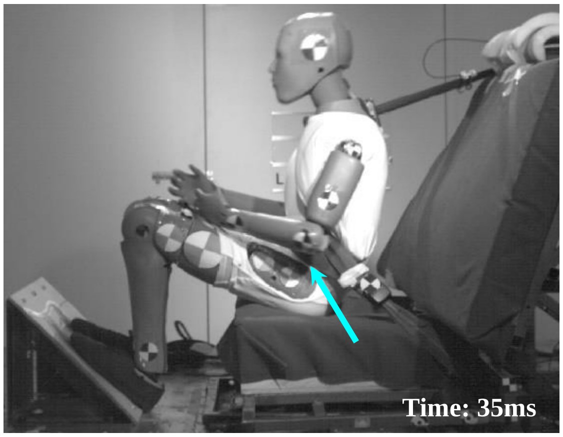

Figure 3: Still images of maximum knee excursion with original lumbar spine element in the dynamic submarining test

DISCUSSION

Previous studies have shown that the standard Hybrid III 5th percentile female ATD is unable to accurately mimic submarining due to the high stiffness of lumbar spine element, and is thus poor at assessing the risk of abdominal injury due to submarining (Demetropoulos, 1999). Results from computer simulation and dynamic tests of a new prototype lumbar spine element show that a more flexible lumbar spine that more closely matches the behaviour of the human spine and submarines more appropriately can be achieved without redesigning other parts of the ATD. It therefore has potential to more accurately assess submarining-related injury. While this study shows an acceptable level of biofidelity for the lumbar spine prototype for submarining injury risk analysis, further work is required to validate this lumbar spine element in other test series, with other crash test dummies, and at other test speeds.

CONCLUSION

The data collected from this study suggests that the prototype of lumbar spine is more flexible than the standard lumbar spine in the Hybrid III 5th percentile female ATD, and mimics submarining under loading conditions where submarining would be expected, but when submarining does not occur with the standard spine element.

NOVELTY/TRAFFIC SAFEY IMPLICATIONS

This new lumbar spine element may be useful for evaluating the risk of submarining, injuries related to submarining, and performance of anti-submarining vehicle design features.

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Using Real-World Crash Data to Predict the Number of Occupant Rib Fractures

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INTRODUCTION

From 2010 to 2016, the National Trauma Data Bank conducted a study of patients who suffered one or more traumatic rib fractures, and out of the 564,798 patients, 95% had blunt chest injury caused by motor vehicle crashes [1]. Occupant factors, such as age, seat restraints used, and obesity, have the potential to vary the likelihood of rib fracture [2]. However, to successfully achieve a confident prediction of rib fracture(s) in future crashes, it is necessary to create a model with previous real-world crash data to understand how certain occupant factors contribute to rib fractures.

RESEARCH QUESTION/ OBJECTIVE

The purpose of this study was to estimate potential rib fracture(s) of occupants in passenger vehicles, using a multinominal logistic regression model and real-world crash data.

METHODS

Case Selection

Real-world crash data was obtained from the Crash Investigation Sampling System (CISS), a national representative of probability sample of US tow-away passenger vehicles [3]. This study used crashes from case years 2017 to 2021. CISS contains detailed occupant injury information including which rib, if any, were fractured. The cases looked at were frontal crashes with a driver and a right front passenger. The occupants had to be at least 14 years old to be eligible for selection. The vehicles also needed to have an EDR, Event Data Recorder, to collect the appropriate delta-v. To be eligible for the study, cases could not have any missing values across demographics, belt use, seat position, and delta-v.

Model Development

The data frame was designed to group the total number of ribs fractured with each occupant. For this study the groups were 0, 1–2, 3–4, or 5+ rib fractures. Then a baseline was made to analyze the difference between different factors. A multinominal logistic regression model was created to analyze the differences of factors to show the regression model outputs based on the data from CISS. In R code, the function "multinom" took the weight of each case into account when producing a model.

$$\begin{aligned}\ln\left(\frac{P_x}{P_{0\ ribs}}\right) = \beta_0 + \beta_1(Delta - V) \\ + \beta_2(Belt\ Use) \\ + \beta_3(Obesity) \\ + \beta_4(Driver) \\ + \beta_5(Male) \\ + \beta_6(Airbag\ Deploy) \\ + \beta_7(Age > 65)\end{aligned} \tag{1}$$

To take into account of the coefficient of each variable, Equation 1 was designed to predict the probability of rib fractures. The equation takes the researched determined baseline and multiplies it by the different coefficient computed by the R code to give a probability for each range of fractured ribs. The model was trained with 90% of the data, and the remaining 10% was reserved as a test dataset.

Table 1. Number of cases that suffered rib fracture(s) compared to the total of crashes.

	Case Count	Weighted Case Count
0 Rib Fractures	2,776	1,708,821
1-2 Rib Fractures	50	10,145
3-4 Rib Fractures	45	15,146
5+ Rib Fractures	54	18,201
Total	2,925	1,752,312

RESULTS

A multinominal logistic regression model was used to create Figures 1-3 below. To analyze the effects of different occupant factors, a baseline was needed to compare the differences. For the baseline, the following factors were chosen to get a standard for the data. The baseline is a driver that is a male, who is younger than 65 years old, belted, is not obese (BMI < 30.0) [4], and had the airbags not deployed during the crash. The baseline was determined to be the parameters least likely to have a rib. The computed model accuracy was 94.57% among the trained dataset.

Table 2. Researcher determined baseline parameters. (*) Indicates parameter conditions resulting in the lowest likelihood of sustaining any rib fracture.

	If Value = 0	If Value = 1
Belt Use	Belted*	Not Belted
Role	Driver*	Passenger
Obese (BMI > 30)	Not Obese*	Obese
Airbag Deployment	Not Deployed*	Deployed
Age	< 65*	≥ 65
Sex	Male*	Female

Table 3. Coefficients of all researchers determined variables of predicting rib fractures. (*) Indicates statistical significance $p < 0.05$.

	1-2 Ribs	3-4 Ribs	5+ Ribs
Intercept	-8.619*	-9.972*	-11.446*
Delta-V	0.058*	0.061*	0.065*
No Belt Used	0.032	1.678*	1.722*
Passenger	0.291*	1.337*	1.085*
Obese (BMI > 30)	0.797*	0.695*	1.139*
Airbag Deployment	1.651*	1.113*	2.786*
Age ≥ 65	1.513*	3.989*	3.713*
Female	-0.126*	0.147*	0.174*

The occupant belt status had a positive coefficient, which indicates that an unbelted occupant would likely have a higher the probability of any rib fracture and more rib fractures. As for occupant sex, the probability of fracturing 1–2 ribs were higher for males than females. However, fracturing 3-5+ ribs was more likely among females than males.

Figure 1 represents the solid baseline and the isolated factor, in this case, obesity how this affects the possibility of rib facture. Furthermore, when contributing obesity into the established baseline, the probability of rib fractures had a direct relationship with each other. The probability of fracturing 0 ribs decreased with the increased delta-v and an increase to all ranges, with 1–2 ribs having the greatest increase. There was little change to each rib range based on the delta-v alone because other factors such as age have a much stronger effect.

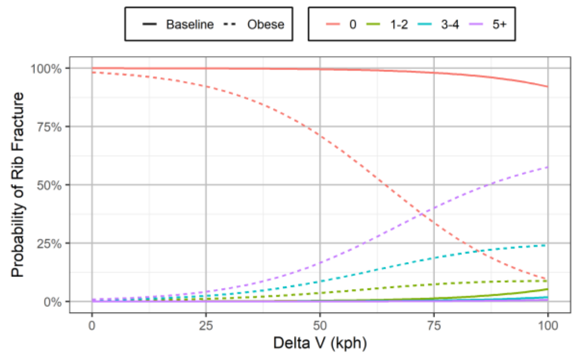

Figure 1. Observing baseline and the effects of obesity on rib fractures.

Figure 2 represents the solid baseline and visualizing how age could impact a rib fracture. The probability of fracturing 0 ribs in the < 65-year-old population was high and rapidly decreased as delta-v increases because the probability of rib fracture equates to 1. Occupants over 65 years old, shown in Figure 2, had an overall greater chance of multiple rib fracture than the baseline as delta-v increased. As delta-v increased, the probability of fracturing 5+ ribs increased at a higher delta-v compared to 1–2 ribs. The potential to fracture more than 5 ribs was much higher than the other ranges due to older occupants being more susceptible to injury because of their age. The probability of 5+ rib fractures was rather low because the occupants were using the first line of safety, a seat belt.

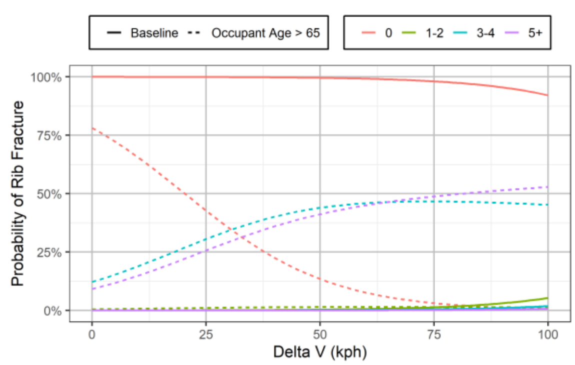

Figure 2. Observing baseline and the effects of older age on rib fractures.

Figure 3 represents the baseline, and how being unbelted could affect the probability of rib fracture. Restrained occupants had a much lower likelihood of fracturing 3–4 ribs. When observing the dotted line of unbelted occupants, the probability of fracturing 1–2 rib was relatively the same as delta-v increases. In contrast, the probability of fracturing 5+ ribs increased rapidly with delta-v among unbelted occupants. Not having the primary restraint increased the probability as delta-v increased and after 60 kph the probability of fracturing 5+ rib steeply increased.

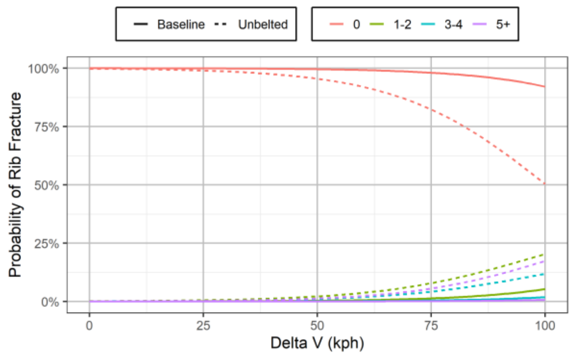

Figure 3. Observing baseline and the effects of unbelted occupants on rib fractures.

DISCUSSION

For this study, the model and variables were a great foundation for estimating rib fractures using real-world crash data. Rib fractures often occur along the loading path of the seatbelt when an occupant is buckled. This study showed that wearing a seatbelt, although having risk of rib fracture, still shows lowered risk of rib fracture compared to unbelted occupants. Improvements to consider for this study is to look at other occupants, like passengers in the rear seat. This would allow for potentially a larger case population and allow for the rib fracture protection contribution of belts to be isolated from frontal airbags. Also, looking at previous model years for this study would allow researchers to quantify the benefit of restraint improvements such as pretensioners and load limiters on rib fractures.

Two limitations of this study were that the overall restraint system and the occupant compartment architecture was not taken into full consideration. The study only looked at whether the occupant was wearing a seat restraint or if the occupant was the driver or passenger. Future work would have to look at the different types of seat restraints and the orientation of the occupant's seat or steering wheel and how they could affect rib fractures.

CONCLUSION

The model used over 2,925 total real-world crash data including 149 crashes that had one or more rib fractures. Factors like age and seat restraint used played a large role when predicting whether a rib fracture could occur. This study has shown a model that can be a good predictor of fracturing ribs during crash scenarios because the model validated the data and achieved a 91.13% accuracy. Lastly, this study has shown that wearing a seat restraint is first line of protection for rib fractures and occupants are encouraged to wear seat restraints.

NOVELTY/TRAFFIC SAFEY IMPLICATIONS

This study is the first study to use real-world crash data to predict the number of rib fractures an occupant may sustain in a frontal crash based on the crash delta-v, safety systems, and occupant demographics.

ACKNOWLEDGEMENTS

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Acoustic Characterization of Vehicle-Pedestrian impact

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INTRODUCTION

Accident Reconstruction has always been dependent on vehicle speed calculations.[1] In vehicle-pedestrian collision reconstruction, many of the proposed methods for speed calculations depend heavily on the throw distance of the pedestrian. However, for most vehicle-pedestrian collisions, the first point of impact between the vehicle and the pedestrian cannot be determined reliably. Modern vehicles record dynamic data from several on-board sensors for events that precede a crash. This data can be used to reconstruct the behavior of a vehicle prior to collision with a pedestrian, but the accuracy of these reconstructions has not yet been quantified.[1,2] For example, the major difficulty is that when a pedestrian hits the ground, the motion is extremely unpredictable and even a tiny change in the parameters while computer modelling of the crash could result in a major change in the outputs.[2] Hence, relying on just a single form of analysis based on speed calculations is not ideal.

The hypothesis being tested and presented in this paper is whether the audio captured from vehicle-pedestrian impacts could be used to characterize the events of the impact. Hence, multiple impact sound analysis conducted for door slams[3] and gunshots[5] were studied to formulate a research background for better understanding of vehicle-pedestrian impact sound.

There is increasing interest in urban soundscapes and analysis of general background sound in cities. Acoustic characterization of impacts within urban soundscapes can provide valuable information about collisions and could be of help to forensic engineers.

This study joins a separate recent study by Vega et al. to show that audio information can be associated with speed and specific crash events.[6]

RESEARCH QUESTION/ OBJECTIVE

• Is there any evidence leading to correlations between level vs. time analysis of audio files for impacts and events recorded via video before, during and post impact?

• What features of level vs. time and spectrograph analysis of audio signals from the collisions correlate to collision parameters.

METHODS

This study evaluated various methods of reconstructing the vehicle kinematics in vehicle-pedestrian impacts for three different vehicles – 2003 Pontiac Vibe, 2005 Mercury Montego and 2009 Jeep Patriot based on video analysis. The test dummy a.k.a. Anthropomorphic Test Device (ATD) was stationary, and the vehicles were made to impact them at speeds varying between 25-40 mph (40-64 km/h) in nine different impacts tests, for three tests per vehicle. For each vehicle, a frontal impact offset on the driver's side, passenger's side and a central region impact were conducted. After each test, the ATD was checked for damage along with photographing the scene of the crash for debris. The vehicle was equipped with a tape switch to identify the time of impact which was then used for video and audio analysis purposes.

The vehicle speed at impact was recorded by the Vericom VC4000, an onboard GoPro Hero Black8 as well as multiple GoPro Hero Black8 placed along the North and South side of the road. An aggregate of these speed outputs was used to define the impact speed of the vehicle with the ATD. An unmanned aerial vehicle (UAV) was also used to record the arial view of the impact.

A total of 14 GoPro Hero8 cameras were used to record the crash and the scene after the impact. Video analysis was conducted on these video files using Kinovea (open source: kinovea.com) to verify the speed of impact and to determine the ATD trajectory post impact, angle of projection, maximum height of ATD center of gravity (COG), ATD throw distance. Pedestrian Drag Factor calculations were conducted before and after running all tests by conducting multiple drop tests from a moving vehicle.[1,6]

Audio files (MP3) sampled at 44.1kHz, were extracted from the GoPro recording, converted to WAV, then imported to the ArtemiS Suite software (HEAD Acoustics GmhB, Germany) for 1/3rd spectrogram analysis. Audio files were recorded by multiple GoPro Hero8 cameras. However, for analysis purposes, the audio files from one of the cameras recording the impact was utilized to find corresponding data correlations between the audio and video files based on sound pressure level (SPL) vs. time, spectrogram analysis and level decay over time. Event times in the crash videos were matched to times in the sound spectrogram.

A comprehensive analysis and comparison of the audio recording capabilities between GoPro Hero8, a free field microphone and a binaural head have also been conducted to better understand the directivity of stereo audio recordings made by the GoPro Hero 8 during these tests.

DATA SOURCES

Data utilized for vehicle speed and acceleration calculations was collected using the Vericom VC4000 (Vericom LLC, Minn, USA). ATD speed and trajectory calculations were done using the video recorded by multiple GoPro Hero8 cameras.

The audio files used for various audio analysis were recorded by multiple GoPro Hero8 cameras as well.

RESULTS

While not the focus of the current manuscript, the vehicle speeds were obtained prior to analysis of the audio data, including any pre-impact braking effects and impact speeds for the crashes examined in this manuscript. The reporting of these video speed analysis results is a portion of this project that is currently in progress.

Audio files from nine different configurations of vehicle and pedestrian impact were analyzed and compared against each other. The import into ArtemiS Suite assigns a rough estimate of sensitivity, but the GoPro camera was not calibrated. Further, the GoPro Hero8 audio recording function has some sort of automatic level control algorithm that adapts the audio amplitude. Hence, the sensitivity is not constant. Therefore, any results for sound pressure level could only be compared within short time spans when the levels were consistent. Spectrogram analysis, on the other hand, was able to provide a much better insight to help correlate events from the impact video to the audio files. The results, featuring the 1/3rd octave spectrogram from one of the nine tests conducted, have been explained in detail below.

Exemplar Crash Event/Acoustic Correlation

For the vehicle-pedestrian impact discussed below, the test was conducted using a 2005 Mercury Montego at 40 mph and the vehicle braked approximately 5 feet before impact. The ABS was not functioning for this vehicle and the impact occurred at the center of the vehicle. The moment of impact was considered to be a reference point for correlating the events from the audio and video files.

A 1/3rd Octave spectrogram analysis was conducted on the impact audio recorded (Figure 1.1) and the interpretations are listed below.

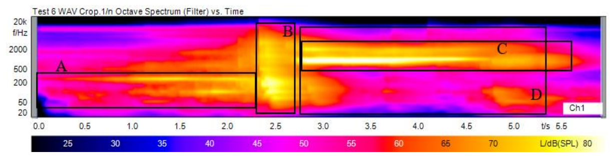

Figure 1.1: 1/3rd Octave Spectrogram

In Figure 1.1, the vertical axis represents band frequency, effectively a log frequency scale while the horizontal axis is time scaling from zero to roughly five seconds. The color map gives uncalibrated sound pressure level in dB. In region marked A, it is seen that there is a relatively higher SPL at lower frequencies, below 500 Hz, during the 2 seconds prior to the impact. The dominant frequency is the sound of the vehicle engine being recorded as the vehicle is moving towards the dummy. The associated precrash event region is depicted by Figure 1.2 below.

Figure 1.2: Vehicle Motion pre-impact.

In region marked B, there is a high SPL recorded over a broad range of frequencies (bright yellow vertical band). This region represents the point of impact between the vehicle and the pedestrian as shown in

Figure 1.3: Vehicle- Pedestrian Impact

Figure 1.3. The sudden bright yellow region is an indication of a high amplitude sound being generated from the impact.

Region C marked on Figure 1.1 features two narrow bands of high frequency sound just below and just above 2000 Hz, extending over nearly two seconds. This is because the ABS for the vehicle was non-functional, and the tires had locked up while the vehicle was in a pure skid motion. This developed a screeching sound in the higher frequency range. In region marked D, there are several occurrences of high SPL in short intervals. This represents the secondary and tertiary impacts between the vehicle and the pedestrian as well as all the impacts between the items and the ground as shown in Figure 1.4.

Figure 1.4: Vehicle – Pedestrian Post impact

DISCUSSION

From this study, the operational capacity of the vehicle ABS was verified. Pedestrian impact for all cases investigated was characterized by a vertical region of high SPL, with braking observed as a high SPL streak at high frequency. The duration of impact and the timestamp (relative to the moment of impact) when the vehicle brakes were engaged could also be determined using the audio analysis.

The location of the impact with the pedestrian did not have any correlation with the spectrogram analysis. However, the spectrogram did output a higher SPL in the range of 50Hz – 500Hz for most engine noise in all the tests while a high SPL was recorded in the range of 2000 Hz only when the brakes were engaged.

CONCLUSION

This study was able to qualitatively correlate the acoustic signatures from certain pre-impact, impact and post-impact events to its corresponding video. Future research should develop a method to record, analyze and provide crash event details to crash/impact to the forensic engineer and aid them to reconstruct the events of the impact.

NOVELTY/TRAFFIC SAFEY IMPLICATIONS

This research provides a background for further research using vehicle impact audio to better understand vehicle-pedestrian impacts. It also provides a new dimension to aid forensic experts and accident reconstructionists predict the event leading up to the impact and post impact analysis along with predicting the type of impact with higher accuracy.

ACKNOWLEDGEMENTS

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Advanced vehicle technologies and vehicle purchasing decisions for older Australians: a discrete choice experiment

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INTRODUCTION

In line with the "Safe Vehicles" pillar of the Safe System Approach, advanced vehicle technologies (AVTs) are a mechanism to enhance safety and are currently widely available in new cars entering the market. There have been a plethora of studies evaluating the safety benefits of AVTs: lane departure, speed and forward collision warnings, and autonomous braking systems can reduce the risk of crashing and serious injuries (Chauvel, Page, Fildes, & Lahausse, 2013; Chouinard & Lécuyer, 2011; Davis, Morris, Achtemeier, & Patzer, 2018; Fildes et al., 2015). However, the use of AVT is lower amongst drivers aged 65 years and older, compared to younger age groups. This is despite older drivers ranking "safety" as a higher priority than younger-aged drivers when looking to purchase a new car Koppel, Clark, Hoareau, Charlton, & Newstead, 2013; Vrkljan, Miller-Polgar, & systems, 2005). Older drivers tend to drive older cars (Cox & Cicchino, 2022) and little is known about how AVTs, as mechanism to improve "safety", influence vehicle choice and purchasing decisions amongst older drivers.

RESEARCH QUESTION/ OBJECTIVE

This study aims to use a discrete choice experiment (DCE) to investigate what vehicle features influence vehicle purchasing decisions in older Australian drivers, with a particular focus on AVTs.

METHODS

Older drivers (≥65 years) living in metropolitan and regional NSW, Australia completed a DCE and participant demographic questionnaire, which included the EQ-5D, either face-to-face or over the phone with research personnel. Recruitment was done by placing advertisements in senior newsletters and pinning them onto boards located within senior community centres. Social media advertisement via Facebook targeted at those aged 65 years and older were also utilized. The structure of the survey was guided by data from semi-structured interviews of 24 drivers from the same population of interest. A multinomial logit modelled, fractional factorial DCE was created using Ngene software (v1.3). Beta-coefficients were estimated for each attribute using previous literature and were revised after piloting the DCE. The final DCE was item and level balanced and had a D-efficiency score of 96.7% indicating that the design had good overall statistical power and efficiency. It has twelve choice sets, with three, independent alternatives (Vehicle 1, Vehicle 2 and Neither) for vehicles described by four attributes: Access (hip or knee height), Fuel Efficiency (poor, average or good), Cost in Australian Dollars ($30000, $35000 or $40000) and AVTs (Safety Package 1-3). Ngene software estimated a minimum sample size of 127 participants for any investigate main effects to reach statistical significance; this sample size was achieved. Statistical analyses based on a classic conditional logistic model adjusting for age and sex were run in R v4.2.2 with odds ratio (ORs) and 95% confidence intervals (Cls) reported. This base model was then extended to include *a priori* interactive terms for socio economic status (Pension Yes/No), mobility limitations (any/none) and sex (male/female) with select attributes.

DATA SOURCES

Participant answers from DCEs and participant demographic questionnaires completed either face-to-face or over the telephone with research personnel.

RESULTS

133 participants (mean age: 73.6 years; 66% males) living in NSW completed the survey. Participants significantly preferred vehicles with better "Fuel efficiency" (OR 1.57, 95%Cl 1.44-1.71) and AVT inclusions (OR 1.29, 95%Cl 1.20-1.40), and were less likely to choose more expensive vehicles (per $5000 increase; OR 0.91, 95%Cl 0.86-0.99). "Access" did not influence choice between the two vehicle options. Those on a pension were more sensitive to purchase price and running costs: twice as likely to choose a vehicle with better "fuel efficiency" and were approximately 40% less likely to choose a more expensive vehicle. There were no statistically significant differences in the AVT packages chosen between sex. Mobility issues did not significantly impact "Access" choices, though the OR was increased in participants with mobility limitations.

DISCUSSION

This study reports on what vehicle features influence purchasing decisions in older Australian drivers. The results show that older drivers, preferred cars which were more fuel efficient, had more AVTs in them and were lower in price. Drivers with a lower income, defined by receiving an aged-pension were more price sensitive. Participants' preferences for vehicles with more AVTs aligns with previous research showing older drivers to rate "safety" as a priority during time of purchase. There were, however, no differences in the AVT preferences between sex. Men have been shown to have more positive attitudes towards AVTs and are more willing to trial them when driving compared to women (Eby et al., 2018; Hulse, Xie, & Galea, 2018). Differences between sex may not have been seen in this study as there were not many female participants. It could also be that those who participated were already interested in AVTs and vehicle safety. Nonetheless, the interest towards AVTs highlights that it is useful to re-consider how these technologies are packaged and priced to make them more attainable for older adults. Newer vehicles, including those with AVTs, are a viable strategy to increase safety of older drivers.

Mobility issues did not significantly increase the odds of choosing a vehicle with a higher seat off the ground, though there were few participants with significant mobility limitations to explore this association. The lack of association is consistent with a questionnaire completed by 1013 older British drivers which found no significant differences in the difficulties between getting in and out from a small versus a large sized vehicle (Herriotts, 2005). The relationship between mobility and access height would be best investigated by future studies primarily focused on populations with mobility limitations. Difficulties with vehicle access, however, can also be due to the cabin design such as the placement of the cant rail, sill, and steering wheel. Poor seat and cabin designs make it difficult for older drivers to reach, access, find and operate controls to adjust head rest height, seat recliner, lumbar support, and steering wheel adjustments (Karali, Mansfield, & Gyi, 2017). Policies on vehicle design for older drivers should consider how the cabin is planned out to make the vehicle more accessible and comfortable for older adults and their needs.

Both price and fuel efficiency have been identified by previous studies as important features during time of purchase for older drivers (Koppel, Clark, Hoareau, Charlton, & Newstead, 2013; Zhan, Porter, Polgar, & Vrkljan, 2013). Older drivers, particularly female drivers, have been found to consume more fuel per mile in off-peak times than younger drivers due to their tendency to drive slower and have greater speed variance (Zhang, Sun, Tian, & Environment, 2020). Rising fuel prices increase the incentives to buy new vehicles which are more fuel-efficient (Langer, Miller, & Statistics, 2013). Resources about AVTs for older adults should therefore aim to increase awareness of select in-vehicle systems which can provide ways to decrease fuel consumption (Guo, Brake, Edwards, Blythe, & Fairchild, 2010). Such examples include navigation systems which provide faster route options.

CONCLUSION

Older drivers have multiple considerations which influence their preferences for a new vehicle including price, fuel efficiency and technological features like AVTs. These preferences were consistent regardless of socio-economic status. It is encouraging that this study found a preference for AVTs which offers guidance for pricing and packaging of vehicle features to meet the needs and improve safety of older drivers.

NOVELTY/TRAFFIC SAFEY IMPLICATIONS

This study uses a DCE to look at how vehicle safety features, defined only as select AVTs, is considered by older adults during their decisions to purchase a new vehicle. With the results showing an interest for AVTs, there are potential implications towards the packaging and pricing of these safety features to make them more accessible for older drivers.

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Analysis of Fatal Bicycle Crashes for Bicycle Scenario Testing

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INTRODUCTION

With the increase in bicycle use, there has been an increase in reported crashes involving bicyclists [1]. However, the crashes between cyclists and vehicles often go unreported [2]. This presents a challenge for understanding the nature of crashes that involve a bicyclist. To reduce these crashes, how these vehicle crashes with cyclists occur, the locations where these crashes occur, what causes them, etc. need to be understood.

RESEARCH QUESTION/ OBJECTIVE

The purpose of this study was to characterize fatal crashes that involved a bicyclist and propose relevant scenarios for understanding cyclist and driver behavior.

DATA SOURCES

The data used in this study was from the Fatal Analysis Reporting System. FARS includes basic crash information extracted from police reports for all fatal crashes in the US. FARS provides additional information for bicyclists and pedestrians involved in a fatal crash. For this study, only crashes involving a fatally injured cyclist were selected. The crashes were characterized by cyclist sex, cyclist age, crash type, direction of travel, and cyclist location.

RESULTS

The number of fatal bicycle crashes increased from 2014 to 2020 (Figure 1). Sex of the fatally injured bicyclists was dominated by males with 85.7% being male and only 13.9% being female (Figure 1). This is likely due to the fact that there are many more male cyclists than female cyclists [3].

Another point of interest was the age of the cyclist involved in the crash. Compared to other ages, there were relatively few cyclists under the age of 12 that were fatally injured. Compared to younger ages, cyclists between 50 and 65 years old were the most likely to be fatally injured. (Figure 2). This narrow age range likely corresponds to a lower injury tolerance compared to younger individuals coinciding with a more active population compared to older individuals.

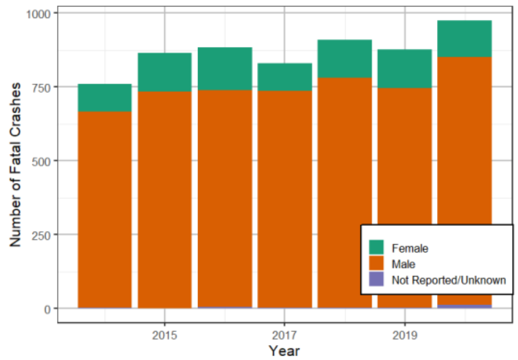

Figure 1. Number of fatal bicycle crashes from 2014 to 2020 and the sex of the cyclist involved.

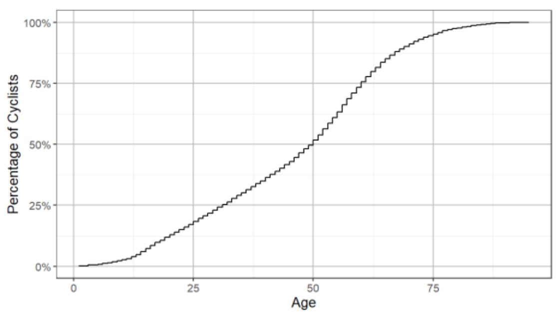

Figure 2. Age of all bicycle riders who were involved in a fatal crash.

About 65% of the crashes happened when the cyclist was traveling in the same direction as traffic. Only 16% of the crashes happened when the cyclist was traveling against traffic (Figure 3).

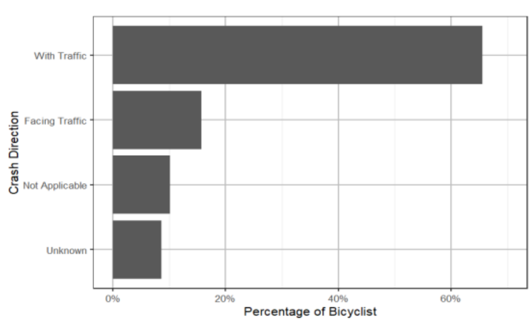

Figure 3. Direction the cyclist was traveling.

The majority (63%) of the cyclist fatal crashes did not occur at an intersection. Only 28% of the crashes occurred in an intersection and 18% occurred in an area within 50 feet from an intersection or related to the flow of traffic through an intersection (Figure 4).

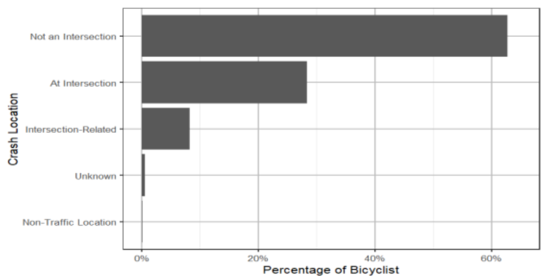

Figure 4. Location (intersection) of the fatal bicyclist crashes.

The travel lane was the location with the highest percentage of fatal crashes at 77% of the crashes, followed by sidewalk/crosswalk/driveway access at 11% and bike lane/paved shoulder/park lane at 9% (Figure 5).

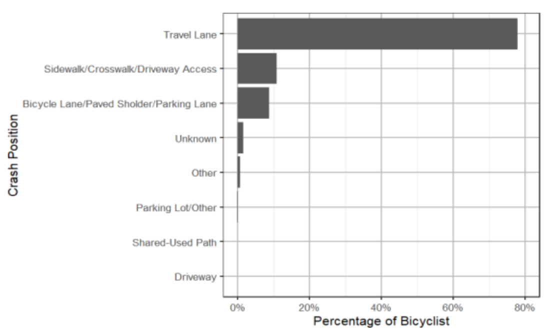

Figure 5. Location (bike lane, sidewalk, etc.) of fatal bicycle crashes.

Motorists overtaking a bicyclist was the highest cause of these fatal crashes at 30%. Overtaking is defined as approaching from behind at a faster speed and performing a passing maneuver. Then, the next leading critical factor of the fatal crashes was bicyclists failing to yield, which, when adding each of the different failures to yield, was around 20% (Figure 6-7). Of fatal bicycle crashes, 71% occurred in urban areas while only 29% occurred in rural areas (Figure 8).

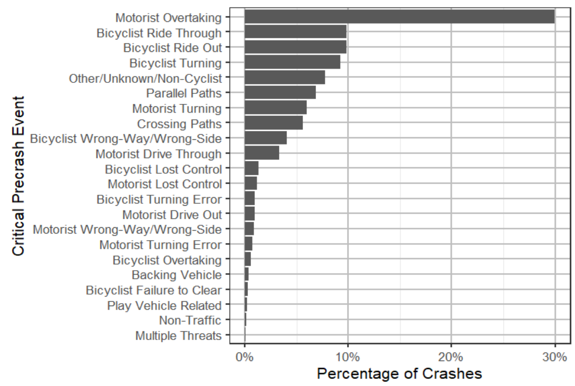

Figure 6. Type of critical bicyclist pre-crash events (Fatal Crashes).

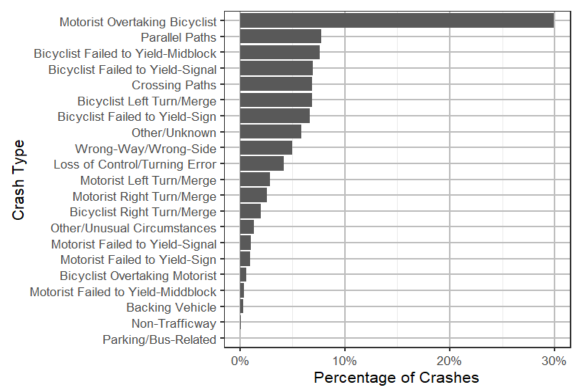

Figure 7. Bicyclist crash types (Fatal Crashes).

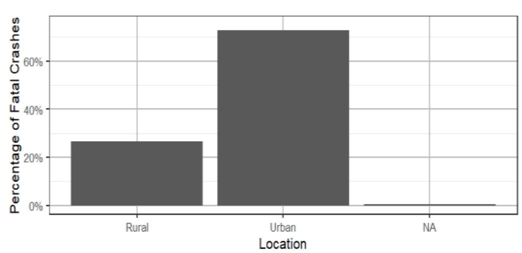

Figure 8. Fatal crashes in urban and rural areas.

DISCUSSION

From the analysis, scenarios were developed for analyzing cyclists' behavior. The first scenario will include the cyclist travelling in the same direction as traffic when not in a bicycle lane. In this scenario, there will be a vehicle, travelling 40 mph, that will perform overtaking of the cyclist as the cyclist is travelling in the direction of traffic (Figure 9). The reasoning for this scenario was motorists overtaking bicyclists was by far the largest crash type and cyclists traveling in the direction of traffic with no bike lane were also the highest for crash direction and crash position (Figure 5-7). The second scenario would be similar to the first but would include a bike lane to analyze the behavior difference due to the inclusion of a bike lane (Figure 10). The last scenario would be how cyclists would interact in an intersection (Figure 11). In this scenario the vehicle and cyclist will each travel straight crossing paths in the intersection. This is based on intersection crashes being the second most common crash location (Figure 4).

Figure 9. The cyclist travelling in the same direction as traffic, and not given a bicycle lane.

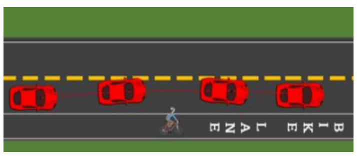

Figure 10. The cyclist travelling in the same direction as traffic and given a bicycle lane.

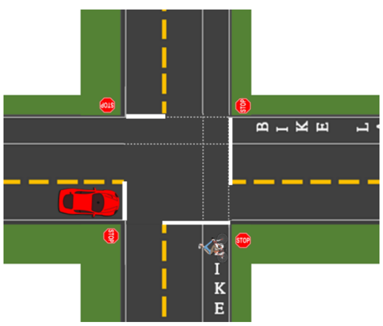

Figure 11. The cyclist meeting a vehicle in an intersection.

For future work that includes bicyclists and their safety, how bicyclists interact in different situations should be observed. The main focuses of these observations should be on age, the direction and the location the cyclists are traveling and how they interact with vehicles. Some other things that need to be considered are helmet use, time of day, month of the year, and blood alcohol concentration. Helmet use results in less fatalities in crashes [4]. This could also be included in a future study to see how the cyclist interacts with and without a helmet. Also, the time of day that a majority of the crashes happened was at night between 6 and midnight [4]. To take this into account, the study can be run in different lighting. They also happen between June and August, which is usually when the weather is warmer. As for the BAC, about 25% of all bike crashes are cause by the cyclist being classified as legally drunk with a BAC of 0.08% of higher [4].

There are limitations to this analysis that need to be reiterated. This includes the fact that this data is only fatal crashes that involve a bicyclist. This means that the crashes where a cyclist may have only been injured or didn’t endure any injuries are not included in the data. The analyzed data certainly is not representative of all bicycle crashes. However, this analysis covers the most sever cyclist crashes, which resulted in a fatality.

CONCLUSION

Most fatal bicycle crashes were caused by motorists overtaking cyclists and most of these crashes happen in a traffic lane where the bicyclist is traveling in the direction of traffic. Most of the crashes happen in urban areas and the cyclists involved in the crashes are usually 50- to 65-year-old males. From this conclusion, it should be possible to set up a study to see how safety can be improved for cyclists.

NOVELTY/TRAFFIC SAFEY IMPLICATIONS

Not much is known about bicycle crashes due to them not being reported often. This study characterizes crashes between cyclists and vehicles and proposes relevant scenarios to understand cyclist behavior. These scenarios could be used to improve cyclist detecting automatic emergency braking systems.

ACKNOWLEDGEMENTS

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USER-CENTRIC SOLUTIONS TO INCREASE USE OF BOOSTER SEAT AND APPROPRIATE USE OF ADULT SEAT BELTS AMONG CHILDREN

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INTRODUCTION

Road trauma is a leading cause of child mortality and morbidity in Australia (Australian Institute of Health and Welfare, 2020; Pointer, 2014). Australian Road Rules defines laws for the use of child restraints in Australia (New South Wales Consolidated Regulations, 2014). As in many other jurisdictions globally, the laws define the minimum acceptable restraint practice and do not always align with the best practice for safety. The timing of the transition from booster seat to the adult seat with lap and sash belt is a good example of this.

In Australia, law requires the use of a dedicated child restraint such as a booster seat up until 7 years of age. Different metrics and thresholds for a minimum legally acceptable transition exist in other jurisdictions. For example, different states in the US variously require a child to be 6–9 years of age, 145 cm tall or 29–36 kg in weight before legally being able to use an adult seat belt (Klinich et al., 2017). Some European countries such as Germany, do not allow seat belt use until children are older than 12 years and/or taller than 150 cm (European Consumer Centre Germany, 2020). However, best practice from a safety perspective depends on the match between the anthropometry of the individual child and the geometry of the actual vehicle seat and restraint system in the car the child is travelling in (Parab et al., 2022).

Decisions about how to optimally protect children around this transition period are therefore largely left to parents and carers. The most commonly available tool to assist parents and carers make this decision is the *5-step test* (Neuroscience Research Australia [NeuRA] and Kidsafe, 2020) , however it is unknown how effective this is as a decision aid. Furthermore, while user-centric and Behaviour Change Techniques (BCT) approaches have been developed to successfully address incorrect child restraint use (Hall et al., 2020) there has been no attempt as yet to use these approaches to develop innovative mechanisms to support parents making complex decisions about transition from boosters.

RESEARCH QUESTION/ OBJECTIVE

The objective is to develop an effective tool to assist parents make appropriate decisions when transitioning their children from booster seats to adult seat belts. The aim is to:

1. Evaluate existing tools used to advise parents on this decision.
2. Examine to what extent exposure to the *5-step test* information improved knowledge of good fit criteria.
3. Understand the level of knowledge associated with parent's accurate assessment of seat belt fit for child.
4. Understand the metrics parents think about when making the transition decision.
5. Identify behaviours and drivers of behaviours associated with transition decisions using the COM-B framework.

PROJECT DESCRIPTION

To meet the project objectives, two studies were conducted. Study 1 focused on evaluating the existing tool to support parents and carers (the 5-step test) and identify the drivers of behaviour associated with transition decisions (NeuRA and Kidsafe, 2020). Study 2 investigated user needs in making transition decisions through focus groups.

METHODS

STUDY 1 – TASK ANALYSIS

A randomised laboratory-based trial was used to evaluate whether parents who used the *5-step test* were more likely to make appropriate determination than those not exposed to this resource. The trial involved 36 parents of children aged 7-12 years seating their child in a simulated rear seat with three different seat/seat belt configurations representing 'good', 'partially good' and 'poor' seat belt fit (see Figure 1).

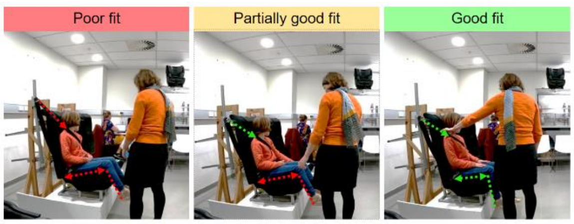

Figure 1 : *Depiction of belt fit state*

Parents were asked to observe their child in the seating condition and to 'think aloud' as they decided if this provided a good seat belt fit for their child. The researcher observed and recorded the correctness of each decision. This think aloud task analysis was video and audio recorded. See Figure 2 for trial summary.

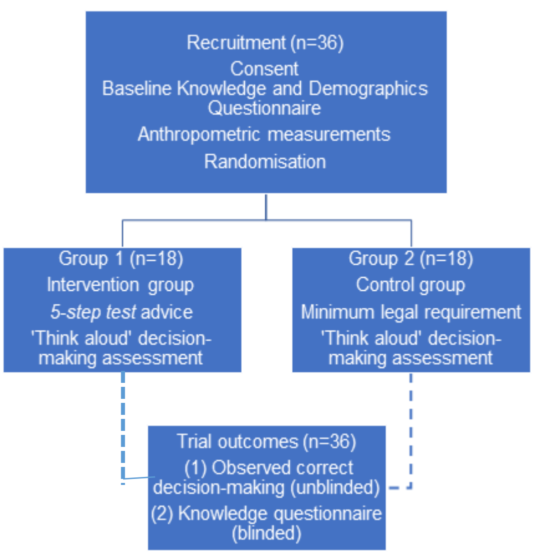

Figure 2: *Trial summary*

For quanitative analysis, the chi-squared test was used to test differences between intervention and control groups in parent's correct determination of fit. Logistic regression was used to estimate odds ratios (OR) and 95% confidence intervals (95% CI) for overall correct decision making for the intervention group compared to the control group. An independent t-test was used to examine differences between intervention and control groups in knowledge and the association between knowledge assessment scores and parent decision making.

Using a qualitative task analysis approach, the think aloud data and video recording were used to examine behavioural drivers of parent's decision-making in the assessment of a safe seat belt fit for their child. The framework of Behaviour Change Wheeel (BCW) and COM-B (Michie S, 2014) was used to map the behaviour tasks and subtasks to a parent's capability, motivation and opportunity for correct transition decision making.

STUDY 2 – FOCUS GROUPS

Carers of children aged 0-9 were recruited to participate in a 60-minute focus group. A total of eight focus groups were conducted. The focus groups explored parental awareness and perceived needs for making accurate decisions about the transition from booster seat to adult seat, guided by the COM-B framework (Michie et al., 2011). Deductive qualitative analysis techniques were used to examine parental needs in terms of capability, opportunity, and motivation to achieve appropriate decision making as well as understanding facilitators and barriers to accurate seat belt fit for their child.

RESULTS

The results of Study 1 show that the *5-step test* may not adequately support parents with more than 50% of parents exposed to this information failing to correctly identify seat belt fit consistently across three seating conditions. Exposure to this information did however significantly improve knowledge of the criteria required to achieve good seat belt fit but overall, but there was no significant relationship between knowledge of this criteria, and correct decision making.

Additional analysis of Study 1, using the COM-B framework, was completed to diagnose and map out the potential behavioural drivers of making the transition decision. The results of this show the strongest drivers of behaviour that parents need to be successful are knowledge of safe seat belt fit (psychological capability) and belief of achieving a good fit is important for the child's safety (reflective motivation).

Results for Study 2 highlight the differences of barriers experienced between mothers and fathers when making the transition from booster seat decision. Results of the qualitative analysis show that the primary barriers faced by fathers are a reliance of child's height and legal requirements regardless of vehicle and restraint characteristics. Mothers' barriers include a reliance on child's age to determine the transition. Shared barriers of both parents include the use of instinct over knowledge of a good seat belt fit. Additionally, mothers and fathers are both influenced by the child's comfort in booster and complaints of using boosters.

DISCUSSION

The findings of Study 1 demonstrate that while the existing *5-step test* provides some support for parents, more is needed, specifically aimed at the parents' motivation and capability. This is the first study to look at critical actions and behavioural drivers of parents making the transition from booster decision. When looking at the critical actions that led to correct behaviour, some parents did carry out these actions, yet this did not lead to correct decision making. This shows us that there are gaps in knowledge and understanding. There are also issues in translating this into correct practice.

Results from Study 2 confirm the need to better support the different needs of both mothers and fathers making this transition decision. The delivery of this information must consider access to the information at the moment of decision. Additionally, there is room to develop an intervention or component of the intervention directed at the child to help them understand the importance of a good seat belt fit, as was the original intention of the 5-step test (Tombrello, 2021).

Results from Study 1 and 2 will be used to develop an initial draft prototype decision aid and delivery mechanism. Iterative user testing of the prototype where groups of 10 participants will be given the prototype and asked to make the same decisions as described above in Study 1. After each round comprehension of the information presented in the prototype by the users will be tested and feedback from users collected as the basis of iterative refinements of the tool. This will be repeated until 90% correct use and a high level of acceptability among users is achieved, and the prototype materials will be finalised (Jay et al., 2011).

CONCLUSION

Thus far, we found that parents do not have adequate support when making the transition from booster decision. Parents lack knowledge of good fit criteria and are influenced by the child's desire to move out of the booster seat. Building upon the work conducted by (Brown et al., 2020) about instructional messaging for child car seat installation, expected outcomes of this project include the creation of an effective tool to support transition decisions, informed by user input.

NOVELTY/TRAFFIC SAFETY IMPLICATIONS

This body of work is using a novel approach to identify the critical needs of parents to correctly make good seat belt fit assessments by focusing on the complex behaviour components associated with the transition decision. This work is also the first to evaluate the only existing resource to support parents and has shown that parents need more than the current resource. The overall output of this body of work will be a new resource, developed by user input, and a preliminary evaluation of its effectiveness.

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