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Children in cars: The role of in-vehicle behaviour in child occupant protection

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Abstract

Motor vehicle crashes remain a leading cause of fatality and serious injury for children in Australia. Paediatric injuries are recognised as a significant global public health problem with profound implications to the injured individual, their families, the community and the economy. Child restraint systems (CRS) provide specialised protection to child occupants in the event of a motor vehicle crash. CRS usage rates are high in Australia but the protection provided to child occupants by the CRS requires both appropriate and correct use. In contrast, incorrect and/or inappropriate use are both associated with increased injury risk.

A literature review revealed that CRS misuse is prevalent in Australia, as well as most developed countries. The relationship between CRS misuse and elevated injury risk was also established. This PhD research program explored the role of behaviour in child occupant protection. Understanding how behaviour affects child occupant protection offers opportunities to reduce the individual, familial and societal burden of child occupant injuries. A focus of this study was the head position of a child occupant. Head injuries represent the most common serious injury type sustained by child occupants as a result of a motor vehicle crash and are likely to have long term health and economic implications.

The overarching aims of the PhD research program were to examine: 1) what parents say, think and believe about CRS use and child occupant travel safety, and 2) how child occupants were restrained and behaving in their CRS during real-world, every-day motor vehicle trips. The PhD research program comprised three stages that build on the findings from previous research. Stage 1 used an online survey to explore parental beliefs relating to CRS use and child occupant safety. Stages 2 and 3 used a naturalistic driving study (NDS) to observe the characteristics and behaviours of child occupants during their real-world, everyday, motor vehicle trips. Stage 2 identified common characteristics of child occupant travel when travelling in a CRS. Stage 3 used the NDS and survey data to identify the travel characteristics (e.g., familial-, child-, trip-related) associated with suboptimal head positions for child occupants when travelling in a forward-facing CRS (FFCRS) or a booster seat (BS).

In Stage 1, 380 parents responded a survey that included questions relating to parental beliefs relating to CRS use and factors that may influence child occupant safety. Findings revealed that CRS-related knowledge varied among parents and a number of important gaps in knowledge were identified. For example, more than half of the parents (59%) incorrectly reported that the minimum recommended height (145cm) for a child to most safely transition from a CRS to an adult seatbelt would be reached by the time a child reaches seven years of age. However, it was interesting to note that the majority of parents (64%) attributed the responsibility of child occupant safety to internal factors, such as their own driving abilities and their own safety compliance. This suggested that most parents had an internal locus of control (LOC) related to child occupant safety which is advantageous for the potential uptake of future child safety campaigns.

Stages 2 and 3 analysed the behaviour of child occupants through NDS methodology in two study vehicles. Forty two families used the study vehicles for their real-world, everyday motor vehicle trips for a period of two weeks. Using video data collected during this period, a randomly selected child occupant travelling in FFCRS or BS was observed (5-second intervals or epochs were analysed at nine time points) during 414 trips. Factors observed and analysed included: child head position (optimal/suboptimal), restraint type (FFCRS/BS), restraint use (correct/incorrect), interactions (verbal, non-verbal, both, nil), behaviour (passive/active), affect (positive/negative) and the primary activity that the child occupant was engaged in (e.g., looking, conversation, playing with a toy). Key findings from the NDS data were that child occupants were observed in suboptimal head positions for 26 percent of the epochs and CRS misuse was observed in 42 percent of the epochs. Elevated head injury risk from CRS misuse guided the research to conduct statistical modelling to identify factors that predict child occuppant suboptimal head positions. A key finding was that child occupants travelling in a BS were twice as likely to be observed in a suboptimal head position than child occupants travelling in a FFCRS. Child occupants were also one and half times more likely to be observed in a suboptimal head position if they were in the older age ranges for their recommended CRS when compared to child occupants that were in the younger age range for their recommended CRS and if the child occupant had incorrect shoulder belt placement when compared to child occupants with correct belt placement.

This PhD research program has significantly contributed to existing research, using both conventional survey methods to study parents' knowledge and beliefs about their children's safety, as well as innovative NDS methods which afforded unprecedented observations of real-world, everyday behaviours to understand factors associated with child occupants' head position when travelling in a motor vehicle. This PhD research program has highlighted a number of key findings. Importantly, parents attribute the responsibility of child occupant safety to themselves. This highlights a potential direction for translation of this research to best CRS practice behaviours. That is, parents are likely to be receptive to future initiatives to address the CRS-related knowledge gaps child occupant travel safety, such as using shoulder markers to guide transition to adult seatbelts and adjusting harnesses/belts for each trip). Secondly, the NDS findings highlight the need for future CRS/vehicle design efforts and educational campaigns to address or accommodate the factors that were identified as contributors to child occupant suboptimal head positions when travelling in CRS, such as forward leaning when engaged in lap-based activities. Recommendations of the PhD research program include targeted educational campaigns and CRS/vehicle design improvements to address suboptimal head position and to eliminate crash-related deaths and injuries for child occupants.

Declaration

Thesis including published works declaration

Publications during enrolment

Arbogast, K. B., Loeb, H., Cross, S. L., Davydov, J., Mascarenhas, K., Koppel, S., & Charlton, J. L. (2013). Use of Kinect™ for naturalistic observation of occupants in vehicles. Ann Adv Automot Med.,57:343-344 (see Appendix D).

Bohman, K., Arbogast, K. B., Loeb, H., Charlton, J. L., Koppel, S., & Cross, S. L. (2018). Frontal and oblique crash tests of HIII 6-year-old child ATD using real-world, observed child passenger postures. Traffic Injury Prevention, 19(sup1), S125-S130 (see Appendix B).

Cross, S. L., Charlton, J. L., & Koppel, S. (2017). Understanding parental beliefs relating to child restraint system (CRS) use and child vehicle occupant safety. Journal of the Australian College of Road Safety, 28(3), 43-54 (see Publication 1).

Cross, S. L., Charlton, J. L., & Koppel, S. (In Press). The common characteristics and behaviours of child occupants in motor vehicle travel. Traffic Injury Prevention. (see Publication 2).

Cross, S. L., Koppel, S., Arbogast, K. B., Bohman, K., Christina M. Rudin-Brown, C. M. & Charlton, J. L. (Submitted). Modelling factors of child occupants when travelling in child restraint systems. Accident Analysis & Prevention (see Publication 3).

Kuo, J., Charlton, J. L., Koppel, S., Rudin-Brown, C-M. & Cross, S. L. (2016). Modelling driving performance using in-vehicle speech data from a naturalistic driving study. Human Factors, 58(6), 833–845 (see Appendix E).

Loeb, H., Kim, J., Kuo, J., Koppel, S., Charlton, J. L. & Cross, S. L. (2017). Automated recognition of rear seat occupants' head position using Kinect™ 3D point cloud. Journal of Safety Research, 63, 135-143 (see Appendix C).

I hereby declare that this thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

This thesis includes 1 original papers published in peer reviewed journals and 2 unpublished publications (1 in Press). The core theme of the thesis is exploration of the role of in-vehicle behaviour in child occupant protection. The ideas, development and writing up of all the papers in the thesis were the principal responsibility of myself, the student, working within the Monash University Accident Research Centre under the supervision of Professor Judith L. Charlton and Associate Professor Sjaan Koppel.

I have not renumbered sections of submitted or published papers in order to generate a consistent presentation within the thesis.

Student signature: Date: 23/8/2019

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the student's and co-authors' contributions to this work. In instances where I am not the responsible author I have consulted with the responsible author to agree on the respective contributions of the authors.

Main Supervisor signature: Date: 28/08/2019

Acknowledgements

An enormous thank you to my supervisors, Professor Judith Charlton and Associate Professor Sjaan Koppel for your invaluable support, expertise, and mentorship. I have learned so much from you both over the last seven years and feel forever indebted to you for your investment in me. Above all, you believed in me when life threw some crazy obstacles in my way and did not hesitate to remind me of my own worth as I faced each of them. I am sincerely grateful for the time, patience and appraisal relating to the opportunities that you have provided me over the PhD journey and feel privileged to have been able to work under your guidance. Thank you also to my fellow PhD candidate Dr Jonny Kuo for the many laughs along our PhD journeys on this project. We shared many happy road trips delivering and picking up the study vehicles. Also a big thank you to Jonny for vigilantly handling the more technical aspects as they cropped up.

Thank you to Monash University Accident Research Centre (MUARC) for supporting my PhD from start to finish. No PhD journey is the same and I think mine was proof of this. MUARC were very supportive after I sustained a serious back injury midway through my candidature that resulted in some permanent impairment. Thank you to Monash University Graduate Research Office, all of my colleagues at MUARC, and particularly my supervisors for their support in enabling me to overcome this and continue my PhD endeavour. I would also like to personally thank my candidature and pre-submission milestone panel members, Dr Dianne Sheppard and Dr Carlyn Muir, and a special thank you to Associate Professor Jennie Oxley and Samantha Bailey for your PhD advice and guidance.

Another big thank you to Lesley Rees for our walks that were not only advantageous for my physical rehabilitation, but also invaluable in keeping my life in check and my focus on the project. Thank you also to my MUARC employment supervisors for your ongoing support and to Chernyse Wong for her assistance with coding for reliability and project data entry.

This thesis is in honour of my wonderful family and friends who ensured my PhD dream became a reality. I could not, and would not, have done this without the love and support of my husband/best friend Jeff, my beautiful children Lachlan and Amber, and my mother Patricia Delabertauche. Hopefully I have modelled goal setting, persistence and self-investment for my children and not the ability to chaotically juggle!

On a more formal note, this project was supported by the Australian Research Council Linkage Grant Scheme (LP110200334) and was a multi-disciplinary international partnership between Monash University, Autoliv Development AB, Britax Childcare Pty Ltd, Chalmers University of Technology, General Motors-Holden, Pro Quip International, the Royal Automobile Club of Victoria (RACV), The Children's Hospital of Philadelphia Research Institute, Transport Accident Commission (TAC), University of Michigan Transportation Research Institute, and VicRoads. All of the project partners were an absolute pleasure to collaborate with but an extended thank you must also go to Kristy Arbogast, Katarina Bohman and Missy Rudin-Brown for the time you gave me.

Contents

1. Introduction

Motor vehicle crashes remain a leading cause of childhood death and injury in Australia and in most developed countries (Commonwealth of Australia, 2018a; Mitchell, Curtis, & Foster, 2017; World Health Organization, 2008, 2015). Child restraint systems (CRS) are a vehicle add-on structure that provide specialised protection for child occupants in the event of a motor vehicle crash and can effectively reduce the risk of child occupant injury by approximately 70 percent when compared to restraint by an adult seatbelt (Durbin, Elliott, & Winston, 2003). CRS are required by law to be used in motor vehicle travel by children up until the age of at least seven years in Australia (National Transport Commission, 2009). In Australia, CRS use is high at around 99 percent (Brown, Hatfield, Du, Finch, & Bilston, 2010a; Koppel, Muir, et al., 2013; Lennon, Titchener, & Haworth, 2010). Notwithstanding prevalent use of CRS, high rates of death and serious injury from vehicle crashes suggest urgent solutions are needed to improve the protection being offered by the CRS to the child occupant. This PhD research program explores how child occupant behavioural factors may affect the level of protection provided by the CRS in the event of a motor vehicle crash. The PhD thesis presented here addresses the first two critical stages of injury prevention; i) surveillance, to identify the problem and ii) risk factor identification, to identify protective and risk factors.

Research on child occupant behaviour provides an opportunity to complement existing initiatives to reduce child occupant fatality and serious injury rates in a number of ways by identifying and focussing on improving the way a child occupant interacts with a CRS. Several initiatives have been implemented in Australia to enhance CRS use and improve child occupant travel safety in Australia (CREP, 2014; Koppel, Charlton, & Rudin-Brown, 2013; Lennon, Siskind, & Haworth, 2008; Lennon et al., 2010; National Transport Commission, 2009; Standards Australia/Standards New Zealand, 2010). These include revised legislation for CRS use (National Transport Commission, 2009) and provision of CRS evaluation guides for parents (CREP, 2014). Initiatives that have contributed to child occupant travel safety include safety standards and CRS safety testing using test dummies (Standards Australia/Standards New Zealand, 2010).

Conventionally, CRS are tested to measure the level of protection provided to the child occupant in the event of a motor vehicle crash by using child-like test dummies that are placed in an upright, static position in simulated crash tests (CREP, 2014; Standards Australia/Standards New Zealand, 2010). However, previous research has shown that child occupants do not always sit still and often do not adopt the upright posture of test dummies (Andersson, Bohman, & Osvalder, 2010; Bohman et al., 2011; Charlton, Koppel, Kopinathan, & Taranto, 2010; Forman, Segui-Gomez, Ash, & Lopez-Valdes, 2011; van Rooij et al., 2005). Research indicates that various forms of misuse are prevalent in everyday travel (Charlton et al., 2010; Fong, Bilston, Paul, & Brown, 2017; Koppel, Charlton, et al., 2013), potentially increasing the injury risk to the child occupant in the event of a motor vehicle crash. Exploring the way child occupants behave when travelling in a CRS can help identify opportunities to reduce injury and mortality rates.

1.1. Context

This PhD research program was conducted as part of a broader Australian Research Council (ARC) Linkage Project (LP110200334). The broader project - *Children in cars: an international collaboration,* used innovative naturalistic driving methods to observe and quantify the positions of child occupants in cars, identify the injury effects of out-of-position status and its impact on driver distraction. The project was comprised of two major components:

1. The first component examined how children were restrained and seated in their child restraint systems (CRS) or booster seats (BS) and their behaviour during real-world, everyday motor vehicle trips, using naturalistic driving study (NDS) recording equipment that was installed in the study vehicles, and

2. The second component examined whether children's behaviour and/or their seating positions during real-world, everyday motor vehicle trips was a potential source of distraction to the driver, and if this behaviour and/or distraction affected driver behaviour/performance.

The PhD research described in this thesis focussed on the first component of the ARC Linkage Project. Specifically, this research contributed to the broader project by exploring the role of in-vehicle behaviour in child occupant protection. This PhD research program was inclusive of institutional ethics approval, study design, recruitment of participants, data collection, analysis and interpretation of results. To supplement the NDS data, an online survey on parents' knowledge, attitudes and beliefs was also developed. Findings from the NDS component of the PhD research program also informed crash sled testing protocols and other analyses in the broader project which were designed to quantify child occupant head position and the potential injury risk of suboptimal head position (Arbogast et al., 2016; Bohman et al., 2018; Loeb et al., 2017). See Appendix A, B and C, respectively.

Experts were consulted in the development of the research methodologies for the thesis. The experts comprised investigators and partners from the broader ARC Linkage Project who represent a range of scientific disciplines, including injury biomechanics, engineering, and behavioural science and motor vehicle/transport industry experts[1] :

[1] Affiliations for each investigator was at the time of the award to the ARC Linkage Project – LP110200334 (November 2013).

- **Professor Judith Charlton,** PhD Supervisor and Project Principal Investigator, Monash University Accident Research Centre; Behavioural Science;
- **Associate Professor Sjaan Koppel**, PhD Supervisor and Project Chief Investigator, Monash University Accident Research Centre; Behavioural Science;
- **Professor Mats Svensson,** Department of Applied Mechanics, Chalmers University of Technology, Sweden, Injury Biomechanics;
- **Dr Katarina Bohman,** Research Engineer at Autoliv Development, Chalmers University of Technology, Sweden, Mechanical Engineering;
- **Professor Lotta Jakobson,** Department of Applied Mechanics, Chalmers University of Technology, Sweden, Vehicle Safety Engineering;
- **Professor Flaura Winston,** Professor of Pediatrics, University of Pennsylvania, Scientific Director, Center for Injury Research and Prevention Director, Center for Child Injury Prevention Studies, The Children's Hospital of Philadelphia; Pediatric Injury;
- **Dr Kristy Arbogast,** Engineering Core Director for the Center for Injury Research and Prevention at The Children's Hospital of Philadelphia, Bioengineering;
- **Dr Christina (Missy) Rudin-Brown**, Transport Canada; Human Factors, Behavioural Science;
- **Dr David Eby,** Head, Behavioral Sciences, University of Michigan Transportation Research Institute; Behavioural Science;
- **Mr Steve Curtis,** Manager - Vehicle Structure & Safety Integration, GM Holden, Motor vehicle industry expert;
- **Mr Mike Lumley,** Technical Director, Britax Childcare, Child restraint design, assembly and marketing expert;
- **Ms Melinda Congiu, Mr Tim Davern** and **Ms Elvira Lazar**, Public Policy and Road User Behaviour Team, Royal Automobile Club of Victoria (RACV);
- **Ms Louise Purcell**, VicRoads; road safety expert, and;
- **Ms Elizabeth Knight (Waller),** Transport Accident Commission (TAC); road safety expert.

This PhD research program covered new ground in the area of child occupant safety and:

- In a naturalistic driving context, monitored, recorded and analysed the behaviours of child occupants in their CRS using a large sample of parent/drivers and child occupants on a scale not previously observed;
- Contributed to and drew from a unique collaboration with international leading experts on the broader ARC Linkage Project to develop injury outcome protocols and measures;
- Included comprehensive parent reporting to investigate behavioural variables that are not easily measured through observational studies (e.g., knowledge, beliefs), using an internet research tool that was both cost and resource effective;
- Examined the complex interaction between parents' beliefs and children's behaviour relating to child occupant safety by combining the parent variables from the survey with real-world the observations, and;
- Findings from the PhD research program have the potential to inform safety priorities in child occupant protection and guide strategies (i.e. parent education, and vehicle and CRS design and policy) to reduce child injury and mortality from motor vehicle crashes when travelling in a CRS.

1.2. PhD Design

The PhD research program is a Thesis by Publication. It is presented as three stages of research and includes three peer-reviewed manuscripts that present the findings from each stage. Two methods were implemented in this PhD research program: an online survey and a NDS. Stage 1 comprises the online survey of parents' beliefs relating to CRS use and child occupant safety. Stage 2 uses NDS methods to understand child occupant behaviour. Stage 3 brings together the data from the online survey and the NDS to explore factors that may contribute to suboptimal head position. The PhD research program design and the contribution of each of the three stages of research are described in more detail in the next section and illustrated in Figure 1. The three publications that present the findings from each of the stages are listed below.

Cross, S. L., Charlton, J. L., & Koppel, S. (2017). Understanding parental beliefs relating to child restraint system (CRS) use and child vehicle occupant safety. *Journal of the Australian College of Road Safety*, 28(3), 43-54.

Cross, S. L., Charlton, J. L., & Koppel, S. (In Press). The common characteristics and behaviours of child occupants in motor vehicle travel. *Traffic Injury Prevention*.

Cross, S. L., Koppel, S., Arbogast, K. B., Bohman, K., Christina M. Rudin-Brown, C. M. & Charlton, J. L. (Submitted). Modelling factors of child occupants when travelling in child restraint systems. *Accident Analysis & Prevention.*

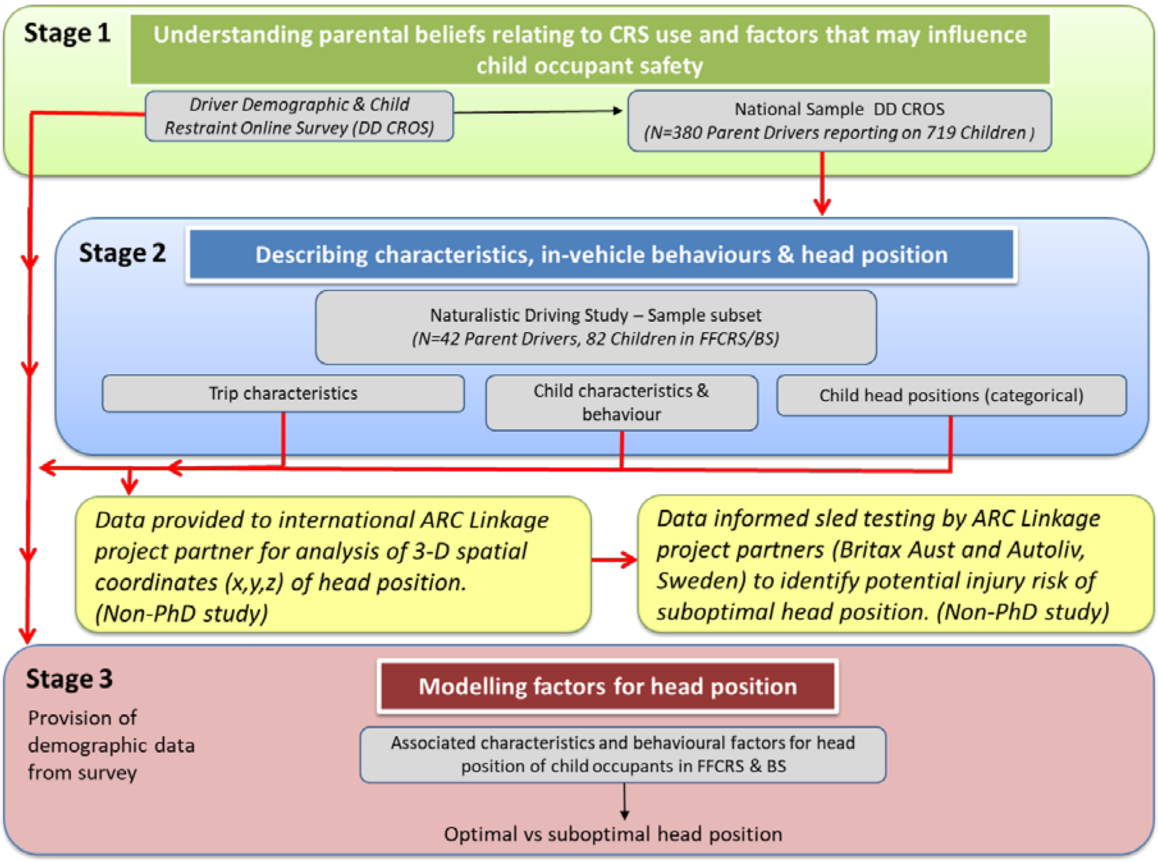

Figure 1. PhD design: description of the three stages of the PhD research program

STAGE 1

In Stage 1, an online survey method was used to better understand parental beliefs about correct CRS use, and the factors that may influence child occupant safety

Survey development was guided by the Health Belief Model (HBM) (Rosenstock, 1974) and the Locus of Control (LOC) theory (McDonald, Spears, & Parker, 2004; Rotter, 1954; Wallston, Strudler Wallston, & DeVellis, 1978). The survey collected self-reported information on parental beliefs that may relate to CRS use and child occupant safety within the Australian context. (See Appendix F.)

This research explored:

- Parents' beliefs regarding CRS use;
- Parents' beliefs relating to their susceptibility of being involved in a motor vehicle crash;
- Parents' attribution of responsibility for their child's occupant safety;

- Parents' perceptions about the influence of internal and external factors (e.g., vehicle factors, CRS factors, child factors, driver and driving factors) on child occupant safety, and;
- The relationship between parent and family characteristics and CRS-related knowledge.

Findings are presented in Publication 1: Understanding parental beliefs relating to child restraint system (CRS) use and child vehicle occupant safety.

STAGE 2.

In Stage 2, a NDS was used to observe and quantify the common characteristics and behaviours of child occupants during their everyday, real-world motor vehicle travel. The NDS used two instrumented study vehicles to collect everyday trip information. This research identified the frequency of child occupant behaviours and activities when travelling in their CRS or BS, as well as the role that behaviour has on child occupant head position.

This research:

- Observed and described common child occupant characteristics and behaviours during everyday, real-world motor vehicle travel, and;
- Explored factors for an association with child occupants' head position when travelling in a CRS.

Findings for the Stage 2 research are presented in Publication 2: The common characteristics and behaviours of child occupants in everyday, real-world motor vehicle travel.

The information collected in Stage 2 also contributed to several publications not included in the PhD research program. The contributions to the broader project are illustrated in yellow boxes in Figure 1. The NDS provided three-dimensional spatial information (x,y,z coordinates) derived from a Kinect sensor system which was used to quantify child occupant head position within the vehicle (Arbogast et al., 2016; Loeb et al., 2017). The analysis used the Kinect system's skeleton recognition and two novel analytical algorithms to log head location (Loeb et al., 2017). This analysis methodology was applied to the research by Arbogast and colleagues (2016). (See Appendices C and A, respectively, for full manuscripts). The observations recorded in this research also informed anthropometric test dummy (ATD) head positioning for a sled testing program (in the broader ARC Linkage Project) to investigate the potential injury implications of child occupants' head position in the event of a motor vehicle crash (Bohman et al., 2018) (See Appendix B).

STAGE 3

Stage 3 research brought together data from Stages 1 and 2, describing children's behaviour, the family characteristics and their trip patterns. The primary aim was to identify behavioural, child and in-vehicle factors associated with child occupant's head position when travelling in a CRS or BS. The primary outcome measure of interest for the analysis was child occupants' head position [optimal, suboptimal], which was generated from the NDS data using both video and audio recordings.

This research used General Estimating Equations (GEE) to:

- Describe travel characteristics (familial, child related, trip related) that are associated with suboptimal child head position when travelling in a FFCRS or BS, and;
- Determine whether the travel characteristics that contribute to suboptimal child head position are different for FFCRS and BS type CRS occupants.

Findings are presented in Publication 3: Modelling factors of child occupants when travelling in child restraint systems.

1.3. Aims and research questions

The three stages of this PhD research program explore the role of in-vehicle behaviour in child occupant protection. The primary aims were:

- To understand Australian parents' beliefs, knowledge, and attitudes relating to CRS (FFCRS and BS) use and child vehicle occupant safety by identifying any gaps in CRS related knowledge, and;
- To describe and classify the head positions (optimal vs suboptimal), behaviours and activities of child occupants when travelling in a FFCRS or BS during their real-world, everyday driving trips.

The key research questions addressed were:

- What are the parental beliefs relating to CRS use, travel safety and the factors that may influence child occupant safety? (Stage 1).
- What are the common characteristics of child occupant travel during real-world, everyday driving trips? (Stage 2).
- What behavioural factors and characteristics predict child occupant suboptimal head position when travelling in a FFCRS or BS during real-world, everyday driving trips? (Stage 3).

1.4. Presentations

A number of presentations were given throughout the course of the PhD candidature. These included national and international conference papers and an invited presentation for a community forum. Details of the presentations are described below.

Cross, S. L., Charlton, J. L., & Koppel, S. (2013). Australian parents' perceptions, beliefs and attitudes about child occupant safety and their influence on real-world child occupant travel. Protection of Children in Cars 11th International Conference, 4th – 5th December 2013, Munich, Germany.

Cross, S. L., Kuo, J., Koppel, S. & Charlton, J. L (2016). Using in-vehicle data to better understand the impact of child occupant behaviour, in-vehicle factors and driving distraction. International Conference on Traffic and Transport Psychology (ICTTP), August 2nd – 5th , 2016, Brisbane, Australia.

Cross, S. L., Koppel, S. & Charlton, J. L (2017). How do child occupants really behave during motor vehicle travel? Protection of Children in Cars 15th International Conference, 7th - 8th December 2017, Munich, Germany.

Cross, S. L., Koppel, S. & Charlton, J. L (2017). Using NDS data to understand child vehicle occupant behaviour when travelling in CRS, Australasian Road Safety Conference, 10th – 12th October 2017, Perth, Australia.

Cross, S. L., Koppel, S. & Charlton, J. L (2017). Occupy, entertain and distract: How does children's in-vehicle activity affect safety? 13th Australasian Injury Prevention and Safety Promotion Conference, 13th – 15th November 2017, Ballarat, Australia.

Cross, S. L., Koppel, S. & Charlton, J. L (2018). The role of the child restraint system in child occupant protection. Victoria Police Community Education Project, 20th August 2018, Springvale, Australia.

1.5. Other publications and presentations

The PhD researcher contributed to several publications and conference presentations as part of the broader project that were not part of the PhD thesis. These were as follows:

1.5.1. Publications

Arbogast, K. B., Loeb, H., **Cross, S. L.,** Davydov, J., Mascarenhas, K., Koppel, S., & Charlton, J. L. (2013). Use of Kinect™ for naturalistic observation of occupants in vehicles. Ann Adv Automot Med.,57:343-344 (see Appendix D).

Bohman, K., Arbogast, K. B., Loeb, H., Charlton, J. L., Koppel, S., & **Cross, S**. **L.** (2018). Frontal and oblique crash tests of HIII 6-year-old child ATD using real-world, observed child passenger postures. *Traffic Injury Prevention, 19*(sup1), S125-S130 (see Appendix B).

Kuo, J., Charlton, J. L., Koppel, S., Rudin-Brown, C-M. & **Cross, S. L.** (2016). Modelling driving performance using in-vehicle speech data from a naturalistic driving study. *Human Factors, 58*(6), 833–845 (see Appendix E).

Loeb, H., Kim, J., Kuo, J., Koppel, S., Charlton, J. L. & **Cross, S. L.** (2017). Automated recognition of rear seat occupants' head position using Kinect™ 3D point cloud. *Journal of Safety Research, 63,* 135-143 (see Appendix C).

1.5.2. Conference presentations

Charlton, J. L, Koppel, S., **Cross, S. L.,** Rudin-Brown, C., Kuo, J., Arbogast, K. B., Loeb, H., Eby, D., Bohman, K., Svensson, M. & Jakobsson, L. (2013). Naturalistic observation of children in cars: an international partnership. Protection of Children in Cars 11th International Conference, 4th – 5th December 2013, Munich, Germany.

1.6. Media

Cross, S. L. on Channel 9 News. News segment, Media television interview (recruitment effort), 13/09/2013.

Cross, S. L. & Kuo, J. on ABC Radio. 774 ABC radio interview – Baby Talk (marketing effort), 31/10/2015.

Carey, A. (2013, August 24). Wrong use of car seats puts lives in danger. *The Age/The Sunday Age*, p. 7.

1.7. Thesis structure

Chapter 2 presents a literature review of child occupant safety research, including an overview of child occupant mortality and injury risk statistics to identify the need for the current research. This aim of this chapter was to explore existing evidence that quantifies how children behave when travelling in a CRS or BS and how this behaviour may affect their safety in the event of a motor vehicle crash. This Chapter describes the strengths and limitations of existing research, identifies gaps in knowledge, and outlines the aims and approach used in the PhD research.

The chapter also provides broad contextual information of CRS and BS types in common use in Australia and relevant product safety standards, testing and legislation (National Transport Commission, 2009; Standards Australia/Standards New Zealand, 2010). Evidence is reviewed on the nature and extent of CRS use and misuse, child occupant injury mechanisms and outcomes and the critical role that CRS and BS play in the protection of child occupants in a motor vehicle crash.

Chapter 3 describes Stage 1, the online survey, with a focus on the content of the survey and the strategies used to recruit a sample of parents that were representative of the Australian population. This chapter also describes how the Health Belief Model (Bandura, 1977; Rosenstock, Strecher, & Becker, 1988), the Locus of Control theory (Rotter, 1954) and industry expert knowledge was used to frame the online survey of parents.

Chapter 4 introduces and presents the first publication from Stage 1 of this PhD research program: *Understanding parental beliefs relating to child restraint system (CRS) use and child vehicle occupant safety.*

Chapter 5 describes the NDS methodology used in Stages 2 and 3 of the PhD Research program. The chapter presents recruitment information including eligibility criteria and the recruitment pathways used. A description of the data acquisition equipment installed in the two study vehicles is presented and the procedures for the driving study are outlined. The measures relating to trip variables, vehicle occupant and the selected child occupant are detailed and examples of output from the data acquisition systems and the coding computer software are provided.

Chapter 6 introduces and presents the second publication from Stage 2 of this PhD research program (NDS): *The common characteristics and behaviours of child occupants in motor vehicle travel.*

Chapter 7 introduces and presents the third publication from Stage 3 of this PhD research program. The study builds on the findings from both Stages 1 and 2 to provide a better understanding of factors that contribute to suboptimal child occupant head position during real-world, everyday driving trips. It presents the travel characteristics (e.g., familial-, child- and trip-related) associated with suboptimal head positions for child occupants when travelling in a FFCRS or a BS as reported in the final publication: *Modelling factors of child occupants when travelling in child restraint systems.*

Chapter 8 integrates the findings from all three stages of the PhD research program and highlights the contributions to knowledge about child occupant safety and discusses practical applications of the findings for addressing gaps in parents' beliefs identified in the DDCROS data in Stage 1 and solutions for improving suboptimal head positions observed in Stages 2 and 3. Several study limitations are considered and opportunities for future research are proposed.

2. Literature Review

Motor vehicle crashes remain a leading cause of childhood death and injury in Australia and in most developed countries (Commonwealth of Australia, 2018a; World Health Organization, 2008, 2015). In Australia, land transport crashes are the leading cause of death for children between 1 and 5 years of age (Australian Coordinating Registry, 2019) and a leading cause of childhood injury and disability (Australian Institute of Health and Welfare, 2012a; Mitchell et al., 2017).

The requirement for child occupants to use a CRS when travelling in a motor vehicle is widely accepted and practiced in Australia. Previous research reports that CRS use is around 99 percent (Brown, Hatfield, et al., 2010a; Koppel, Muir, et al., 2013; Lennon et al., 2010). CRS are a vehicle add-on structure that are required by the Australian Road Rules to be used in motor vehicle travel by child occupants up until at least seven years of age in Australia (National Transport Commission, 2009). CRS are designed to provide specialised protection to the child occupant in the event of a motor vehicle crash by reducing risk of ejection, distributing energy loading to stronger parts of the body, limiting crash forces and limiting the potential for contact with the vehicle interior (Durbin, 2011; Rudin-Brown, Kramer, Langerak, Scipione, & Kelsey, 2017). There is strong evidence that CRS can effectively reduce the risk of child occupant injury by approximately 70 percent when compared to restraint by an adult seatbelt (Durbin et al., 2003).

The level of protection that CRS can provide in motor vehicle crash depends on how the structure is used (Standards Australia/Standards New Zealand, 2010). Correct and appropriate use of CRS in everyday motor vehicle travel is achieved if the system is used according to manufacturer's recommendations and if the child occupant maintains an optimal/ideal body position (Neuroscience Research Australia and Kidsafe Australia, 2013). Any other use is considered 'CRS misuse' and is associated with decreased protection in the event of a motor vehicle crash (Andersson, Pipkorn, & Lövsund, 2013; Bilston, Yuen, & Brown, 2007; Brown, McCaskill, Henderson, & Bilston, 2006; Kapoor et al., 2011; Rudin-Brown et al., 2017).

The need to explore CRS misuse and associated factors is amplified by the popularity of motor vehicle travel in Australia. Private passenger motor vehicle travel accounted for 76 percent of all registered vehicles in Australia in 2013 (Australian Bureau of Statistics, 2013). An annual average growth of four percent has been recorded from 1955 to 2013 in Australia (Australian Bureau of Statistics, 2013). In an Australian survey of 272 parents, 77 percent reported that they use their vehicle to transport their children 'daily' or 'almost daily' (Koppel, Muir, et al., 2013). Motor vehicle crashes resulted in approximately 1,146 deaths and 36,000 serious injuries in 2017 (BITRE, 2019). The annual costs are estimated at $AUD 27 billion (DIRDC, 2019). With popularity of motor vehicle travel increasing, the potential of being in a crash may also rise.

The National Road Safety Strategy 2011–2020 acknowledges the popularity of motor vehicle travel and the need to improve motor vehicle occupant protection (Commonwealth of Australia, 2018b). The strategy supports actions that aim to reduce fatalities and serious injuries caused from motor vehicle crashes on Australian roads (Commonwealth of Australia, 2018b). This research addresses the National Road Safety Strategy 2011-2020 for child occupants by contributing findings for a Safe System; informing 'Safe People' and guiding motor vehicle and CRS design for 'Safe Vehicles' (Commonwealth of Australia, 2018b).

The level of protection that a CRS can provide in the event of a motor vehicle crash is tested in refined laboratory conditions using anthropometric test dummies (ATDs) that are placed in an optimal seating position (Standards Australia/Standards New Zealand, 2010). However, previous research indicates that child occupants do not behave like ATDs (Charlton et al., 2010). Rather, they move around in their CRS and engage in activities such as eating, sleeping and playing when travelling in a motor vehicle (Charlton et al., 2010). However, what is not well understood is how such behaviours might influence child occupant head positioning.

Identifying specific travel characteristics and behaviour that contribute to suboptimal child occupant head positioning in CRS can reduce childhood injuries and fatalities. Current legislative and educational initiatives can be extended to incorporate the findings that contribute to suboptimal child occupant head positioning. 'Optimal' child occupant head position is defined as still, upright, in the reference position and within the protective structure of the CRS (CREP, 2014). In contrast, 'suboptimal' child occupant head position is defined as the child's head position away from the optimal position/reference position and outside of the protective zone of the CRS (Bohman et al., 2018). Importantly, the suboptimal positions resulting from such travel behaviours can also place the harness or the seatbelt in positions that may not offer the child occupant the best protection in the event of a crash (Bohman et al., 2011; Brown et al., 2006). Limited research has been conducted that has explicitly explored the role of behaviour relating to CRS use and CRS misuse.

2.1. Current Australian CRS initiatives

This section describes the existing CRS initiatives in Australia. The types of CRS on the Australian market are described, current Road Rule Legislation for the use of CRS (National Transport Commission, 2009), and the ASNZ 1754 safety standard for CRS products are introduced (Standards Australia/Standards New Zealand, 2010) and the Child Restraint Evaluation Program (CREP) which is designed to provide parents with information about safe CRS choices is also outlined (CREP, 2014).

2.1.1. Types of CRS on Australian market

Several different types of CRS are available in Australia for use by child occupants of different ages/sizes. Broadly, the CRS types that are recommended by legislation can be categorised as: i) Rear-facing CRS (RFCRS), ii) FFCRS, and iii) BS.

RFCRS are designed for children from birth to six months of age, dependent on the child's height and weight (National Transport Commission, 2009). NHMRC best practice guidelines recommend the use of a RFCRS for children from birth. The RFCRS have a built-in 5-point restraint system, where the child faces the rear of the car and a tether connects the RFCRS to the vehicle (see Figure 2). These types of CRS are also known as baby capsules, infant restraints and baby carriers in Australia and are referred to as Type A CRS in the Australian Standard (Neuroscience Research Australia and Kidsafe Australia, 2013).

Figure 2. An exemplar of a typical RFCRS with a five-point harness, installed in a motor vehicle in Australia (Source: RACV, 2019).

FFCRS are designed for children from at approximately six months of age, dependent on the child's height and weight (National Transport Commission, 2009). FFCRS use the vehicle seatbelt which provides a 5-point restraint system to secure the child occupant (although a 6-point harness has recently been approved by Australian Standards to use). A FFCRS is a child restraint with a built-in harness where the child faces the front of the car (see Figure 3). A FFCRS is also known as a child safety seat in Australia and is referred to as a Type B CRS in the Australian Standards (Neuroscience Research Australia and Kidsafe Australia, 2013) .

Figure 3. An exemplar of a typical FFCRS with a five-point harness, installed in a motor vehicle in Australia (Source: RACV, 2019)

FFCRS are fitted with a 5-point harness to secure the child occupant. The new Australian and New Zealand Standard AS/NZS 1754, 2013, also includes a Type G restraint that is fitted with 6-point harness, and is designed to be used with the in-built harness for child occupants from approximately 6 months through to 8 years old, depending on size (Australian Competition and Consumer Commission, 2019). However, no restraints of this type were observed in this study as none were on the market at the time the study commenced.

BS are designed for children from approximately 4 years of age, dependent on the child's height and weight (National Transport Commission, 2009). BS use the vehicle seatbelt which provides a 3-point restraint system to secure the child occupant. A BS is a CRS that boosts the child up and positions the adult lap sash belt properly over the child's hips and chest (see Figure 4). A BS is also known in Australia as a belt positioning booster seat or booster cushion. Booster cushions do not have a back support or side wings and are no longer recommended for use in Australia. BS are referred to as either Type E or F CRS in the Australian Standard. Type E seats are designed to forward face to a large 8 year old. The new Australian and New Zealand Standard AS/NZS 1754, 2013, also includes Type F restraints that are designed to be used for child occupants through to 10 years of age, depending on size (Australian Competition and Consumer Commission, 2019). However, no restraints of this type were observed in this study as none were on the market at the time the study commenced.

Figure 4. An exemplar of a typical BS installed in a motor vehicle in Australia (Source: RACV, 2019).

CRS are designed to be used as a dedicated or single mode restraint type or to be used as two alternative CRS types dependent on the child occupant growth. In addition to the separate CRS types CRS on the Australian market, CRS are also available as convertible or combination CRS. A convertible CRS means the restraint can be used as a RFCRS or a FFCRS with inbuilt harness. A combination means it can be used as a FFCRS with inbuilt harness or as a BS with a lap-sash seatbelt (Raising Children Network, 2019).

CRS types are designed to maximally protect children based on their development and size. Hence, recommendations relating to the best time to transition a child occupant to the next restraint type include;

- Keeping each child in the CRS designed for their size as long as they will still fit into it. Don't be in a hurry to move them into the next stage restraint, and;
- Exhausting all options for CRS in the child's 'recommended' restraint type before transitioning them to the next type of restraint (Neuroscience Research Australia and Kidsafe Australia, 2013).
- A height of 145cm as the safest time in child development to transition from a BS to an adult seatbelt in Australia, however it is acknowledged that height recommendations for transition to an adult seat belt do vary around the world (European Union, 2019).

2.1.2. Australian legislation

Laws mandating the use of CRS have been implemented across most developed countries over the last 30 years, including the United States, Canada, Europe and Australia (AAA/CAA Digest of Motor Laws, 2019; CLEK Inc, 2015; European Union, 2019; Government of Canada, 2019; National Highway Traffic Safety Administration, 2019; National Transport Commission, 2009). These CRS laws aim to protect child occupants in the event of a motor vehicle crash. In Australia, the use of CRS is mandatory for children up to the age of seven years through Australian Road Rules legislation (National Transport Commission, 2009).

Previous Australian legislation mandated CRS use until the age of 12 months (National Transport Commission, 1999). In 2009, more expansive Road Rules were approved by the Australian Transport Council and introduced nationally (National Transport Commission, 2009). The updated legislation extended the age of mandated CRS use for children to the age of seven years and included the following Australian Road Rules:

- All children under the age of 6 months must be restrained in a RFCRS;
- All children aged between 6 months and 4 years must be restrained by an approved RFCRS OR FFCRS, with the type of CRS dependent on the child's height and weight;
- All children aged between 4 and 7 years of age must be restrained in either an approved FFCRS with an inbuilt harness, or an approved BS, with the type of restraint dependent on the child's height and weight;
- A child aged 7 years to 16 years must travel in either an approved BS or an adult seatbelt, with the type of restraint dependent on the child's size, and;

- A person aged 16 years and over must travel in an adult seatbelt.

2.1.3. CRS standards

In Australia, all CRS that are used or sold must comply with the AS/NZS 1754 Australian/New Zealand Standards 2010 (Royal Automobile Club of Tasmania, 2018; Standards Australia/Standards New Zealand, 2010). The AS1754 describes the standards for the design, construction, performance, user instructions, marking and packaging of CRS and BS (Standards Australia/Standards New Zealand, 2010). AS/NZS 1754 tests head acceleration of ATDs that are instrumented with head and chest accelerometers and restrained in CRS in the following sled tests;

- A frontal impact at about 49km/h with a peak deceleration of 24g;
- A 90 degree side impact test with a peak deceleration of 14g and an impact speed of 32km/h, and;
- A rear impact test with a peak deceleration of 14g and an impact speed of 32km/h (Paine, Griffiths, & Brown, 2001).

In addition to structural and design safety compliance specifications, the Standards require that all CRS manufactured after 2011 must provide information on the recommended age of children for which the CRS is appropriate (National Transport Commission, 2009). It must also display a height guide to improve correct CRS choice/fit. Prior to 2011, manufacturers were required to provide recommended age and weight information only, as a guide for correct CRS choice (National Transport Commission, 2009).

2.1.4. CRS evaluation program

The Child Restraint Evaluation Program (CREP) is designed to provide advice to assist parents in making the best choices relating to CRS selection (CREP, 2014). CREP was developed by a consortium of government agencies and motorist organisations and originally introduced in Australia in 1994 (Paine & Vertsonis, 2001). CREP provides an independent consumer's guide on all compliant and approved CRS that are currently available on the Australian market (CREP, 2014). CRS are tested for their crash protection in a dynamic sled test program using a child-sized ATD or dummy. CREP also tests CRS for ease-of-use and installation. The CREP initiative tests CRS to more stringent standards and performance requirements than the Australian Standards (CREP, 2014; Paine et al., 2001). Sled tests are performed with ATDs with a focus on head excursion and impact (Paine et al., 2001). AS1754 tests are performed as described above in Section 2.1.3 plus an additional frontal test with an impact speed of 56km/h and a peak deceleration of 34g is conducted and a side impact at 45 degrees. In the side impact test, a structure that is intended to replicate the interior of a side door is added to the test configuration (Paine et al., 2001).

There are no limits set for performance; rather, CRS are compared with each other and ranked on their performance using a star rating system with an emphasis on head excursion and contact (CREP, 2014). The results of CRS tests are incorporated into a Buyers' Guide (Transport Accident Commission, 2019). Importantly, CRS are excluded from the 'preferred buy' list if the ATD has:

- Head excursion outside prescribed limits in frontal test or rear impact test, and/or;
- Head contact with the test rig during side impact test (Paine et al., 2001).

2.1.5. Anthropometric test device (ATD) to evaluate safety

The CREP and safety standard testing protocols focus on ATD head movement for evaluating the protection that would be offered to a child in the event of a motor vehicle crash (Paine et al., 2001). The safety testing is performed in a controlled, experimental condition with an ATD placed in the ideal, manufacturer recommended position (CREP, 2014; Standards Australia/Standards New Zealand, 2010).

Paediatric ATDs are full scale test devices that are designed to replicate the head and body of a child (6 months or 3, 6 or 10 years old). The ATDs are calibrated with sensors to measure the loadings associated with impact, including sensors on the head and torso (Schmitt, Niederer, & & Walz, 2004). Testing is conducted with the ATD seated in an optimal position and restrained by an appropriate and correctly used CRS (CREP, 2014).

2.2. CRS use and misuse

While CRS are evaluated in ideal laboratory conditions for the purposes of AS/NZS 1754 and CREP, research has found that appropriate and correct CRS use is not always observed in everyday motor vehicle travel (Charlton et al., 2010; Fong et al., 2017; Koppel, Charlton, et al., 2013). Although current CRS availability, legislation, manufacturing standards, and CRS evaluation initiatives have been effective in increasing CRS use to around 99 percent in Australia (Brown, Hatfield, Du, Finch, & Bilston, 2010b; Koppel, Muir, et al., 2013), motor vehicle crashes remain a leading cause of child fatality and serious injury (Commonwealth of Australia, 2018a; Mitchell et al., 2017). One potential explanation for this is that the protection provided to the child occupant by the CRS requires both appropriate and correct use (Neuroscience Research Australia and Kidsafe Australia, 2013), with incorrect and/or inappropriate use associated with increased injury risk (Bilston et al., 2007; Brown et al., 2006).

'Appropriate use' is defined as the use of a CRS by a child occupant that the system was designed for; that is, within the range for weight, height or age, as specified by the manufacturer (Brown et al., 2006). The converse of this is a type of CRS misuse and is defined in the research literature as 'inappropriate use' (Ivers et al., 2011), or use other than that for which the device was designed and safety tested (i.e., the wrong age or height, Ivers et al., 2011).

The 'correct use' of a CRS is also required for optimal child occupant safety protection. 'Correct use' is defined as the use of a CRS as specified by the manufacturer's instruction (Ivers et al., 2011). 'Incorrect use' is defined as use of a CRS in a way that is other than that intended (Ivers et al., 2011). 'Incorrect use' or misuse can be categorised into three main types, and these are defined in more detail in the methodology chapters (see Chapter 3 and 5) of this thesis. The three main mechanisms of CRS misuse are:

1. Seatbelt/harness errors, including twists, incorrect or lack of use of seatbelt/harness guides (e.g., seatbelt incorrectly placed on CRS arm support structure or harness threaded through wrong shoulder guide for child's height, and adjustment errors [e.g., loose harness/seatbelt or placed incorrectly across child's body]);

2. CRS fitment to vehicle errors; CRS not fitted to vehicle correctly according to manufacturer' instructions and according to appropriate use guidelines for a CRS, and;

3. Suboptimal child occupant positioning, when the child is not seated within the protective zone of CRS structure (e.g., head, arms, legs not optimally positioned). The optimal/ideal position for a child travelling in a CRS is defined as 'sitting in an upright, still position with their back in contact with the CRS structure' (VicRoads, 2012). When not seated in the optimal/ideal position, the child occupant is described as being out of position (OOP) or in a suboptimal position. Suboptimal positions are the focus of this research and are presented in detail in Section 2.3.

There are many influences that play a role in all three CRS misuse categories listed above. Factors range from broad demographic vulnerabilities, such as low socio-economical background and belonging to culturally and linguistically diverse (CALD) communities, (Bachman et al., 2016; Bilston, Du, & Brown, 2011; Hall et al., 2018; Keay et al., 2013) to the influence of individual behaviours such as belief systems (Hochbaum, Rosenstock, & Kegels, 1958; Rosenstock et al., 1988; Rotter, 1954; Wallston et al., 1978). The influence of behaviour is presented in an in-depth review in Section 2.5.

2.3. Mechanisms of child occupant injury

Anatomical, anthropological and biomechanical changes are evident in the developing child making them vulnerable to serious injury in the event of a motor vehicle crash (Schmitt et al., 2004). As a child ages, bone ossification and morphological and geometric changes of the spine and pelvic area occur, and relative changes in body-head proportions are observed (Schmitt et al., 2004). These developments provide increased protection against crash forces by altering the kinematics of the child's body in the event of a motor vehicle crash (Arbogast, Balasubramanian, Seacrist, Maltese, & García-España, 2009). For example the anatomical changes occurring at the atlanto-occipital joint potentially influence the degree of head excursion and acceleration in the event of a crash (Arbogast, Cornejo, Kallan, Winston, & Durbin, 2002). Until this biological transformation is complete in the human child, the additional head-neck support of a CRS is crucial for protection (Arbogast, Balasubramanian, et al., 2009; Schmitt et al., 2004). At the age of approximately eight years of age, the cervical spinal vertebrae C1 through to C7 ossify (Yoganandan, Pintar, Lew, Rao, & Rangarajan, 2011), and ossification of the iliac crest does not typically occur until the child is between the ages of 13 and 15 years, when it eventually provides added pelvic strength for seatbelt support in the event of a motor vehicle crash (Ponseti, 1978).

The types of injuries that are commonly sustained by child occupants involved in motor vehicle crashes have been well documented and generally reflect the limited capacity of the developing body to withstand biomechanical forces (Arbogast, Balasubramanian, et al., 2009; Arbogast et al., 2005). The most common types of serious injuries for forward facing child occupants are reported to involve the brain, spinal cord and abdomen (Arbogast et al., 2002; Arbogast et al., 2005; Arbogast & Jermakian, 2007; Arbogast, Locey, Zonfrillo, & Maltese, 2010; Arbogast, Wozniak, Locey, Maltese, & Zonfrillo, 2012; Brown, Bilston, McCaskill, & Henderson, 2005; Brown et al., 2006; Cameron, Purdie, Kliewer, & McClure, 2008; Durbin et al., 2003; Howard et al., 2004). Arbogast et al. (2012) analysed the data from two in-depth crash databases in the United States (U.S.); the Crash Injury Research and Engineering Network and the Partners for Child Passenger Safety Study. The research characterised 24 paediatric injuries from child occupants aged between birth and 15 years that resulted from side impact crashes. Head injuries were found to be the leading type of injury. Similar findings were reported by Stewart and colleagues (2013) who investigated severe injury patterns from all crash types resulting in child hospital admissions in Canada. The authors compared two paediatric groups: 1) aged between birth and eight years, and 2) aged between nine and 17 years and found that skull fractures, subdural hematomas, subarachnoid haemorrhage, brain contusions and edema were statistically more common in the younger age group (Stewart et al., 2013). These injury patterns suggest that, until the biological transformation is complete in child occupants, the additional head-neck support of a CRS is crucial for their protection in the event of a motor vehicle crash. The specialised protection that a CRS provides to a child occupant's head is compromised if CRS use is not ideal (Bilston et al., 2007; Brown et al., 2006).

2.4. Injury outcomes from CRS misuse

The elevated injury risk associated with CRS misuse is widely acknowledged by research from most developed countries (Bohman et al., 2018; Bulger, Kaufman, & Mock, 2008; Elliott, Kallan, Durbin, & Winston, 2006; Kapoor et al., 2011; Nance et al., 2010; Rudin-Brown et al., 2017; Wolf et al., 2017). Previous Australian research has also demonstrated that CRS misuse is associated with increased injury risk in the event of a crash, particularly to the head, spine and abdomen (Bilston & Sagar, 2007; Bilston et al., 2007; Brown & Bilston, 2006, 2007; Brown et al., 2005; Brown et al., 2006; Brown, Wainohu, et al., 2010; Charlton et al., 2005; Lucas, Brown, & Bilston, 2008; Tai, Bilston, & Brown, 2011). For example, Brown and colleagues (2006) explored the crash injury outcomes associated with optimal and suboptimal CRS use (correct CRS use and CRS misuse) from a cohort of 152 children, aged between two and eight years. Although overall general CRS use was high (94%), the authors reported that suboptimal CRS use resulted in more injuries and more severe injuries. For example, from the 152 children analysed, seven children were fatally injured – all of whom were suboptimally restrained. The authors also noted that no optimally restrained child occupants sustained any significant injuries.

Bilston and colleagues (2007) also explored the relationship between child occupant injury outcome and suboptimal CRS use. The research team confirmed the increased injury risk of suboptimal use by reconstructing eight crash scenarios of children travelling in a BS. Suboptimally restrained or out-of-position (OOP) children who sustained substantial injuries from four crash case studies were compared with four car crashes involving optimally restrained children (Bilston et al., 2007). Simulated crash tests, using the Hybrid III ATD to represent a three year old child, were conducted to examine the role of CRS use in injury prevention, with both suboptimal position and optimal dummy placement. This post-hoc crash analysis and reconstruction confirmed the significant contribution of suboptimal position to increased injury risk. Cases simulated that included misuse of a lap/sash belt (in some cases leading to head, spinal, and abdominal injuries) resulted in excessive upper body excursion (Bilston et al., 2007). Alternatively, scenarios that included optimally restrained ATDs demonstrated a reduction to the upper body motion, indicating that these serious injuries associated with excessive motion may have been able to be minimized or even prevented (Bilston et al., 2007). However, the authors cautioned that their findings were drawn from a limited number of events and that the limited ability to physically position the ATDs in realistic pre-crash postures (e.g., slumped or sleeping) for the testing likely influenced the dummy kinematics and dynamic responses (Bilston et al., 2007).

2.4.1. The burden of child occupant injury

CRS misuse elevates injury risk in the event of a motor vehicle crash (Arbogast, Jermakian, & Ghati, 2009; Bilston et al., 2007; Brown et al., 2006) with behaviour being one influential factor. Paediatric injuries are recognised as a significant global public health problem (World Health Organization, 2008) with profound implications to the injured individual, their families, community and the economy (Mitchell et al., 2017). In the US, it is estimated that US$496 million are spent in medical costs and a further US$991 million in costs of total work lost over the child's life time as a result of injuries sustained by children 0-19 years of age (Centers for Disease Control and Prevention, 2012).

In Australia, motor vehicle crashes resulted in approximately 1,146 deaths and 36,000 serious injuries in 2017 (BITRE, 2019). The annual costs are estimated at $AUD 27 billion (DIRDC, 2019). The hospitalisation costs of child occupants from motor vehicle crashes in Australia are ranked as one of the most costly at approximately $AUD12.6 million per annum over the past ten years (Mitchell et al., 2017). Head injuries are the most common cause of all injury-related paediatric hospitalisation (Mitchell et al., 2017) with transport incidents accounting for 13.7% of these injury hospitalisations. Serious head injuries, in particular, are likely to have high impact, long term and costly implications, potentially requiring rehabilitation, specialised care, funding and on-going support for the rest of their life (Australian Institute of Health and Welfare, 2011; Bureau of Infrastructure Transport and Regional Economics, 2006; Centers for Disease Control and Prevention, 2012; World Health Organization, 2008). For every single dollar spent on BS or CRS injury prevention interventions in the US, a significant savings of US$71 and US$42, respectively, is achieved (Centers for Disease Control and Prevention, 2012).

2.5. The role of behaviour in CRS use and misuse

This section provides an overview of the complex role of human behaviour and the importance of understanding behaviour relating to child occupant protection in motor vehicles. The approach draws on Behavioural Change Theories and how they can contribute to the enhancement of injury prevention programs (Gielen & Sleet, 2003). Specifically, the Health Behaviour Model (HBM) (Bandura, 1977; Hochbaum et al., 1958; Rosenstock, 1974) and the Locus of Control (LOC) theory (Rotter, 1954) were explored to better understand the role of parental factors in child occupant safety.

The HBM, initially developed in social psychology by Hochbaum (1958), is commonly used to explain and predict health behaviour based on an individual's beliefs about health (Bandura, 1971; Glanz, Rimer, & Viswanath, 2008; Janz & Becker, 1984; Rosenstock, 1974). The HBM was originally developed to explain why individuals participate in public health screening and immunisation programs, and has since been applied to other types of health behaviour (Gielen & Sleet, 2003). The foundation model describes four main constructs to account for an individual's readiness to engage in behaviour: perceived susceptibility, perceived severity, perceived benefits and perceived barriers. An added concept by Rosenstock (1974), 'cues to action', is a trigger that would activate readiness to engage in a behaviour and stimulate the likelihood of the behaviour (e.g., how-to information, awareness campaigns, reminders). In the context of child occupant safety, the constructs can be described in terms of the desired health behaviour of correct/appropriate CRS use. The HBM as applied to correct/appropriate CRS use by this PhD research program includes;

- ***Perceived susceptibility:*** the perceived likelihood of being involved in a motor vehicle crash;

- ***Perceived severity:*** the perceived seriousness of injury or fatality from a motor vehicle crash if a CRS is not used correctly/appropriately;
- ***Perceived benefits:*** the perceived additional protection offered by a correctly/appropriately used CRS;
- ***Perceived barriers:*** the perceived difficulties to correct/appropriate use, such as affordability of a CRS, time required to harness and adjust, child occupant cooperation or perceived comfort of the child occupant), and
- ***Cues to action:*** triggers to engage in the behaviour change, such as the provision of information on correct/appropriate CRS use, advice from family or friends, CRS legislation and awareness campaigns.

Following the development of self-efficacy social learning theory (Bandura, 1977), Rosenstock et al. proposed that self-efficacy be added to the HBM (Rosenstock et al., 1988). The construct of self-efficacy provided a measure of an individual's sense of confidence that they could successfully change behaviour to produce the desired outcomes (Bandura, 1977). Bandura's self-efficacy theory postulated that positive thinking, in terms of an individual's competence and effectiveness, results in behaviours such as persistence and the use of skills for problem-solving and coping to overcome life's obstacles (Bandura, 1977). The addition of self-efficacy to the HBM opened up the potential for behavioural influences, by incorporating subjective feelings, choices and motivations that are guided by personal experiences, persuasion and vicarious experiences (Glanz et al., 2008). The self-efficacy of parents relating to S use includes skillset, experience and desire to take the appropriate actions to achieve correct/appropriate CRS use. The foundation model by Hochbaum, Rosenstock and Kegals, (1958) and the revised constructs of cues to action and self-efficacy (Rosenstock et al., 1988) are depicted in an adapted version of the HBM model in Figure 5.

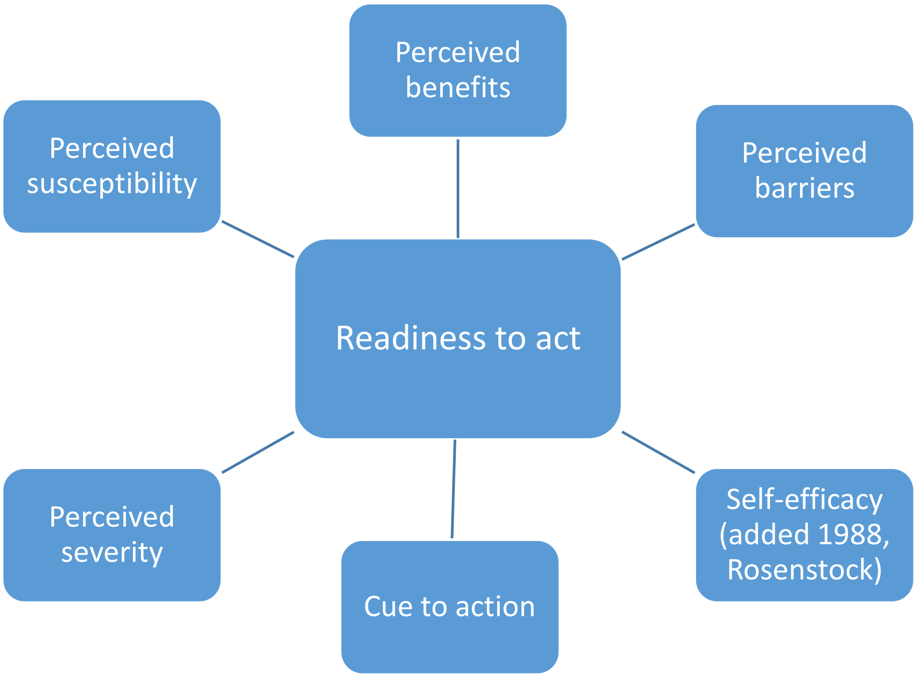

Figure 5. The Health Belief Model (HBM) – Adapted (Hochbaum et al., 1958; Rosenstock, 1974; Rosenstock et al., 1988).

The HBM has been applied in previous child injury research. For example, Peterson and colleagues (1990) demonstrated significant associations between parents' reported actions in teaching safe behaviour and HBM constructs (e.g., knowledge, competence to teach, effort required and perceived benefits to safety) relating to various injuries including transport (R^2 = .17 to .47). These findings suggest that initiatives that aim to understand and address HBM constructs can reduce child injury risk (Peterson et al., 1990). Other authors have attributed the low participation of parents in available CRS safety intervention programs (e.g., CRS checkpoints) is due to parents' perceptions of low injury risk from CRS misuse and a lack of understandable education platforms (e.g., installation instructions) (Hall et al., 2018). A cluster randomised controlled trial of 830 families conducted by Hunter and colleagues (Hunter et al., 2015) in New South Wales, Australia, also supports the value of enhancing parent knowledge. The study revealed that the use of appropriate CRS improved after the delivery of information sessions to parents of children attending preschools and day care centres. The findings that explicitly use HBM to frame their research suggest that inappropriate and incorrect CRS use can be reduced by addressing the constructs of the HBM to collect information on current CRS knowledge of parents and then develop future targeted initiatives to guide parents' beliefs and skills relating to optimal CRS use.

The LOC theory adds value to the constructs of the HBM in the prediction of behaviour by attributing the sources of control to an outcome (Rotter, 1954; Standards Australia/Standards New Zealand, 2010). The theory conceptualises an individual's belief in the extent to which they can control an outcome (Gray, 2002). Internal LOC refers to an individual's belief that an outcome is based on the result of their own responsibility, skills and efforts. In contrast, external LOC is defined as when an individual places the responsibility of an outcome in their life on outside forces, such as policy makers, fate or luck (Rotter, 1954).

Previous research findings have shown that parents with a high internal LOC are more likely to engage in behaviours that optimise the chances of direct action from the parent and a positive outcome (Sheppard & Crocker, 2008). In relation to child occupant safety, it is envisaged that a parent with high internal LOC would be more likely to be engaged, and receptive to any future travel safety initiatives (Hoyt, 1973). Road safety research has confirmed an association between high internal LOC and seatbelt use in motor vehicles (Hoyt, 1973) and an association between high driver 'externality' and involvement in fatal motor vehicle crashes (Montag & Comrey, 1987). The association between parents' beliefs relating to internal/external responsibility for children's travel safety had not yet been explored. The HBM and LOC constructs were adopted for use within this PhD research program to facilitate understanding of the multifactorial influences on parents' behaviour in relation to CRS use. A description of the approach is provided in Chapter 3, Section 3.2.

2.6. CRS use/misuse research designs

CRS use/misuse has been studied using a variety of methods, including surveys, CRS inspection programs, and more recently, NDS. Previous research investigating CRS use/misuse using these methodologies is reviewed in the following section.

2.6.1. Survey and interview information

Survey and interview methodologies enable an understanding of parents' knowledge and behaviour relating to child occupant safety and CRS use/misuse. More specifically, surveys and interviews enable information to be collected on relevant CRS related topics (e.g., transition age) and also provide an opportunity to gain information on implicit beliefs (e.g., LOC of child occupant safety). CRS use and misuse has been widely investigated through surveys and interviews in many different countries, including Australia, the US, China and Belgium (Arbogast, Durbin, Morris, & Winston, 2000; Bilston, Finch, Hatfield, & Brown, 2008; Charlton et al., 2010; Chen, Yang, Peek-Asa, & Li, 2014; Koppel, Charlton, Fitzharris, Congiu, & Fildes, 2008; Koppel, Charlton, et al., 2013; Lennon et al., 2010; Roynard, Silverans, Casteels, & Lesire, 2014).

Arbogast and colleagues (2000) conducted a survey on CRS use in the state of Pennsylvania in the U.S. This study also conducted inspections of CRS in vehicles to determine the extent to which CRS misuse can be evaluated by parental survey. The authors reported that parents were able to accurately report several aspects of CRS use—in particular, the attachment and fit of the CRS, the use of the harness clip, and the CRS incline. Arbogast and colleagues acknowledged that survey methods provide value to the research domain.

Surveys provide an opportunity to screen for correct CRS use and can assist in identifying targeted gaps in knowledge that would otherwise be time consuming through other methods such as CRS inspections.

A survey was also conducted at a trauma centre and emergency department in Southern California (U.S.) by Vaca and colleagues (2002) to explore parental knowledge of age-appropriate restraint use and airbag safety. The survey was administered to 655 parents (60% Hispanic) in native tongue. Responses revealed that only 46 percent of parents knew the appropriate weight range (40 to 60 lb) for a child occupant to travel in a BS and 59 percent knew that the California State Law required CRS use for children up to 4 years and weighing up to 40 lb. When knowledge scores were examined in association with other factors collected by the survey, ethnicity, fluency in English, income, and years of education, fluency in English was found to have the greatest influence on correct CRS and airbag knowledge. The authors concluded that survey methodology is useful for collecting background information that can guide future targeted educational initiatives, with particular inclusion of the Hispanic or other less fluent English speaking populations.

In addition to enabling identification of target groups, surveys are also able to provide valuable information on general beliefs of populations, such as parents' receptiveness to CRS use in countries with low CRS use rates. Chen and colleagues (2014) conducted static inspections that were supplemented with a survey to explore beliefs relating to CRS use in China. This research identified that although CRS use in China was very low (1%), parents' attitudes towards CRS use was encouraging with 62 percent of parents reporting that they thought it was necessary to use CRS while traveling in a car. The positive attitude of parents towards CRS use identified by Chen and colleagues holds promise that parents will also be receptive to future education and awareness efforts for improving CRS use.

Another useful application of surveys is to collect information that can assist in understanding a population-based prevalence of CRS use and misuse. A roadside survey of CRS use was conducted in Belgium (Roynard et al., 2014) to gather information on parents' beliefs relating to CRS use and obtain an estimate of CRS use and misuse. The research observed CRS use and interviewed the drivers regarding reasons for misuse. Half of the child occupants observed were not correctly restrained but interview responses revealed that most of the drivers were unaware of their own errors concerning the inappropriateness and/or misuse. The interview responses indicated no changes in the prevalence of appropriate CRS use suggesting campaigns and other actions are required to inform and motivate the population. These findings suggests that although surveys have value in providing a cost effective data collection method in child occupant safety (Arbogast et al., 2000) and can assist in identifying target groups who may benefit from interventions (Vaca et al., 2002), the accuracy of survey responses should be validated by observations, where possible.

Previous Australian survey research provides population specific information relating to CRS use relevant to this PhD research program and supports the findings from Roynard and colleagues that parents' may be unaware of what they don't know. Research conducted in Sydney, New South Wales, by Bilston and colleagues (Bilston et al., 2008) surveyed parents with children aged between birth and ten years of age over the telephone to collect information on age-specific CRS knowledge relating to best restraint transition practices and appropriate CRS use. Height and weight measurements were used as the primary criteria to assess the appropriateness of their child/children's restraint. Bilston and colleagues (2008) found that CRS knowledge regarding appropriate restraint transition points that were specific to their child/ren's age was associated with an increased likelihood of appropriate restraint use. Results differed across child occupant age groups. Parents of children aged between one and four years with the knowledge that BS should be used by children aged four years and older were nearly four times more likely to have their child appropriately restrained for their age and size. Parents of children aged between five and eight years with the knowledge that children should not use adult belts alone until at least eight years of age (or appropriate height/weight) were nearly five times greater likelihood of having their child appropriately restrained for their age and size.

Overall CRS knowledge, including items not relevant to the age of the specific child occupant, was not associated with higher appropriate restraint use. These results suggest that age-specific CRS knowledge, relating to the next ''appropriate'' transition for a particular child, can increase the likelihood of appropriate CRS use, more so than overall CRS knowledge. In this research by Bilston and colleagues, survey methodology was able to identify patterns of knowledge dependent on child occupant age and that parents generally know what they need to know for their individual child.

Additionally, Bilston and colleagues (2008) also showed that the majority (77%) of parents reported that they felt that they knew everything they needed to know to restrain their child safely (agree or strongly agree with question: ''I know everything I need to know to ensure my child is properly restrained in a car''). Yet there was no significant association between this belief and if their children were assessed as being appropriately restrained. The study highlighted that what parents report that they do 'know' does not necessarily translate into behaviour for correct or appropriate CRS use, as supported in the research conducted in Belgium by Roynard and colleagues (2014). While parents may report that they have sufficient knowledge relating to appropriate restraint use and best transition practice, this may be a misplaced belief and not aligned with current legislation and recommendations.

Factors that influence children's correct and appropriate use of restraints were also explored by Charlton and colleagues (Charlton, Koppel, Fitzharris, Congiu, & Fildes, 2006). The research surveyed 699 parents from the Australian states of New South Wales and Victoria. The survey investigated parents' knowledge about restraint usage rates, patterns of restraint use and ‘appropriateness’ of restraint use by children in the ‘BS age group’ (i.e., 4-11 years), as well as the demographic characteristics and attitudes of parents of children in the BS age group towards restraint use behaviour. One of the main findings reported by the authors was that only 24 percent of children in the ‘BS age group’ were actually travelling in a BS (Charlton et al., 2006). The remaining 76 percent were reported to be using an adult seatbelt, of which, the majority were inappropriately restrained; that is, they were too short according to the best fit for an adult seatbelt of 145-150cm as recommended in a guide developed for parents, carers and road safety practitioners (Neura, 2019; Neuroscience Research Australia and Kidsafe Australia, 2013)**.**

Using a similar survey approach, Koppel and colleagues explored the factors associated with premature graduation of Australian children 4–11 years of age into adult seatbelts (Koppel et al., 2008). The authors reported that 195 children met the BS height–weight criteria (height: 100–145 cm and weight: 14–26 kg), of which 56 percent had been moved prematurely into an adult seatbelt. A number of key predictors were identified as being associated with the premature graduation to adult seatbelts. For example, children who were moved prematurely into a seatbelt were more likely to: be older, have other children travelling in the vehicle and have younger parents compared to children appropriately restrained in a BS.

Researchers have also investigated the effectiveness of CRS-related behaviour changes following the introduction of Australia’s CRS legislation changes in 2009 (Koppel, Charlton, et al., 2013; Lennon et al., 2010; National Transport Commission, 2009). Koppel and colleagues conducted a survey of 272 parents of children between three and ten years of age (Koppel, Charlton, et al., 2013; National Transport Commission, 2009). Findings revealed several misconceptions relating to CRS use. Although most parents reportedly ‘always’ restrained their child/ren (99%), over half did not know the best time to graduate their children from a BS to an adult seatbelt (53%) or the age for which it is appropriate for their child to sit in the front passenger seat of the vehicle (20%). Similarly, Lennon, Titchener and Haworth (2010) surveyed parents to assess restraint practices in the Australian state of Queensland, following the introduction of a legislation amendment in Queensland (National Road Transport Commission, 2009). The authors interviewed parents of 153 children aged between birth and 9 years of age about legislation changes and found that the restraint status of 18 percent of the children would not be compliant with the new legislation (Lennon et al., 2010). The authors recommended that other initiatives, in addition to legislation, are required to improve child occupant safety.

The review of evidence from survey and interview methods presented here has provided important information on knowledge gaps of parents, such as CRS transition timing and regulations on age of children and front seat occupancy (Arbogast et al., 2000; Bilston et al., 2008; Charlton et al., 2006; Chen et al., 2014; Koppel, Charlton, et al., 2013; Vaca et al., 2002). However, caution is warranted when interpreting survey findings in the absence of corroborating observational information from vehicle/CRS inspections (Bilston et al., 2008; Roynard et al., 2014). Whilst surveys have provided valuable information relating to CRS use and misuse, previous research has not explored how parental beliefs may influence their use of CRS and whether their knowledge is likely to transfer to best CRS practice during real world, everyday travel.

2.6.2. Static and roadside inspections

Research conducted through static inspection stations or programs has also added to the body of evidence relating to CRS use and misuse, internationally (Bachman et al., 2016; Brown, Hatfield, et al., 2010a; Cicchino & Jermakian, 2015; Johns, Lennon, & Haworth, 2012; Koppel & Charlton, 2009; Snowdon et al., 2010). CRS are typically observed at particular roadside destinations or inspection stations and are able to provide population estimates (Snowdon et al., 2010). Several studies have focused on differences in CRS use pre and post legislation (Brubacher, Desapriya, Erdelyi, & Chan, 2016; Johns et al., 2012; Koppel, Charlton, et al., 2013), while others have compared geographical regions with/without legislation (Simniceanu et al., 2013). Static inspections at nominated inspection stations also provide the opportunity to assess if a CRS is fitted to the vehicle correctly (Cicchino & Jermakian, 2015). Vehicle seat belts can be checked to determine if they are routed through the CRS correctly, buckle/locking clips are fastened, and whether the top tether straps for FFCRS are attached to the anchor point within the vehicle and that belts are adjusted for secure fit (Brown, Hatfield, et al., 2010a). Static inspections also provide a valuable opportunity to determine appropriate use while the child occupant is using the CRS (Koppel, Charlton, et al., 2013).

Researchers have cautioned, however, that static inspections may yield different error prevalence results to roadside observations (Snowdon et al., 2010). For example, inspections generally rely on recruitment of volunteers who arguably may be more safety-conscious and therefore more likely to demonstrate correct CRS use than parents who declined to participate. To investigate this hypothesis, Snowdon and colleagues designed a multi-stage study to compare (2010) the differences in Canadian national estimates of correct child restraint use obtained using the standard roadside inspection method (with random sampling of passing traffic) compared to a parking lot static inspection/interview. The study included roadside inspections of the restraint status of 11,674 child occupants using approximate age and static inspection/parking lot interviews with 1,697 drivers. Correct CRS use for child occupants in BS was observed in nearly 68 percent of static inspection/parking lot interviews compared to just under 30 percent of roadside inspections. This study acknowledged the richer data obtained from the interview method (e.g., child occupant age, size and weight) but also recognised the value of random sampling from roadside inspections which have less potential for consent bias to inflate the correct CRS use rates

Another Canadian study (Simniceanu et al., 2013) used the roadside inspections approach to compare CRS use between provinces with no legislation, old legislation (pre-2006 and new legislation (post-2006). The research team found that legislation had an impact on restraint use in Canada with provinces with old legislation reporting significantly higher CRS use compared to those with no legislation (95% vs 82%, respectively). The research team also found that correct CRS use rates were slightly higher between provinces without legislation when compared to those with new legislation (52% and 54%, respectively). Authors suggest that a secular trend may have improved correct CRS rates in the provinces with no legislation as a plausible reason for this small difference.

In the United States, static inspections are used to collect national population estimates of CRS use every two years (Pickrell & Choi, 2014). In 2013, information was collected on 11,098 child occupants up to 12 years of age in 2013. Interviews were conducted to obtain data on race and ethnicity, as well as height, weight, and age of all child occupants who were judged to be under 13 years of age. Static inspections were conducted at gas stations, recreation centres, day care centres, and restaurants. One finding from the roadside inspections was that premature graduation of child occupants aged 1 to 3 years to a BS, significantly decreased from 2011 to 2013 (12% and 9%). This finding suggests that parents are making more informed decisions about correct CRS types and transition times. Differences in restraint use were also observed for the 4 to 7 year olds from 2011 to 2013 across ethnicity/race with a decrease in restraint use observed with Black or African-American Non-Hispanic child occupants (84% to 78%). In contrast, an increase in restraint use was observed for Hispanic or Latino child occupants across the study period (79% to 85%). In contrast, White Non-Hispanic child occupant restraint use remained comparatively high at 96% across the period from 2011 to 2013. The roadside inspection data was useful in identifying the differences between CRS practices and race and ethnicity. It suggests that child occupant safety initiatives are more effective amongst the White Non-Hispanic population and Hispanic or Latino population and more inclusive child occupant safety education efforts are needed to raise awareness amongst Black or African-American Non-Hispanic populations of the safety benefits of CRS use.

More recently, Bachman and colleagues (2016) conducted a CRS inspection study in the U.S. state of California to explore whether three factors – vehicle age, child passenger age, and child passenger weight – predicted specific aspects of CRS misuse (Bachman et al., 2016). A total of 1,104 inspections were conducted at paediatric tertiary hospital, childcare centres, churches, community centres, schools, and grocery stores (Bachman et al., 2016). A key finding was that CRS in newer vehicles were significantly more likely to have the safety belt routed incorrectly compared to those in older vehicles (OR = 1.1; 95% CI = 1.0–1.1). This was contrary to expectation and the authors speculated this may be explained in part by higher prevalence of (more complex) lap-sash seatbelts with more opportunity for routing errors compared to older vehicles which are more likely to have simple lap belts. In addition, inappropriate CRS use was observed with CRS being installed in the incorrect direction for the child occupant's age (OR = 0.82; 95% CI = 0.70–0.96) with younger child occupants being more likely to be observed facing forward instead of rear-facing. The findings from this inspection study suggest a need for further research to elucidate reasons for belt routing errors in newer vehicles and to explore initiatives for improving knowledge relating to best CRS type for child occupant age and size, and particularly for convertible CRS, which are designed for use in both forward- and rear-facing modes.

A recent European study conducted by the Belgian Road Safety Institute (Roynard et al., 2014) also employed static inspections of CRS use and misuse. The aim of this study was to obtain population-based estimates of the prevalence of use and misuse of CRS and to identify predictors of misuse on the basis of observations. A total of 1,461 child occupants (< 135 cm) were observed in detail and interviews were conducted with the driver. Some key findings from the static inspection related to adult seatbelt use. The use of a seatbelt by the driver was a significant factor associated with CRS use with 31 percent of unrestrained child occupants for unbelted drivers, compared to seven percent for belted drivers. In addition, child occupants were significantly less likely to be observed to be correctly restrained when their driver was unbelted (32%) compared to when their driver was belted (54%). The static inspection also collected information from the driver relating to CRS use and misuse and found that most of the drivers were unaware of their own errors concerning the inappropriateness and/or misuse of the CRS (Roynard et al., 2014). This study also used surveys (as discussed in Section 2.6.1) and the authors acknowledged the value of having inspections to assess the accuracy of self-reported travel safety practices.

In Australia, Koppel and colleagues (Koppel & Charlton, 2009) also investigated CRS use through inspections that were conducted at childcare centres, kindergartens, community centres, hospitals, and child expos in Australia. The study examined 1,995 CRS that were located in 1,386 vehicles. The majority of CRS (79%) were reported as having at least one instance of misuse. The most common forms of misuse included harness errors such as: adjustment, faulty, twisted, and/or incorrectly positioned (38%) and seat belt errors such as the seatbelt being incorrectly routed, twisted, and/or incorrectly adjusted (32%). Missing or incorrect fitting of gated buckle/locking clip was also observed in nearly a quarter of CRS misuse cases (23%). Brown and colleagues (2010a) also conducted onsite inspections in the Australian state of New South Wales to provide population estimates of incorrect restraint use, including across different restraint types. Results from the inspections of 501 children aged between birth and 12 years revealed that just over half (51.4%) were incorrectly restrained (Brown et al., 2010a) , with belt/harness use the most common CRS error (85%). Both studies (Brown et al., 2010a; Koppel & Charlton, 2009) reported that the most common CRS misuse observed related to the belt or harness. However, the overall rate of CRS misuse reported by Brown and colleagues (2010a) was considerably lower than CRS misuse observed by Koppel and colleagues (Koppel & Charlton, 2009) (51% vs. 79%).

Plausible reasons for this difference may be that Koppel and colleagues observed child occupants retrained in CRS only, and across a large sample from multiple states across Australia, whereas the inspections reported by Brown and colleagues involved children restrained in adult seat belts as well as CRS and inspections were restricted to the state of New South Wales only. Koppel and colleagues reported CRS misuse was highest in FFCRS when compared to BS, (88% compared to 63%, respectively), whereas Brown and colleagues found CRS misuse was higher BS when compared to FFCRS or adult seatbelt (approximately 50% for BS compared to approximately 20% for both FFCRS and adult seatbelt). The study by Brown and colleagues (2010a) also provided comparisons of multiple harness and belt errors for convertible/combination CRS (e.g., RFCRS to FFCRS or FFCRS to BS) and dedicated/single mode CRS. Multiple restraint errors (approximately 30%) were significantly more common in convertible seats than single mode restraints and reported in 31 percent of observations (adjusted for restraint type, OR 2.8, 95% CI 1.6–4.7) as were installation errors (adjusted for restraint type, OR 3.6, 95% CI 1.9–7.0). This finding was supported by more recent research that investigated CRS misuse pre- and post-legislation showing that CRS misuse was most prevalent in convertible restraints compared with dedicated forward-facing restraints (Koppel, Charlton, et al., 2013).

Johns, Lennon and Haworth (2012) also conducted roadside vehicle and CRS inspections in the Australian state of Queensland over three different time points to explore the effects of the most recent legislation amendments that were introduced in 2009 (National Road Transport Commission, 2009). Data was collected from 3,201 vehicles carrying 4,264 child occupants approximately aged between birth and 12 years, across three time points, including pre-legislation changes and post legislation changes**.** Inspections indicated that aspects of child occupant restraint improved post-legislation (Johns et al., 2012) with significantly lower ($p < .001$) observed levels of front seat use for vehicles carrying only one child occupant (from 33.6% to 21.5%) and significantly higher observed levels of child occupants using a BS (rather than adult seatbelts), which increased from 32.4 percent to 37.2 percent (Johns et al., 2012). However, Johns and colleagues (2012) noted that many children (25%) remained inappropriately seated and restrained in the front seat.

The positive impact of legislation was also shown in the roadside child occupant safety inspections conducted in areas with and without CRS legislation in Canada (Simniceanu et al., 2013). In contrast however, the findings of the survey conducted by Koppel and colleagues relating to CRS use pre- and post-legislation changes (2013) revealed no significant difference in the proportion of CRS with misuse and/or inappropriate use between the pre- and post-legislation changes. A possible reason for the difference in findings between the studies comparing pre- and post-legislation changes (Koppel, Charlton, et al., 2013; Simniceanu et al., 2013) is that Koppel and colleagues analysed the difference of overall CRS misuse, while the study by Simniceanu and colleagues was conducted in Canada and investigated BS to adult seatbelt transitions specifically.

In sum, the findings from static inspection research reviewed here has confirmed that CRS misuse is prevalent in Australia and elsewhere in the world. In the following section, research using *dynamic* observations of child occupants is reviewed. This approach has potential to reveal more in depth information on factors that contribute to CRS misuse during motor vehicle on trips.

2.6.3. Dynamic observations

Whilst static inspections provide pertinent information about CRS misuse, particularly inappropriate use and fitment errors, other approaches are necessary to capture the dynamics of child occupant travel and how the child behaves and moves within their CRS during motor vehicle trips (Andersson et al., 2010; Bohman et al., 2011; Charlton et al., 2010; Forman et al., 2011; van Rooij et al., 2005).

In one of the first studies to investigate suboptimal positions adopted by child occupants when travelling in a CRS, Van Rooij and colleagues (2005) studied ten children aged between one and three years during their everyday motor vehicle trips, on short and long drives. The virtual testing approach explored the effect of the posture of the child occupant in a CRS, on the injury potential in a typical motor vehicle crash (van Rooij et al., 2005). Parents photographed the children at the beginning and end of each trip, and at 15 minute intervals throughout the trip (van Rooij et al., 2005). A total of 141 still image photographs were analysed to determine children's positions/postures, where the 'optimal' position/standard posture was defined as the child occupant sitting up straight (van Rooij et al., 2005). From these analyses, Van Rooij and colleagues (2005) determined that child occupants commonly adopted alternative (or suboptimal) positions, including the head being tilted or rested to one side or the other.

In another component of the research, the researchers conducted virtual frontal impact crash tests through the use of ATDs and computer models (representing a child occupant aged 3 and 1.5 years of age) to compare and validate the biofidelity response of the virtual computer dummies (van Rooij et al., 2005). The MADYMO Q3 and Q1.5 dummies (MADYMO, 2004) were created using computer hardware. Computer simulations allowed for unlimited test conditions and parameters to explore conditions that may be outside of normal test range, including a variety of suboptimal positions. Dummies were seated in the optimal position prescribed by the CRS manufacturer as well as in five common child occupant suboptimal positions, as identified from the photographs from the observational study described above. Neck injury (Nij) was greater for simulations in which child occupants were in slanting positions, such as sleeping, and also when leaning to touch their feet, with legs stretched out against the front seat. Head excursion was also greater when the virtual model occupant was out of the shoulder harness. A limitation of this study was that children's seating status was obtained from static images, captured every 15 minutes during trips. This methodology, whilst informative, failed to fully capture the dynamic nature of children's behaviour while travelling.

In another small scale observational study, Andersson et al. (2010) investigated the influence of the type of BS on children's tendency to adopt suboptimal positions. In particular, the researchers were interested in exploring the effect of large side wings which, while designed to provide support to the head, also have potential to block children's view. Of interest was whether this design feature might unintentionally lead to children leaning forward in a way that potentially compromised the protection offered by the BS. Six children between three and six years of age were observed using continuous video recording during car trips. The children were taken on two trips by their parents in their own family motor vehicle during daylight hours. Each trip was between 40 - 50 minutes in duration. The children were seated in a BS with large side wings for one trip and a different BS with smaller side wings for the second trip. The positions of child occupants observed in each booster were described. When seated in the BS with large side wings, children leaned forward and adopted suboptimal positions 30 percent more often than when they were seated in the small-wing BS. The results suggested that for day time trips, BS with larger side wings may encourage children to adopt suboptimal positions.

In a similar study, Forman and colleagues (2011) examined the child occupant positions for different types of BS during night time travel. Thirty children aged seven to 14 years were observed during a 75-minute car trip in a study vehicle. A low light camera recorded the positions of the children throughout the trip. The authors analysed the first frame from each minute of the trip with the use of a head marker to determine lateral head position relative to a designated optimal position frame. The authors reported that suboptimal positions were significantly more common for child occupants travelling in a low back BS (without large side wing supports) and an adult seatbelt, compared with children travelling in a high back BS with larger wing supports. Larger side wings were observed to reduce some of the head movement, suggesting that larger side wings may be beneficial for reducing suboptimal positions for sleep and sleep behaviours that are common on longer trips (Forman et al., 2011). Perhaps unsurprisingly, these findings for a positive influence of highback BS on head position during night time travel differ from the findings for daytime travel described by Andersson and colleagues (2010). Forman and colleagues (2011) also noted that there was a tendency for a child to rest their head against the window-side of their restraint when restrained in a low-back BS or adult seatbelt. Notwithstanding the useful insights on child occupants' suboptimal positions, CRS design features, and day/night travel, the research by Andersson and colleagues (2010) and Forman and colleagues (2011) should be interpreted with caution given the small sample sizes and limited data sampling. The studies also highlighted the need to take into consideration multiple factors when interpreting NDS findings. The time of the day (night time vs day time), the duration of the trip and the seating allocation are a few factors that should be explored when assessing in-vehicle behaviour.

In a separate study, using the NDS data collected as part of this PhD research program, Arbogast and colleagues (2016) applied a different analytic approach to examine child occupant head position during everyday trips. The study quantified child occupant head position using a Kinect^{TM} sensor to collect 3D information about the position of the rear seat occupants (Arbogast et al., 2016). The authors reported that as the restraint type moved from more to less restraint (FFCRS to BS to seatbelt), the range of fore–aft head position increased: 218, 244, and 340 mm on average, respectively and also increased for left–right movement for every seat position (Arbogast et al., 2016).

Observational studies can also inform the understanding of child occupant injury risk by assessing factors involved in a motor vehicle crash by using crash data sources (Arbogast et al., 2005; Arbogast, Jermakian, et al., 2009; Asbridge, Ogilvie, Wilson, & Hayden, 2018). A systematic review and meta-analysis on impact of BS use on child injury and mortality was conducted by accessing three crash data sources in the United States to explore whether BS, compared to seatbelts alone, reduce injury and mortality from a motor vehicle crash (Asbridge et al., 2018). The review included studies that focussed on child occupants aged between four and eight years, who had been involved in a motor vehicle crash (Asbridge et al., 2018). The researchers (Asbridge et al., 2018) confirmed that CRS use reduced the risk of injury - with high-backed BS use reducing the risk of minor and moderate injuries compared to no BS use.

Another valuable application of dynamic observation is that it provides valid, real-world data on child occupant kinematics for use in simulated crash testing of ATDs for injury risk predictions during (Arbogast, Balasubramanian, et al., 2009; Gras, Stockman, & Brolin, 2017; Stockman, Bohman, & Jakobsson, 2013a, 2013b). Conventionally, safety testing of the structure and performance of CRS is conducted in a controlled, experimental condition with an ATD or dummy placed in the ideal, manufacturer recommended position. Paediatric ATDs are full scale test devices that are designed to replicate the head and body of a child (6 months or 3, 6 or 10 years old). The dummies are calibrated with sensors to measure the loadings associated with impact, including sensors on the head and torso (Schmitt et al., 2004). Although the use of ATDs provide valuable information on predicting injury risk, there are concerning limitations of findings of crash simulations; in particular, children do not behave like ATDs and rarely sit perfectly still while travelling in their CRS (Charlton et al., 2010). Observational research confirms this limitation. For example, research by van Rooij and colleagues (2005) highlighted the importance of testing CRS effectiveness with ATDs in suboptimal positions and contributed to the understanding of the impact of suboptimal position on safety (van Rooij et al., 2005). Optimal positioning of an ATD in a CRS bears little resemblance to the real-world behaviour of children in cars. Children often adopt positions which might be described as suboptimal (e.g., head is well forward of the CRS, the torso slouches or leans sideways) (Andersson et al., 2010a; Charlton et al., 2010a; Forman et al., 2011a; van Rooij et al., 2005). These findings highlight the importance of considering commonly observed child occupant positions when testing the safety protection offered by a CRS.

Controlled sled test environments have explored child occupant safety through the replication of vehicle manoeuvres or crash scenarios (Arbogast, Balasubramanian, et al., 2009; Stockman et al., 2013a, 2013b). Recent research has also used dynamic observations to compare ATD and child occupant kinetics during motor vehicle trips (Stockman et al., 2013a, 2013b). One study (Stockman et al., 2013a) investigated the shoulder belt position and movement of ATDs during steering manoeuvres and compared the kinematics with child occupant volunteers, 4 to 12 years, in the same test setup. The kinematics of the ATDs (Q6, Q10, and Hybrid III 6- and 10-year-old ATDs) and the child occupant volunteers were evaluated in a backless BS cushion and a high backed BS. The research team found that in the later phase of the steering manoeuvres, the lateral motion of the forehead and upper sternum was less for the ATDs tested (7-34%) than the child occupant volunteers (Stockman et al., 2013a). A difference reported was that ATDs tended to fall inboard during emergency steering manoeuvres where children, on the other hand, attempted to return to their initial seated position (Stockman et al., 2013a).

Another study by Stockman and colleagues (2013b) compared the kinematics of child occupant volunteers and ATDs during emergency braking events. The study compared child occupant movement (when seated in a backless BS cushion or a high backed BS) with the Q3, Hybrid III (HIII) 3-year-old, 6-year-old, and 10-year-old ATDs on a braking event. Child volunteers had greater maximum forward displacement of the head and greater head rotation compared to the ATDs (Stockman et al., 2013b). This confirmed the differences in kinematics of child occupants and ATDs observed in their previous work on steering manoeuvres, and showed that child occupants responded to hard braking by rebalancing and correcting their seating position. The results of studies by Stockman and colleagues (Stockman et al., 2013a, 2013b) provide further evidence confirming that children do not behave like ATDs when travelling in a CRS (Andersson et al., 2010; Bohman et al., 2011; Charlton et al., 2010; Forman et al., 2011; van Rooij et al., 2005)

2.7. Where to from here?

A review of literature has identified that motor vehicle crashes remain a leading cause of death and serious injury for children (Australian Coordinating Registry, 2019; Australian Institute of Health and Welfare, 2012b, 2019; Commonwealth of Australia, 2018a), that incorrect and inappropriate CRS use is common (Andersson et al., 2010; Charlton et al., 2010; Forman et al., 2011; van Rooij et al., 2005) and that incorrect and inappropriate CRS use is associated with an increased injury risk in the event of a motor vehicle crash (Bilston et al., 2007; Brown et al., 2006). Optimal protection requires both correct and appropriate

CRS use. Australian research based on CRS inspections indicates that CRS misuse occurs in nearly 80 percent of CRS assessed (Koppel, Charlton, & Rudin-Brown, 2013b). Dynamic observational studies provide evidence that children do not behave like ATDs and commonly adopt a variety of suboptimal positions when travelling in a CRS, however there is limited knowledge about children's interactions with: i) the CRS being used, ii) the motor vehicle, ii) other car occupants, and iv) other contextual factors (i.e., parents' beliefs, trip circumstance, trip length). This PhD research program will contribute to the understanding of the way in which behaviour can lead to optimal vs suboptimal (potentially risky) CRS use by using both survey and NDS methods to collect this information.

A recent Australian pilot study employed NDS methodology to study child occupant positions during real-world everyday driving trips with the aid of covert in-vehicle cameras. Charlton and colleagues (2010) conducted a small-scale pilot study of 12 families (including 19 drivers and 25 children) to examine the feasibility of observing child occupant behaviour in passenger motor vehicles during real-world trips. Participants drove an instrumented study vehicle for a period of three weeks. Suboptimal position was defined as placement of the child's head, body and limbs outside of the protective zone of the CRS structure (Charlton et al., 2010). Analysis of video recordings for 92 trips revealed that all 25 children were out of the protective zone of the CRS and in a suboptimal position at least once per trip and on average, children were observed as being in a suboptimal position 70 percent of the total trip time analysed.

Naturalistic observational research is costly and resource intensive but the method provides a valuable opportunity to study the role of various factors in influencing children's seating position in their CRS during motor vehicle travel. Limitations of the pilot study by Charlton and colleagues (2010) included: a small sample size, a small number of trips analysed, the multiple biological areas (head, body, limbs) that defined suboptimal position and hence varied injury risk, and that the behavioural factors that may be contributing to child occupants adopting a suboptimal position were not fully explored. Other previous NDS have also been limited by their relatively small sample sizes (Andersson et al., 2010; Forman et al., 2011; van Rooij et al., 2005). Larger scale studies are essential to identify common suboptimal positions and to provide a more comprehensive understanding of factors that might influence the optimal and suboptimal head position of the child occupant, and hence the protection provided by a CRS.

NDS methods for studying children's behaviour in cars offers a number of advantages over other methods. Surveys of parents designed to elicit information about children's behaviour (Bilston et al., 2008; Koppel, Muir, et al., 2013) are susceptible to response bias due to social desirability. Crash data from parents or from official surveillance records may also be subject to bias and the delay in obtaining the information can potentially reduce accuracy and completeness of the data on critical details, for example; memory recall deficiencies in a stressed situation or that the CRS may have been removed and is no longer fitted to the vehicle at the post-crash vehicle inspection (Lesire et al., 2001).

The findings from the studies reviewed in this chapter have highlighted the need to improve the ecological validity of CRS crash protection and injury outcome evaluations. Importantly, the review highlighted the need to improve understanding of child occupant behaviour when travelling in a CRS. Further research in child occupant behaviour needs to build on existing findings by conducting; i) comprehensive surveys that include behaviour change constructs, and; ii) more in-depth observational studies enabling the analysis of interactions between children, CRS and other characteristics of the trip to identify the range of potential factors that might influence child occupant suboptimal position.

3. Method for Driver Demographic and Child Restraint Online Survey

This chapter describes the development and method for implementation of the Driver Demographic and Child Restraint Online Survey (DDCROS, see Appendix F). The DDCROS was developed to elicit information about Australian parents' beliefs about correct CRS use, child occupant safety and influence on motor vehicle safety.

The HBM was used to guide the development of survey questions in DDCROS (Chapter 3 – Online Survey Methodology; Appendix F) and the interpretation of parents' responses in Paper 1 (Chapter 4). The exploration of demographics, psycho-social variables and the CRS-related knowledge of parents from the online survey of this research will help guide targeted and tailored interventions to improve overall efficacy (Glanz et al., 2008). Parents' knowledge of CRS contributes to the perceptions of susceptibility and severity and perceived benefits (Butler, 2001a). Furthermore, the exploration of parents' attribution of responsibility or LOC for child occupant safety may assist in understanding the information uptake from correct/appropriate CRS initiatives. Overall, the findings from this survey are expected to assist in the development of a set of recommendations for promoting travel safety awareness, addressing gaps in CRS-related knowledge and guiding targeted educational initiatives for parents that relate to correct and appropriate CRS use and child occupant safety.

3.1. Participants

Parents were eligible to complete the DDCROS if they: 1) had at least one child that usually travelled in either a FFCRS or a BS, and 2) resided in Australia. A total of 380 Australian parents completed the survey and reported on the behaviour of 719 child occupants.

3.1.1. Recruitment

Recruitment was multi-modal with the objective to achieve a sample that was representative of the Australian parenting population (see Figure 6). To facilitate this target, data from the Australian Institute of Health and Welfare (AIHW), Australia's Mothers and Babies, 1995 and 2005 report (Australian Institute of Health and Welfare, 2005) and the Australian Bureau of Statistics (Commonwealth of Australia, 2012) were used to estimate the ages of the current parenting population of Australia. The AIHW (2005) data indicated that first time Australian parents over the age of 35 doubled, from five - ten percent, in the preceding decade. The Australian Bureau of Statistics (ABS) also reported that the median age of Australian mothers and fathers was 30.7 years and 33.1 years respectively (Commonwealth of Australia, 2012). Based on these data, adults aged between 25 and 49 years were specifically recruited for this study.

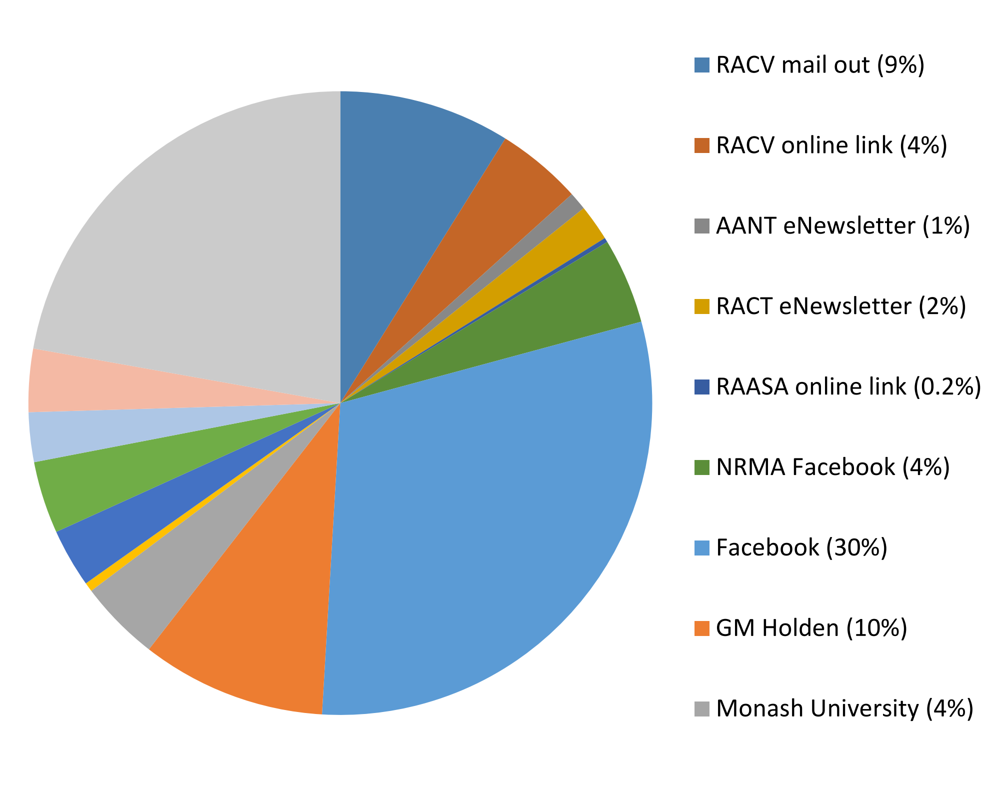

Figure 6. Participant recruitment sources

Recruitment pathways included project partner information dissemination, Australian automobile clubs, social media (Facebook™), poster displays at day care centres near Monash University (see Appendix G) and television and newspaper media. A major recruitment source was the RACV through the automobile club's membership. Random selection of RACV members invited to participate was stratified by the geographic location of the Australian population (74% metropolitan and 26% rural) using categorisation by Local Government Area (LGA). This approach aimed for a representative group from the Victorian metropolitan and rural population (Australian Government, 2019). The RACV mailed 2,000 study invitations (see Appendix H) to selected members on their database who were in the eligible age range and was guided by past response rate of approximately 17 percent from surveys previously conducted in Australia (Charlton et al., 2006). The study invitation included an Explanatory Statement and a link to the online survey.

3.2. Materials

The DDCROS was developed from:

i) Survey items used in a pilot study conducted by the team from the broader ARC Linkage Project (Charlton et al., 2010);
ii) New content from prominent theories, models and scales including the HBM (Bandura, 1971), the LOC theory (Rotter, 1954) and the application of the

Health Belief Model (Butler, 2001b) and validated LOC scales (Huang & Ford, 2012; McDonald et al., 2004; Montag & Comrey, 1987; Özkan, Lajunen, Doğruyol, Yıldırım, & Çoymak, 2012; Wallston et al., 1978), and;

iii) New content from consultation with disciplinary, government and industry experts (broader ARC Linkage Project partners).
  - VicRoads, TAC and RACV were consulted on question development for travel safety beliefs and attitudes to ensure that wording was appropriate in terms of current policy and recommendations.
  - General Motors Holden and Britax were consulted on areas of interest in relation to child occupant and CRS/vehicle interactions.
  - Dr Kristy Arbogast, The Children's Hospital of Philadelphia, Dr Katarina Bohman, Chalmers University of Technology and Dr Christina (Missy) Rudin-Brown (Transport Canada) provided valuable guidance on survey content at Project Advisory Committee (PAC) meetings.
  - Supervisors Professor Judith Charlton and Associate Professor Sjaan Koppel (Monash University Accident Research Centre) were pivotal in assisting with the survey structure and the content.

The DDCROS comprised five discrete sections and 181 items:

Section 1: Participant demographics gathered demographic information from the participant/parent. This section included: gender, age, income level and education level. Number of questions in section = 9.

Section 2: Driving history gathered information relating to the parents' driving information and history: years on full licence, restrictions on licence, type of vehicle driven, the involvement in any motor vehicle crash in the last two years (of self or any of their children), and traffic infringement received in the last two years. Number of questions in section = 14.

Section 3: CRS use gathered information on all of the children in each family under the age of 16 years. This included questions related to: age, gender, height, weight and the type of restraint or CRS each child usually used. It also obtained information on where in the motor vehicle each child typically travelled and if this seating position ever changed, and if so, why? Parents also reported on their children's activities or interactions observed during driving trips as well as typical movements associated with those activities/interactions (i.e., leaning, reaching, sleeping, moving limbs around) and their beliefs about how this affects their children's safety (e.g., improves, no affect observed or worsened). Number of questions in section = 49.

Section 4: Travel safety beliefs and attitudes gathered information on parents' knowledge relating to child occupant safety. Section 4 was guided by a theoretical model, the HBM (Bandura, 1977; Rosenstock et al., 1988) and the LOC theory (Rotter, 1954) as introduced in

Chapter 2: Literature Review (Section 2.5). The HBM model suggests that if an individual believes that they have the skills and information required to fulfil a task, then they are more likely to perform the task (Bandura, 1977; Rosenstock et al., 1988). According to the constructs of the HBM, particular elements are required for behaviour change action. These include self-efficacy, beliefs relating to susceptibility to injury, awareness of benefits and beliefs relating to the risk of injury. The constructs were explored to better understand parents': i) awareness of their child/ren's susceptibility to injury (threat) in the event of a motor vehicle crash if not optimally restrained in a CRS, ii) awareness of the improved safety (benefits) offered from appropriate and correct CRS use, and iii) beliefs relating to the safety consequences and risk from non-compliance. Examples of questions in this section included knowledge of the recommended size for a child occupant to transition into the next CRS type, awareness of the need to adjust the harnesses/seatbelt for each trip, and assessing for correct use of sash guides on BS to assist in correct belt placement around the child. Number of questions in section = 41.

The format and content of questions in this section comprised the following:

- 10 True or False questions relating to current child occupant safety legislation, safety recommendations and correct CRS use. Parents were asked to respond to ten questions relating to CRS use and child occupant safety that were guided by Australia Road Rules (National Transport Commission, 2009). The information from parents' responses was used to assist in understanding the areas of child occupant safety in which parents are best informed and areas in which gaps in knowledge from misconceptions and mistaken beliefs exist. Responses were classified as correct (CRS knowledge) or incorrect (misconceptions/mistaken beliefs) (see Appendix F).

- 11 questions collected information on parents' beliefs relating to their own driving performance and observations relating to child occupant activities and postures. This information was collected to improve understanding of the nature and frequency of child occupant activities and parents' perceptions about whether these activities have a protective or detrimental influence on their driving performance (e.g., Worsens, No affect, Improves).

- 20 questions focused on factors that may contribute to driving distraction and their perceived relationship with driving performance (e.g., talking to passengers, crying or misbehaving children and mobile phone use). These questions were designed to collect information on prevalence of engagement in potentially distracting activities and parents' perceptions of the extent to which activity affected their driving performance (e.g., Worsens, No affect, Improves).

Section 5: General Beliefs and Attitudes included a total of 68 questions that were developed using HBM (Hochbaum et al., 1958; Rosenstock, 1974; Rosenstock et al., 1988) and LOC constructs (McDonald et al., 2004; Montag & Comrey, 1987; Rotter, 1954; Wallston et al., 1978).

- Three independent and validated LOC scales were adapted to explore associations with child occupant safety knowledge and travel safety beliefs. The LOC constructs are discussed in more detail in the literature review presented in Chapter 2:
  1. The Internal-External LOC scale developed by McDonald and colleagues (2004). This LOC scale was used to explore whether there is a link between the salient personality characteristic of LOC and strategic decision-making. Participants' responses on 10 questions were collected using 5-point likert scales (where 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree and 5 = strongly agree). Scores ranged from 5 to 50, with lower scores representing internal LOC and higher scores representing external LOC. (See Appendix F).
  2. Multidimensional Health LOC scale developed by Wallston and colleagues (1978) explored three dimensions of LOC (internal, powerful others and chance). This scale collects information relation to health and well-being and was included as a method to elicit information on beliefs relating injury prevention. Participants' responses to six questions from each internal, powerful others and chance dimensions were collected using 5-point likert scales (where 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree and 5 = strongly agree). Scores on the three dimensions (internal, powerful others and chance) ranged from 6 to 30, with higher scores representing LOC on each. (See Appendix F).
  3. LOC scales of Driver Internality and Externality developed by Montag and colleagues (1987) focussed on road safety and collected information on where the parent / driver placed responsibility when travelling in a motor vehicle. Scores on 15 questions from each of internal LOC (Driver Internality) and external LOC (Driver Eternality) were collected from the Driver Internality scale using 5-point likert scales (where 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree and 5 = strongly agree). Scores ranged from 15 to 75, with higher scores representing internal or external LOC, respectively. (See Appendix F).
- 10 questions captured beliefs relating to safety accountability, perceived risk of being involved in a motor vehicle crash and actions to mitigate risk. These questions were included specifically to collect information on the HBM element of perceived susceptibility (Rosenstock et al., 1988). Parents were asked to rate their level of concern of being involved in a crash on a 4-point likert scale (where 1 = not at all concerned, 2 = somewhat concerned, 3 = quite concerned, 4 = extremely concerned) (see Appendix F). This information provided an indication of whether parents perceived being involved in a motor vehicle crash as a 'real' threat. Understanding perceived susceptibility to an undesirable outcome, such as injury, also helps to

predict whether an individual will be more likely to engage in preventative behaviours. To explore parents' behaviours that may reduce potential injury risk in the event of a motor vehicle crash, parents were asked if they had ever observed any of their children, deliberately or otherwise, removing their belts or harnesses while travelling in their CRS or BS. If parents had observed such behaviour, they were asked how they would normally respond (see Appendix F).

3.3. Procedure

Ethics approval was granted from Monash University Research Ethics Committee (MUHREC) on March 25th 2013 to conduct this research project (see Appendix I).

The DDCROS (see Appendix F) was administered to participants online to collect national information from the Australian parent population. Parents were invited to complete all sections of the DDCROS. Four questions required a forced response: i) participant's gender, ii) whether they hold a full Australian driver's licence, iii) number of children that they usually travel with in the car, and iv) participant's postcode. Responses to all other questions were voluntary. All surveys were submitted to the MUARC researcher electronically through the Qualtrics survey platform and participants remained anonymous unless they volunteered their contact details (at the completion of the DDCROS) to register their interest in participation in other research projects.

3.3.1. Piloting

The DDCROS was piloted with ten disciplinary experts, including the investigators and partners from the ARC Linkage Project, to assess for content accuracy and research relevance. It was also piloted with six parents with children in the target age range, for assessment of clarity and face validity. The DDCROS took approximately 25-30 minutes to complete.

3.4. Analysis

Responses to the DDCROS were collected from 569 Australian parents with at least one child aged between one and eight years who used a FFCRS or BS. A total of 189 incomplete surveys were removed from the analyses due to missing data (i.e., responses relating to CRS related knowledge). Responses from the remaining completed surveys were downloaded and imported into SPSS Statistics 20.0 for analysis.

A total of 380 complete responses were analysed. Descriptive analyses were used to describe sample characteristics and responses to relevant DDCROS items, including: driving, history, CRS use, CRS-related knowledge, and beliefs relating to travel safety.

CRS-related knowledge was determined using ten true or false questions – where scores were summed (i.e., maximum score = 10). For the purpose of further analyses, parents were divided into two groups based on an arbitrary cut-point: low CRS-related knowledge score group (i.e., 7 correct responses or less) and high CRS-related knowledge score group (i.e., 8 correct responses or more), representing 40 percent and 60 percent of the total sample, respectively. The low CRS-related knowledge score group and the high CRS-related score group were compared using chi square analyses to identify any differences in CRS-related knowledge and parent characteristics and driving history. Findings are presented in Publication 1 (see Chapter 4).

Tests for differences were also conducted to explore relationships between parents' CRS-related knowledge score groups and i) their attribution of responsibility to each of the eight child occupant safety factors (4 internal/4 external scores), and; ii) their total scores on each of the LOC scales that were not specific to child occupant safety (McDonald et al., 2004; Montag & Comrey, 1987; Wallston et al., 1978). T-test analyses also revealed no significant differences between the CRS-related knowledge score groups (high/low) and i) parents' attribution of responsibility to child occupant safety factors, or; ii) parents' total scores on the LOC scales (see Appendix J). Consequently, the data from the LOC scales and relationships between CRS-related knowledge scores and attribution of responsibility were not included in any subsequent analyses and the non-significant findings are acknowledged and briefly discussed in Chapter 8.

4. Publication #1

Cross, S. L., Charlton, J. L., & Koppel, S. (2017). Understanding parental beliefs relating to child restraint system (CRS) use and child vehicle occupant safety. *Journal of the Australian College of Road Safety, 28*(3), 43-54.

4.1. Introduction

The first publication presents the findings of the DDCROS (see Appendix F). It is represented in Stage 1 of this PhD research program, as highlighted in Figure 7 below (see Chapter 3, Appendix F).

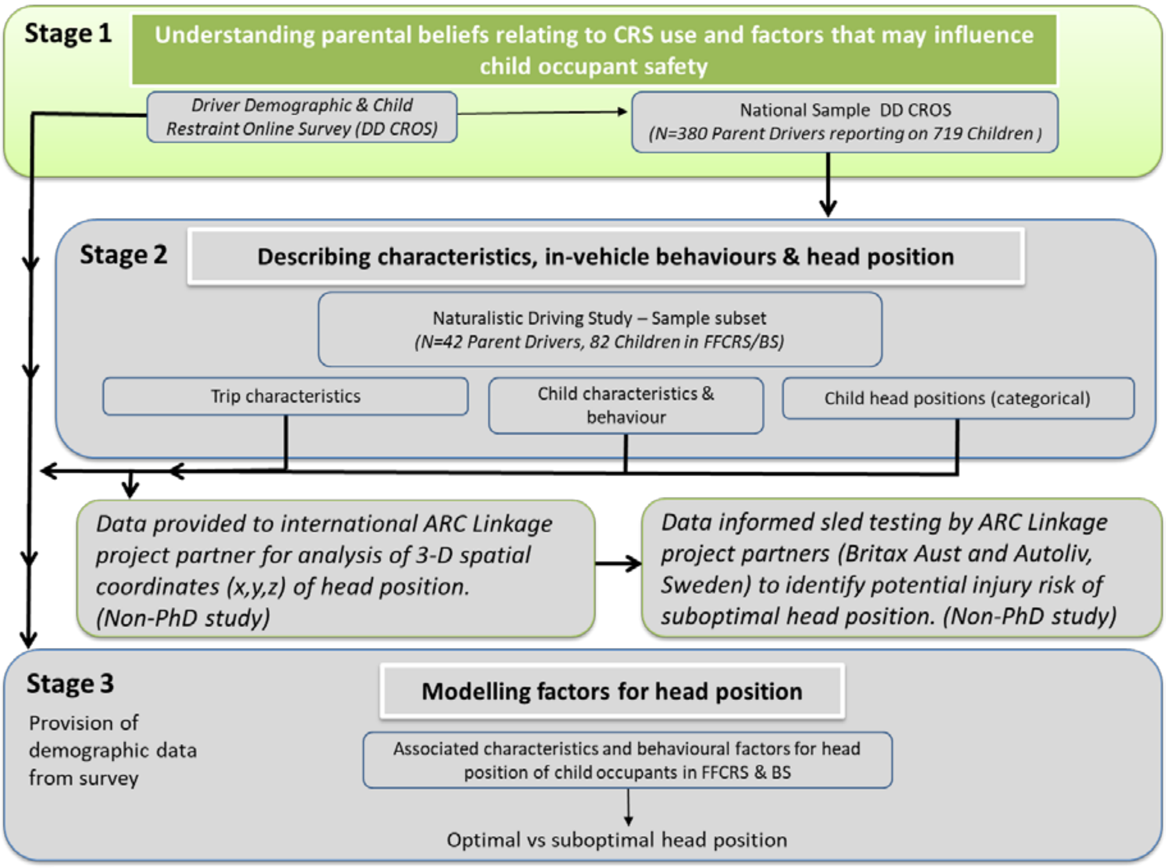

Figure 7. Stage 1 of the PhD research program

The overarching aim of this PhD research program was to examine how child occupants were restrained and behaved in their CRS during every-day motor vehicle trips. One of the key approaches to understanding child occupant behaviour in their CRS was to explore parental beliefs relating to CRS use and child occupant safety. Previous research that has used the HBM and LOC as frameworks suggest that individuals who hold beliefs conducive to safety are more likely to engage in safe behaviours (Butler, 2001a; Gielen & Sleet, 2003; Hoyt, 1973; Peterson et al., 1990). This study explored parents' CRS-related knowledge and their beliefs relating to child occupant safety practices (e.g., best transition times, CRS harness/belt adjustments for each trip). It provides an understanding of how receptive parents may be to future initiatives by exploring where they attribute the responsibility of child occupant travel safety (to self or others). The specific aim of the current study was to explore parents' beliefs relating to CRS use, travel safety and the factors that may influence child occupant safety. The DDCROS provided information on 181 questions relating to demographics, driving history, CRS use, travel safety beliefs and attitudes and general beliefs and attitudes.

The publication described new information on parents' knowledge and beliefs relating to child occupant safety when travelling in a CRS. New information includes;

- **CRS-related knowledge varies among parents;** Females and parents who had a child aged less than four years were more likely to have higher CRS-related knowledge scores compared to males and parents who did not have a child aged less than four years of age. These findings may be explained in terms of females and parents with children aged less than four years of age being more exposed to maternal health care providers and other child-related health professionals where they may have been given information on correct and appropriate CRS use than males and parents of children aged older than four years of age.
- **There are a number of important gaps in parents' knowledge regarding correct and appropriate CRS use;** more than half of parents (59%) reported that the minimum recommended height (145cm) for a child to most safely transition from a BS to an adult seatbelt would be reached by most children by seven years of age. This highlights that over half of parents have limited knowledge of important information relating to transition to different restraint type.
- **The majority of parents attribute the responsibility of child occupant safety to internal factors such as their own driving abilities (64%), safety compliance (64%) and their choice of CRS (61**%). Using a LOC framework, these findings have important implications for behaviour change. In particular, those who indicated high internal control for their children's safety are more likely to be receptive to adopting behaviour changes such as precautionary travel safety behaviours, than parents who consider the responsibility to be placed with others, luck or fate.
- **The HBM (Hochbaum et al., 1958; Rosenstock, 1974) provided a framework for questions explored in this publication;** about parents' beliefs and knowledge regarding CRS use, and parents' perceived susceptibility of being involved in a motor vehicle crash. The HBM assisted with interpretation of these findings by providing evidence that parents are aware of susceptibility to child occupant injury in the event of a motor vehicle crash and will likely be receptive to the uptake of targeted education campaigns on child occupant safety (e.g., best time to transition to a seatbelt). The HBM theory also indicates an opportunity to improve cues to action and self-efficacy by continuing to provide CRS-related safety knowledge to parents as their children get older.

The DDCROS survey provided a cost and time effective way to collect information from parents relating to CRS use, beliefs and influences. It adds to previous research by identifying targeted demographics for future initiatives and the specific gaps in CRS-related knowledge. Importantly, the exploration of parents' attribution of responsibility for child occupant safety indicates that parents attribute child occupant safety to internal factors and will therefore be likely to be receptive to adopting any behaviour change recommendations that are communicated through injury risk reduction initiatives.

The DDCROS also provided a recruitment pathway for the NDS that was used for Stages 2 and 3 of this PhD research program (see Chapters 6 and 7 respectively, see also Figure 7). The NDS methodology used to collect the real-world child occupant data analysed in Stages 2 and 3 is presented in Chapter 5.

Understanding parental beliefs relating to child restraint system (CRS) use and child vehicle occupant safety.

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Key Findings

- Despite motor vehicle crashes being a leading cause of childhood death and serious injury in Australia, significant gaps remain in parents' knowledge regarding child restraint system (CRS) use and child occupant safety.
- More than half of the parents who completed an online survey (59%) reported that the minimum recommended height (145cm), for a child to most safely transition from a CRS to an adult seatbelt, would be reached by most children by the age of seven years.
- Parents tended to attribute the responsibility of child vehicle occupant safety to internal factors such as their own driving abilities and their own safety compliance, rather than external factors such as fate.
- Results suggest that there are still significant gaps in parents' understanding about CRS use and child occupant safety which is important for the development and success of future child occupant safety initiatives.

Abstract

The aim of the current study was to understand Australian parents' beliefs relating to child restraint system (CRS) use and child vehicle occupant safety. Three hundred and eighty parents completed an online survey related to CRS knowledge and their beliefs about which factors (the influence of internal and external) influence child vehicle occupant safety. The online survey was active from June 2013 until November 2014. Results revealed a wide variation in parents' beliefs relating to CRS use and child vehicle occupant safety. The majority of parents responded correctly to CRS related questions, including: the appropriate CRS for child vehicle occupants aged between four and seven years (95%); and the need to adjust CRS harnesses for each trip for optimal safety (91%). However, half of the parents (50%) held the misconception that the after-market H-harness accessory, provided additional protection to their child/ren, regardless of the context of use and 41 percent of parents incorrectly believed that their child/ren would reach the recommended height (145cm) for a safe adult seatbelt fit by the age of seven years. Parents tended to attribute the responsibility of child/ren's vehicle occupant safety to internal factors such as their own driving abilities (64%) and their own safety compliance (64%), rather than external factors (e.g., fate [7%]). The results of the current study suggest that there are still significant gaps in Australian parents' understanding about CRS use and child occupant safety which is important for the development and success of future child occupant safety initiatives.

Keywords

Child vehicle occupant safety, child restraint systems (CRS), CRS use, CRS misuse

Introduction

Motor vehicle crashes remain a leading cause of childhood death and serious injury in Australia and in most OECD countries (Commonwealth of Australia, 2016; World Health Organization, 2008). Child Restraint Systems (CRS) are designed to provide specialised protection to child vehicle occupants in the event of a crash, with research demonstrating that CRS can effectively reduce the risk of child vehicle occupant death and injury by approximately 70 percent when compared to restraint by an adult seatbelt (Brown, McCaskill, Henderson, & Bilston, 2006; Durbin, Elliott, & Winston, 2003). The Australian government introduced new CRS legislation in 2009 mandating the use of an age-appropriate CRS until children reach the age of at least seven years (National Road Transport Commission, 2009). The updated legislation included the following Australian Road Rules (National Road Transport Commission, 2009):

- All children under the age of 6 months must be restrained in a rearward-facing approved CRS;
- All children aged between 6 months and 4 years must be restrained by a rearward-facing OR forward facing approved CRS, with the type of restraint dependent on the child's height and weight;

- All children aged between 4 and 7 years of age must be restrained in either a forward-facing approved CRS with an inbuilt harness, OR an approved belt-positioning booster seat, with the type of restraint dependent on the child's height and weight;
- A child aged 7 years to 16 years must travel in either an approved booster seat OR an adult seatbelt, with the type of restraint will depend on the child's size, and
- A person 16 years of age and over must travel in an adult seatbelt.

In addition, the legislation states that CRS transitions (from one type to the next) be guided by age, however transitions are also dependent on the child's size (National Road Transport Commission, 2009). Shoulder markings on CRS provide a visual guidance for transition based on size and are now included in the Safety Standards of all CRS (Standards Australia/Standards New Zealand, 2010). Use of a child safety harness with a belt positioning booster seat (BS), commonly referred to as the H-harness, 'is recommended only in situations where it is not possible to replace (the) lap-only seatbelt with a lap-sash seatbelt' (VicRoads, 2014, p. 1).

Previous research indicates high CRS use rates by Australian child vehicle occupants aged 0-12 years (Koppel et al., 2008; Koppel et al., 2013b), however the specialised protection provided by CRS relies on correct and appropriate CRS use. 'Incorrect CRS use' is defined as the use of a CRS system contrary to the manufacturer's instruction, and used in ways other than those intended and includes: installation errors, harnessing/belt errors, and child movement/posture away from the 'ideal' position within the CRS (Ivers et al., 2011). 'Inappropriate CRS use' is defined as the use of a CRS by a child that is not within the height or age range for which the system was designed and safety tested (Ivers et al., 2011). Australian research suggests that there are significant implications of CRS misuse for injury risk in the event of a motor vehicle crash, particularly to the head, spine and abdomen (Bilston et al., 2007; Brown et al., 2006).

The role of parental knowledge and CRS use and child vehicle occupant safety

The relationship between parents' knowledge and CRS use and misuse was recently investigated following the introduction of Australia's CRS legislation changes in 2009 (Koppel, et al., 2013b). Koppel and colleagues surveyed 272 parents with children aged between three and ten years. Findings revealed that although most parents reportedly 'always' restrained their child/ren (99%), over half did not know the best time to graduate their children from a booster seat to an adult seatbelt (53%) or the age for which it is appropriate for their child to sit in the front passenger seat of the vehicle (20%). However, previous research has not explored how parental beliefs may influence their use of CRS.

Parental beliefs

The Health Belief Model (HBM) offers a useful framework for understanding how parents' knowledge and beliefs might guide their expectations and influence their behaviour with respect to their children's transportation safety (Butler, 2001). The HBM has its foundations in Social Learning psychology and focuses on understanding beliefs to assist in the prediction of health behaviours (Bandura, 1971; Rosenstock, 1974). In the HBM, beliefs are explained in terms of perceptions of threat, perceived benefits and the perceived consequences (Nelson & Moffit, 1988). Perceptions are described as an individual's internal 'picture' or representation of the world (Reisberg, 2007). Existing belief systems, their subjective interpretation and reflection on past experiences assist the individual to evaluate and interpret a situation or event (Stutts et al., 2003). Importantly, the perception formed, may either reflect reality, or may not, that is, it may be a misconception (Weiten, 2005).

The HBM has been successfully applied to child injury research by Peterson and colleagues (Peterson, Farmer, & Kashani, 1990). Findings from this research show a significant positive association between HBM belief constructs of parents (knowledge, competence to teach, effort required and perceived benefits to safety) and reported teaching and environmental interventions to reduce child injury risk. In other research, the HBM has been used to explore parents' perceptions of risk for the purpose of guiding future interventions for improving CRS use (Chen, Yang, Peek-Asa, & Li, 2014; Will & Geller, 2004).

In the context of children's safety in motor vehicles, the HBM might predict that parents who are aware of their child/ren's susceptibility to injury (*threat*) in the event of a motor vehicle crash and aware of the improved safety (*benefits*) offered from appropriate and correct CRS use are more likely to engage in behaviours conducive to child occupant safety. Arguably, these combined beliefs might influence parents' engagement in precautionary behaviours and facilitate their acceptance of information about safe use of CRS such as routine checking of harnesses and correct decisions regarding CRS transitions. A recent qualitative study in China found that 'lack of awareness' was the most important factor explaining the low rate of CRS use (Chen et al., 2014). In contrast, a recent cluster randomised controlled trial of 830 families conducted by Hunter and colleagues (Hunter et al., 2015) in New South Wales, Australia, demonstrated that the delivery of information sessions to parents of children enrolled in preschools and day care centres significantly improved the use of age appropriate CRS. These findings suggest that there may be a benefit to be gained by providing appropriate knowledge to parents to guide beliefs on child vehicle occupant injury risk and skills on optimal use of CRS to improve the safety of children in motor vehicle travel in Australia.

The concept of Locus of control (LOC) offers another framework for understanding and categorising beliefs (Rotter, 1954). LOC focuses on the individual's belief systems about responsibility and accountability for their own behaviours and the perceived self-control over actual and possible events. Individuals with a high *internal* LOC view themselves as responsible for events and outcomes, conversely individuals with high *external* LOC consider others or external factors predominantly responsible for events and outcomes. The LOC theory has been applied to help predict behaviour in areas such as automobile travel beliefs, business leadership, driving behaviour and health (Hoyt, 1973; McDonald, Spears, & Parker, 2004; Montag & Comrey, 1987; Wallston, Strudler Wallston, & DeVellis, 1978). The relationship between parents' beliefs about the influence of internal and external factors (e.g., LOC) on child vehicle safety has not yet been explored in Australia.

Aims of the current study

The broad aim of the current study was to understand Australian parents' beliefs relating to child restraint system (CRS) use and child vehicle occupant safety. It is important to note that this research forms part of a larger Australian Research Council (ARC) Linkage Project – Child safety in cars: an international collaboration (see Figure 1).

The current study relates to Stage 1 and involves an online survey of Australian parents to explore: i) parents' beliefs regarding CRS use; ii) parents' beliefs relating to their susceptibility of being involved in a motor vehicle crash; iii) parents' attribution of responsibility for their children's transportation safety; iv) parents' perceptions about the influence of internal and external factors (e.g., vehicle factors, CRS factors, child factors, driver and driving factors) on child vehicle occupant safety, and; v) the relationship between parent and family characteristics and CRS-related knowledge.

The current study (Stage 1) will be complimented by a naturalistic driving study (NDS) to observe and quantify child vehicle occupant positions and/or behaviour during real-world, everyday driving trips within an instrumented study vehicle (Stage 2) and a sled testing program to investigate implications of child vehicle occupants' real-world, everyday positions and/or behaviour on injury risk in the event of a motor vehicle crash (Stage 3).

Method

Participants

Participants were defined as Australian parents with at least one child who usually travelled in a forward facing CRS (FFCRS) with an integral 3-point harness system or BS during their everyday driving trips. Data from the Australia's Mothers and Babies, 1995 and 2005 report (Australian Institute of Health and Welfare, 2005) and the Australian Bureau of Statistics (Commonwealth of Australia, 2013) assisted in the identification of an age-representative sample of Australian parents. These sources identified the average age of Australian first time mothers and fathers (30.7 years, 33.1 years, respectively). Based on these figures, adults aged 25 years and over, who were parents of any children in the study age range and from across all states of Australia were recruited.

Recruitment was multi-modal in an effort to recruit a representative sample from both metropolitan and rural areas in Australia (i.e., Victorian population characteristic of 74 percent metropolitan and 26 percent rural, Commonwealth of Australia, 2013). Recruitment included an invitation from various Australian Automobile Clubs with online survey links. The Royal Australian Automobile Club of Victoria (RACV) mailed 2,000 invitations to complete the online survey to members in the eligible age range (e.g., 25+ years) and stratified by metropolitan/rural residence. There was limited capacity to ensure a representative sample due to the survey being computer-based and in written English. To help address this a national television news broadcast, national newspaper media, posters at child care centres near Monash University and project partners (e.g., automobile clubs, RACV and General Motors Holden) were also active in sharing recruitment information to parents in Australia.

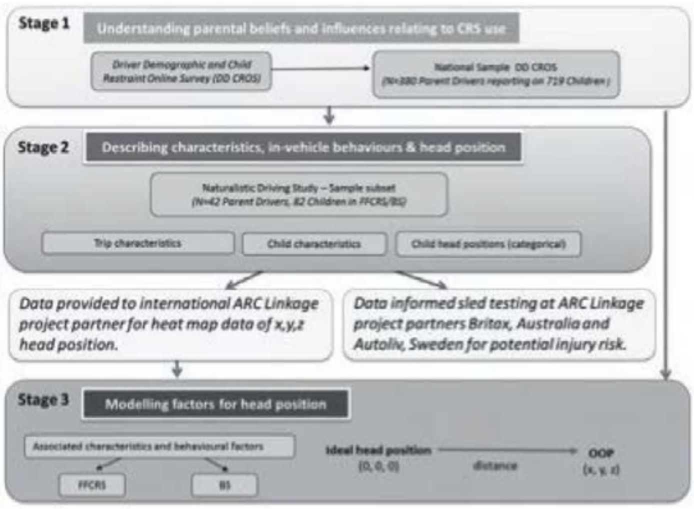

Figure 1: Child safety in cars: an international collaboration

Materials

The Driver Demographic and Child Restraint Online Survey (DDCROS) was developed to investigate parental beliefs relating to CRS use and child vehicle occupant safety. The online survey comprised five discrete sections:

1. Participant demographics;
2. Driving history;
3. Restraint use and knowledge about CRS;
4. Travel safety beliefs, and
5. Child occupant safety LOC beliefs.

For the purpose of this study, beliefs relating to child occupant safety were investigated using 'true' or 'false' answers to questions on CRS related knowledge (Section C, see Table 4). Correct answers were operationalised as knowledge. Incorrect answers, or beliefs that differed from the factual evidence, were operationalised as misconceptions.

The susceptibility of threat construct of the HBM was applied to investigate parents' beliefs about their susceptibility of being involved in a motor vehicle crash. Parents were asked 'How concerned are you about the possibility of being in a car crash?' Responses were on a 4-point Likert scale; 'not at all', 'somewhat', 'quite' and 'extremely concerned'.

Parental perceptions relating to child occupant vehicle safety were also explored using a set of LOC questions which focussed on perceived responsibility and accountability for their own behaviours and control over actual and possible events (see Table 1). Factors were classified as either internal (e.g., their own driving abilities, their safety compliance, their choice of CRS) or external (e.g., other driver's behaviours, road maintenance, legislation, fate). For each safety factor, parents were asked to use a slider scale (lowest to highest: 0-100%) to indicate the strength to which they believed each factor was responsible for child occupant safety. Ratings over 80 percent (≥80%) were classified as a high attribution of responsibility. This measure identified whether parents' considered general travel safety to be the responsibility of self (internal) or others (external).

Procedure

Ethical approval was granted by Monash University Human Research Ethics Committee (MUHREC). Participants were invited to complete the DDCROS. Participation was voluntary and without compensatory incentive and took approximately 25-35 minutes. The DDCROS also included an invitation to participate in an observational driving study that is part of a broader research program (Stage 2, see Charlton et al., 2013).

Analysis

Completed DDCROS responses were uploaded to a secured Qualtrics online survey website and downloaded and imported into SPSS Statistics 20 for data analysis. Data was cleaned and transformed prior to analysis and cases were deleted when critical variables were missing. Descriptive analyses were used to describe sample characteristics and responses to relevant DDCROS items, and univariate analyses (e.g., chi squares) were used to explore the relationships between variables of interest.

Results

Participants

Responses to the DDCROS were collected from 569 Australian parents with at least one child aged between one and eight years who used a FFCRS or BS. A total of 189 incomplete surveys were removed from the analyses due to missing data (i.e., responses relating to CRS related knowledge). Responses from the remaining 380 completed surveys were analysed.

A summary of the parents' demographic characteristics is presented in Table 2. Most parents who completed the DDCROS were: female (80%), only spoke English (91%) and were married or in a defacto relationship (92%). Most parents who completed the DDCROS had completed a

Table 1. Parental beliefs about responsibility for child occupant safety

Factors	High attribution of responsibility (≥80%)	Low attribution of responsibility ≤79%	Unanswered*
Internal LOC (self-accountability)			
Own driving abilities	241 (64)	104 (27)	35 (9)
Safety compliance	241 (64)	104 (27)	35 (9)
Choice of CRS	232 (61)	112 (30)	36 (9)
Choice of vehicle	144 (38)	201 (53)	35 (9)
External LOC (accountability to others)			
Other driver's behaviours	190 (50)	153 (40)	37 (10)
Road maintenance	89 (24)	257 (67)	34 (9)
Legislation/Policy Makers	79 (21)	267 (70)	34 (9)
Fate	25 (7)	321 (84)	34 (9)

*n=380

Table 2. Participant demographics

Demographic variables	*n (%)*
Gender	
Males	76 (20)
Females	304(80)
Area of Residence	
Metropolitan	261 (69)
Rural	119 (31)
Age group of parent (years)	
20-29	60 (16)
30-39	197 (52)
40-49	92 (24)
50-59	9 (2)
60+	3 (1)
Unspecified	19 (5)
Ethnicity	
Born in Australia	305 (80)
Born elsewhere	75 (20)
Language other than English	
No	346 (91)
Yes	32 (8)
Unknown	21 (1)
Marital status	
Married/Defacto	348 (92)
Divorced/Separated	12 (3)
Widowed	1 (<1)
Never married	15 (4)
Not specified	3 (<1)
Education level	
TAFE, VCE/HSC or less	127 (33)
University	167 (44)
Higher Degree	86 (23)
Gross income bracket (000,AUD$)	
<50	37 (10)
50 - <110	163 (43)
110 +	176 (46)
Not Specified	4 (1)
Work status	
Working/Studying full-time, self-employed	146 (38)
Working/Studying part-time/casual,	
Volunteering, Carer (eg. children),	133 (35)
unemployed, parental leave, pension	101 (27)
Number of children	
1	132 (35)
2	176 (46)
3	53 (14)
4+	19 (5)
Parents with at least one child in age group†	
Child under 1 year	60 (16)
Child 1 to under 4 years	252 (66)
Child 4 to under 7 years	172 (45)
Child 7 years plus	104 (27)
Years of parenting experience	
0-<4 years	161 (42)
4-<7 years	116 (31)
7 years+	103 (27)

† Groups are not mutually exclusive and parents may be represented more than once.

minimum of a tertiary/university education (67%), and nearly half of the sample earned a combined household gross income of $110,000AUD (46%). Over one third of parents reported that they worked/studied full time (38%). Most parents reported having two children (46%) and having more than four years' parenting experience (58%).

Driving history

Approximately three quarters of parents who completed the DDCROS had more than ten years driving experience on a full licence (76%, see Table 3). Most parents reported no history of property damage crashes (89%) and no crash history resulting in injury (97%). Amongst those parents who reported receiving a driving-related infringement in the previous two years (25%), the most common infringement types were speeding (83%) and failing to stop (9%).

Table 3. Driving history

Driving history variables	*n (%)*
Years driving experience on full licence	
Less than 5 years	
5-10 years	23 (6)
10-15 years	62 (16)
15-20 years	85 (23)
20+	107 (28)
Not specified	95 (25)
	8 (2)
Crash history - property damage (last 2 years)	
None	340 (89)
1	36 (9)
2	3 (1)
3	0 (0)
4	0 (0)
5+	1 (1)
Crash History – Injury (last 2 years)	
None	
1	368 (97)
Unspecified	5 (1)
	7 (2)
History of traffic infringement (last 2 years)	
No	287 (76)
Yes	92 (24)
Unspecified	1 (<1)
Types of traffic infringements (n=95, 25%)	
Speeding	
Failing to stop	79 (83)
Distraction	8 (9)
Failing to signal	3 (3)
Didn't know	3 (3)
	2 (2)

CRS use

Parents were asked questions about all of their children who were aged under 16 years. This equated to 719 children (males = 365, females = 352, gender not specified = 2). Table 4 shows the types of CRS used for these 719 children. Most children usually travelled in a FFCRS (45%) or a BS (23%). The use of an aftermarket H-harness accessory was minimal (2% or less) with FFCRS, BS or unspecified restraint types.

Parents' knowledge about CRS use

Parents' knowledge about CRS use was ascertained by their responses to ten true/false questions. Table 5 summarises the findings with the questions presented in descending order of percentage of correct responses.

The majority of parents responded correctly to the questions relating to: the safety benefits of children travelling in the rear versus front passenger seat (97%) (Q6); the appropriate CRS for children aged between four and seven years (95%) (Q4); and the need to adjust harnesses for each trip for optimal safety (91%) (Q10). Additionally, most parents correctly identified the purpose of seatbelt guides on BS (89%) (Q9) and the minimum recommended height for use of a seatbelt (85%) (Q5).

Up to three-quarters of parents (66-76%) were able to correctly identify important CRS transition recommendations (Q1-3). Approximately three quarters of parents (76%) were able to correctly identify that the transition from a RFCRS to a FFCRS may occur from six months of age, dependent on size (Q1) and that the transition from a FFCRS to a BS may occur from four years and is also dependent on size (Q2), with visual shoulder markers to guide this transition (75%), (Q3). Approximately two thirds (66%) of parents correctly indicated that CRS transition from a FFCRS into a BS should be guided by age as well as on children's individual height (Q2).

In contrast, forty-one percent of parents incorrectly responded that most children would reach the recommended height for transitioning into an adult seatbelt by seven years of age (Q8) and half of the parents (50%) incorrectly responded that the H-harness provides an added safety benefit for children in all situations (Q7).

Scores were summed to provide an overall score reflecting parents' general level of CRS-related knowledge (see Figure A1 in Appendix). All parents answered at least three questions correctly and 16 percent answered all ten questions correctly. For the purpose of further analyses, parents were divided into two groups based on an arbitrary cut-point: low CRS-related knowledge score group (7 correct responses or less) and high CRS-related knowledge score group (8 correct responses or more). Forty percent of parents were allocated to the low knowledge score group.

The relationship between parent characteristics, driving history and CRS-related knowledge scores (high CRS-related knowledge vs. low CRS-related knowledge) is presented in Table 6. There was a significant relationship between CRS-related knowledge scores and parental age, gender and age of child/ren in family (parental age: $\chi^2(2) = 15.330$, $p < 0.001$; gender: $\chi^2(1) = 8.011$, $p < 0.01$; at least one child aged under one year: $\chi^2(1) = 5.083$, $p < 0.05$; and at least one child aged between one and four years: $\chi^2(1) = 6.102$, $p < 0.05$, respectively). Male parents were more likely to be in the low CRS-related knowledge group (54%) than females (36%). Parents aged 40 years and older were more likely to be in the low CRS-related knowledge group (55%) compared to parents aged 20-29 years and 30-39 years (27%, 36%, respectively). Parents with at least one child aged under one year were significantly more likely to be in the high CRS-related knowledge group (73%) compared to the low CRS-related knowledge score group (27%). Similarly, parents with at least one child aged between one and four years were also significantly more likely to be in the high CRS-related knowledge group (65%) compared to low CRS-related knowledge group (35%). There were no other significant relationships between parent characteristics and CRS-related knowledge scores.

Table 4. Restraint type used by children

Restraint type	*n (%)*
Rearward facing child restraint with integral 3-point harness (RFCRS)	111 (15)
Forward facing child restraint with integral 3-point harness (FFCRS)	326 (45)
Forward facing child restraint with integral 3-point harness with added H-harness accessory	1 (<1)
Booster Seat using shoulder and lap seatbelt (BS)	162 (23)
Booster Seat using shoulder and lap seatbelt with added H-harness accessory	16 (2)
Backless booster cushion with shoulder and lap seatbelt	10 (1)
Adult seatbelt – lap/sash	79 (11)
Adult seatbelt – lap only	4 (1)
H-harness accessory without specification of restraint type	4 (1)
Unknown	6 (1)

Beliefs relating to travel safety

Parents' beliefs relating to crash susceptibility were measured using their rating of concern for being involved in a motor vehicle crash. Most parents reported that they were 'not at all' or 'somewhat' concerned about involvement in a motor vehicle crash (6%, 53%, respectively), while 29 percent were 'quite' concerned and 12 percent were 'extremely concerned'. Almost two-thirds of parents reported a high attribution of responsibility for their children's occupant safety to internal factors such as their own driving ability (64%), safety compliance (64%), and choice of CRS (61%). Fifty percent of parents reported high attributions to other drivers' behaviours, while more modest levels of reporting were observed for other external factors including road maintenance (24%), legislation (21%) and fate (7%).

Table 5. Summary of parents' responses to CRS knowledge questions

Question #	Survey question	*Correct n (%)*	*Incorrect n (%)*	*Unanswered n (%)*
6	Research shows that children under the age of 16 years are at 40% greater injury risk in front seat.	367 (97)	13 (3)	0 (0)
4	Children 4-7 years to use FFCRS or BS. The type will depend on the child's size.	361 (95)	19 (5)	0 (0)
10	Harnesses need to be adjusted for each trip for best protection against injury.	346 (91)	33 (9)	1 (<1)
9	Main purpose of seatbelt guides on BS to encourage correct placement of sash seatbelt.	339 (89)	39 (10)	2 (1)
5	An adult lap/sash seatbelt designed for people with a minimum height of 145cm.	323 (85)	52 (14)	4 (1)
1	Children older than 6 months should only be moved from RFCRS to FFCRS when they have outgrown RFCRS.	287 (76)	92 (24)	1 (<1)
3	FFCRS that comply with recent safety standards do not have a weight limit but instead use shoulder height markers to guide selection.	284 (75)	94 (25)	1 (<1)
2	All children 4-7 years should move into booster	252 (66)	128 (34)	0 (0)
8	Most children reach seatbelt height by 7 years	222 (58)	156 (41)	2 (1)
7	An 'H-harness' add-on accessory does not provide additional protection to all booster seat use.	187 (49)	190 (50)	3 (1)

Parents were asked to rank the factors that may influence their choice of CRS, including the safety rating of the CRS, fines/legal deterrents, and community or family advice (where 1= highest ranked influence, 6 = lowest ranked influence. See Table A1 in Appendix). Most parents reported that the safety rating specified in the CRS Buyers Guide had the most influence over their choice of CRS (84%). Parents were also asked to rank six factors that influence child occupant safety, including type of vehicle, type/brand of CRS, restraint fitment in car, child/ren's rear seating location in car, child/ren's movement during motor vehicle travel and driving performance (where 1 = most influential, 6 = least influential. See Table A2 in Appendix). Parents ranked driving performance (35%) and the fitment of the CRS into the motor vehicle (30%) as the most influential factors for child occupant safety. In contrast, child/ren's movement during vehicle travel was ranked most influential by only three percent of parents.

Discussion

This study has identified a number of interesting findings. The majority of parents were able to correctly answer questions related to the recommended transition from one restraint to the next based on age and visual marker guides. In contrast, most parents were not able to correctly identify the recommended height for transitioning their child into an adult seatbelt safely. Interestingly, parents with children under the age of four years were more likely to be in the high CRS related knowledge group. Females were more likely to be in the high CRS knowledge group, whereas males were more likely to be in the low CRS knowledge group.

The aims of the current study were to explore parents' beliefs regarding CRS use, travel safety and the factors that may influence child occupant safety. Results revealed a wide variation in parents' beliefs relating to CRS use and child vehicle occupant safety. When asked about their knowledge regarding CRS use, 97 percent of parents correctly reported that their children are safest when travelling in the rear of the vehicle. Most parents also correctly reported that the most appropriate type of CRS for children aged between four and seven years is a BS (95%). Most parents also reported the importance of correct CRS use for each individual trip by identifying the need to adjust harnesses for maximum safety (91%) and to use BS sash guides (89%).

Recommended CRS transition times from one CRS type to the next was less well known with three quarters (75%) of parents able to correctly identify transition recommendations from a FFCRS to a BS. Parents were required to have an understanding of transition times being dependent on age, size and be guided by the visual shoulder markers, as outlined in the recent safety standards. Using a different approach, an earlier study by Brown and colleagues (Brown, Fell, & Bilston, 2010) used mannequins for CRS inspections and found significantly fewer restraint errors in judging restraint appropriateness. This suggests some success in communicating CRS transition times to parents. Further initiatives may be warranted to reduce any remaining confusion and ambiguity between age and size that was found in this study.

Over 40 percent of parents incorrectly believed that most children would be at an appropriate height to be restrained effectively and safely by an adult seatbelt by the age of seven years. Previous research suggests that

Table 6. Summary data for participant demographics by CRS-related knowledge groups

Participant demographics variables	Low score group (≤7/10) (n=151) n (%)	High score group (≥8/10) (n=229) n (%)	Total (n=380) n (%)	Chi-square
Parental age (years)				
20-29	16 (27)	44 (73)	60 (16)	
30-39	78 (36)	138 (64)	216 (57)	$\chi^2(2)=15.3, p=0.000$*
40+	57 (55)	47 (45)	104 (27)	
Gender				
Female	110 (36)	194 (64)	304 (80)	$\chi^2(1)=8.0, p=0.005$*
Male	41 (54)	35 (46)	76 (20)	
Education				
HSC/VCE/TAFE	41 (33)	82 (67)	123 (32)	
University degree	73 (44)	94 (56)	167 (44)	$\chi^2(2)=3.3, p=0.194$
Higher degree	37 (41)	53 (59)	90 (24)	
Work status				
Full time: worker/student/self-employed	65 (45)	81 (55)	146 (38)	
Part time: worker/student	50 (38)	83 (62)	133 (35)	$\chi^2(2)=2.4, p=0.308$
Other: carer/pension/leave	36 (35)	65 (65)	101 (27)	
Income (AUD$)				
Low ≤49,999	13 (35)	24 (65)	37 (10)	
Middle 50,000-109,999	60 (37)	103 (63)	163 (43)	$\chi^2(2)=2.1, p=0.352$
High ≥110,000	77 (44)	99 (56)	176 (46)	
Unspecified	1 (25)	3 (75)	4 (1)	
Number of children				
1	56 (42)	76 (58)	132 (35)	
2	70 (40)	106 (60)	176 (46)	$\chi^2(3)=3.2, p=0.366$
3	21 (40)	32 (60)	53 (14)	
4+	4 (21)	15 (79)	19 (5)	
Parents with at least one child in age group†				
Child < 1 year (n=60, 16%)	16 (27)	44 (73)		$\chi^2(1)=5.1, p=0.024$*
Child 1 - 4 years (n=252, 66%)	89 (35)	163 (65)		$\chi^2(1)=6.1, p=0.014$*
Child 4 - 7 years (n=172, 45%)	75 (44)	97 (56)		$\chi^2(1)=2.0, p=0.161$
Child > 7 years (n=104, 27%)	43 (41)	61 (59)		$\chi^2(1)=0.2, p=0.694$

*Statistically significant at $p<0.05$

† Analyses were not mutually exclusive and parents may be represented more than once.

most children do not reach this height until around the age of eleven years (Anderson, Hutchinson, & Edwards, 2007). Further opportunities exist to address the existing ambiguity amongst parents.by recommending height (145cm) for optimal protection from an adult seatbelt and communicating the approximate age range for reaching this height milestone (10-11 years).

Responses relating to the use of an H-harness aftermarket add-on accessory also indicated that there is some confusion regarding its use and safety benefits. Fifty percent of parents incorrectly responded that the H-harness improves safety in all circumstances including when a sash/lap belt is available. However, it should be noted that the H-harness is recommended for use when only a lap belt is available in the vehicle and only in combination with a BS and approved anti-submarining clip (National Road Transport Commission, 2009). Research by Koppel and colleagues (2013a) highlighted a high proportion of H-harnesses were being misused by Australian parents (84%). The relatively low use of H-harness amongst parents in this study (less than 4%) may explain the high level of misconception. Another plausible interpretation of the findings is that parents may be informed of the best practice and choose to not use the accessory and instead use the vehicle's lap/sash belt. Lap/sash belts are commonly available in Australian vehicles. These potential gaps in knowledge could be addressed by more effective communication about the contexts in which H-harness use is appropriate/effective.

The relationship between parent characteristics and CRS-related knowledge was also explored. Male participants were more likely to have lower CRS-related knowledge scores compared to female participants. Older participants (aged 40 years and older) were also more likely to have lower CRS-related knowledge scores compared to younger participants (aged between 22-39 years). Parents with children under four years of age were significantly more likely to have higher CRS-related knowledge than have lower CRS-related knowledge. Younger, female participants with children under four years of age may be more likely to have higher CRS-related knowledge scores because they may have had more recent exposure to maternal health care providers and other child-related health professionals. A plausible explanation for this would be recent communications with maternal health professionals. This finding supports recent research by Hunter and colleagues (2015) that revealed a relationship between exposure to information sessions regarding appropriate CRS use and actual appropriate CRS use. Other research has explored the challenges of promoting and achieving correct CRS use and acknowledged the importance of being able to deliver consistent CRS safety messages, as well as ensuring the delivering of tailored communications to minority groups (Brown et al., 2013; Weaver, Brixey, Williams, & Nansel, 2013). Knowing the target audience of those parents with lower CRS-related knowledge is a critical step to developing strategies that will encourage behaviour change.

Previous studies have identified a link between beliefs in terms of susceptibility to injury, LOC and behaviour (Bandura, 1971; Nelson & Moffit, 1988; Peterson, Farmer, & Kashani, 1990; Rosenstock, 1974). For example, individuals who understand motor vehicle injury risk and believe that they are accountable for safety have been shown to be more receptive to becoming engaged in seatbelt use (Hoyt, 1973). Despite the potential insights offered, no previous studies of LOC analysis of parents' child occupant safety were identified. Arguably, initiatives may be more successful in optimising child safety when travelling in motor vehicles if there is a greater understanding of parents' beliefs relating to crash injury risk, child occupant safety and the accountability for potential motor vehicle crash outcomes. When asked about whether they were concerned about being involved in a motor vehicle crash, parents reported being either 'quite' (29%) or 'extremely concerned' (12%) about being involved in a motor vehicle crash. This finding may mean that these parents will be more receptive to any CRS or child vehicle occupant safety initiatives.

Parents tended to attribute the responsibility of child vehicle occupant safety to internal factors such as their own driving abilities (64%), safety compliance (64%) and their choice of CRS (61%). Fewer attributed the responsibility to external factors such as other drivers (50%), road maintenance (24%) legislation (21%) and fate (7%). Early behavioural change research suggests that individuals who attribute the responsibility of the events/outcomes in their lives to internal factors are more receptive to adopting behaviour changes such as precautionary travel safety behaviours, when compared to the individuals that attribute responsibility of the events/outcomes in their lives on others, luck/chance or fate (Hoyt, 1973). Encouragingly, few parents reported that they believed child vehicle occupant safety was luck or chance and therefore out of their control.

The findings of strong attribution of internal factors to child occupant safety indicates that parents may be receptive to future informative strategies to improve CRS knowledge. The strong influence of the CRS Buyers Guide on appropriate CRS use and the fitment of the CRS into the vehicle for optimal safety reported in this study is indicative of receptiveness to such current initiatives (Kidsafe Australia, 2014; RACV, 2014).

The study also explored parents' perceptions of the factors that contribute to the provision of optimal child occupant safety. CRS use is dependent on correct installation and use. CRS use does not equate to protection (Brown, McCaskill, Henderson, & Bilston, 2006). The movement of the child while travelling in a CRS was considered by parents as most influential to child occupant safety by three percent of parents. Given that correct use of a CRS includes the placement of a child's head within the protective zone of the CRS structure, with other placements potentially compromising safety delivered by the CRS, further exploration on movement is warranted.

Whether there is a relationship between CRS related knowledge and self-reported perceptions (such as safety consequences of child vehicle occupant movement) and child occupant travel behaviour, as suggested by the HBM (Bandura, 1971; Chen, et al., 2014; Rosenstock, 1974), will be further explored in a NDS. The injury consequences of child occupant movement and common OOP head placements will be explored in the next phase of this research through sled testing (see Stage 2, Figure 1). Future educational initiatives will be recommended from these findings.

Some limitations are noted. Despite attempts to recruit a representative sample, participants were predominantly female, had at least a university level of education and were in the two highest brackets for household combined gross income ($110,000 AUD or more). Therefore, the findings may not be representative of the general population. It should be noted that the study did successfully recruit 69% metropolitan participants and 31% rural participants which is consistent with recent Victorian data (Commonwealth of Australia, 2013). Another limitation to consider is the fact that the survey was only available in English language which may have biased the sample.

Also, findings reported in this study are based on responses to an online survey. While survey studies have provided valuable insights into child occupant safety, they have limitations in their capacity for accurate and unbiased reports regarding CRS use and misuse during real-world motor vehicle travel. For example, parents in the current study tended to attribute the responsibility of child occupant safety to internal factors such as their own driving performance. This may also be the result of social bias that has been evident in other research involving behaviours that may be deemed socially unacceptable (Williams, 2003). Parents may have reported themselves as being responsible for child occupant safety as it is socially expected and 'the right thing to do' rather than an accurate representation of their beliefs. Finally, the parental knowledge was measured by true or false questions. Parents' CRS related knowledge should be explored further through the use of more qualitative and open ended interviewing techniques. To address the potential limitations associated with survey-based research on CRS use and misuse, a subset of participants from the current study (n = 42) were invited to participate in a NDS (Stage 2, Figure 1). NDS have been recently used to explore the nature and extent of CRS use and misuse (Andersson, Bohman, & Osvalder, 2010; Bohman et al., 2011; Charlton, Koppel, Kopinathan, & Taranto, 2010; Forman, Segui-Gomez, Ash, & Lopez-Valdes, 2011; Koppel, Charlton, Kopinathan, & Taranto, 2011). Importantly, NDS afford the possibility to examine the relative frequency and duration of occurrence of CRS misuse during everyday motor vehicle travel, providing better insight into the way in which child occupant safety may be compromised in the event of a motor vehicle crash. As part of Stage 2, participating families will be invited to drive an instrumented study vehicle (Charlton et al., 2013).

Conclusion

All parents demonstrated some level of knowledge on correct and appropriate CRS use, however a number of misconceptions and gaps in CRS related knowledge remain. A key finding was that most parents attributed child occupant safety to internal factors, which suggests that parents may be receptive to injury risk reduction initiatives. The recruited sample is not representative of the Australian population and may provide an under-estimation of gaps in CRS related knowledge. Future initiatives need to be broad and multicultural to capture the needs of the general population. Future research will use video data of child occupant behaviour from a NDS from the larger study to compare these self-reported online survey findings with real-world child occupant travel.

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Appendix

Table A1. Factors influencing parents' choice of CRS

Factors influencing choice of CRS (n=341)	1st ranked influence *n (%)*
Fines and legal deterrents	12 (4)
What everyone else chooses	6 (2)
Community/family advice	14 (4)
The safety rating of CRS by Buyers Guide	288 (84)
Other features not safety related (eg price, colour)	17 (5)
Child/ren's choice/preference	4 (1)

Table A2. Factors influencing child occupant safety

Factors influencing child occupant safety Total (*n*=346)	1st ranked influence *n (%)*
Vehicle used	42 (12)
Type/brand of restraint used	44 (13)
Restraint fitment in motor vehicle	104 (30)
Child/ren's rear seating location in car	24 (7)
Child/ren's movement during travel	11 (3)
Provision of best driving performance	121 (35)

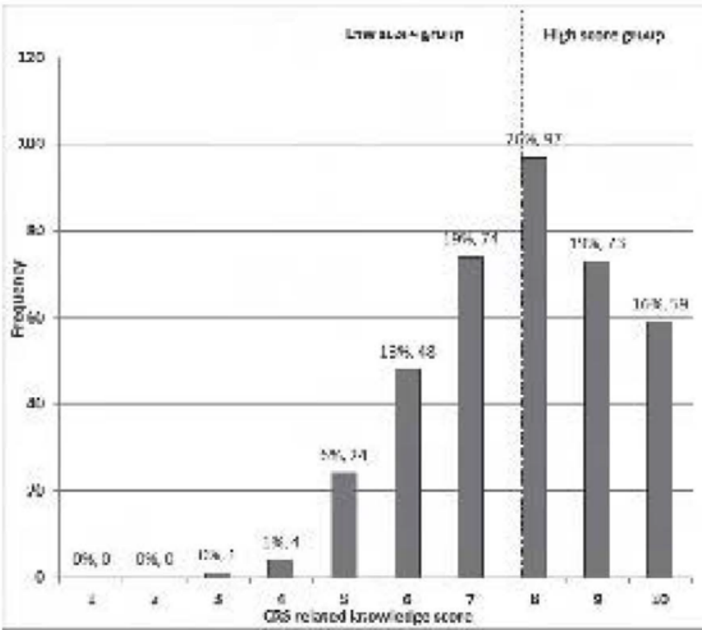

Figure A1. CRS related knowledge total score

5. Naturalistic Driving Study (NDS) methodology

The NDS methodology used in this PhD research program is described in detail in this chapter. The NDS was conducted to collect objective information about what child occupants do when they are restrained in their CRS during real-world, everyday motor vehicle trips. It was anticipated that the findings from the NDS could specifically identify the head positions of child occupants during everyday motor vehicle trips, provide in-depth information about the behaviours that they commonly engage in and how behaviour impacts on the likelihood of the child occupant adopting a suboptimal head position. It was anticipated that the behavioural information gained from this research can guide CRS design, vehicle design and educational to improve child occupant safety.

5.1. Participants

Forty-two families, including 80 child occupants, participated in the NDS. Participants were eligible to participate in this study if they:

- Lived within a 25-kilometre radius from Monash University;
- Held a full driver's licence, and;
- Had at least one child who usually travelled in a FFCRS or BS.

5.1.1. Recruitment

Participants were recruited from two sources (see Figure 8 below):

1) Participants who completed the DDCROS and who had expressed an interest in participating in future research and were eligible to participate in the NDS (see Appendix F), and;
2) Participants who were recruited from additional sources (e.g., automobile organisation website links, emails or newsletters from project partners, and poster advertisements at childcare centres). These participants also completed the DDCROS (see Appendix F) prior to participating in the NDS.

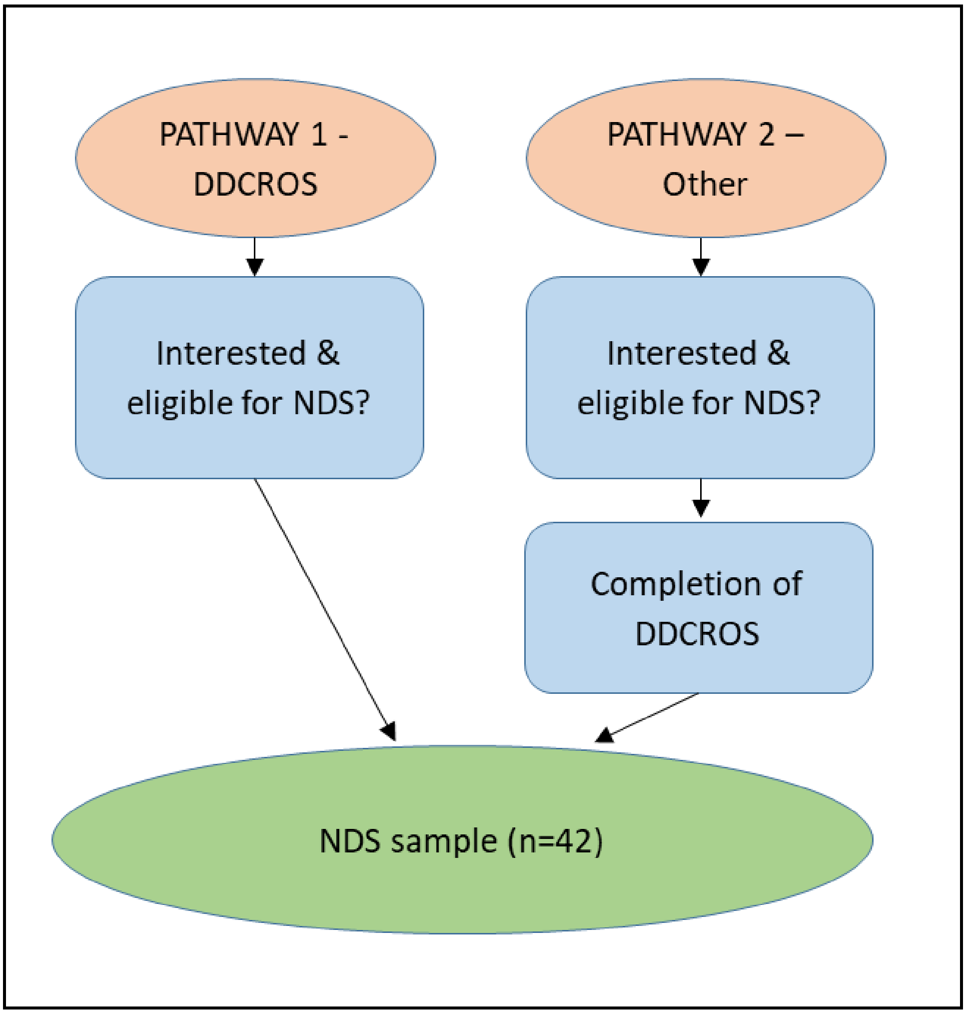

Figure 8. NDS recruitment pathways

5.2. Materials

5.2.1. Study vehicles

Two study vehicles were used, including a luxury model, large family sedans with automatic transmission: a GM Holden Statesman (2006) and GM Holden Calais (2007). The study vehicles were fitted with a discrete camera/audio recording system. Cameras were installed for minimal disruption to the driver's view and were concealed so as not to be obvious to vehicle occupants. The recording systems were operated by a microcontroller that was programmed to allow for automatic start-up and hibernation. The recording system could also be de-activated by the driver by means of pressing a (red) button on the dashboard behind the steering wheel. This feature was necessary to satisfy ethics privacy requirements and allowed participants to opt out of the study temporarily by shutting down the recording system for any reason at the start of a trip or whilst driving. The status of the recording system was indicated by a dim red light so as to not distract the driver. Conversely, when the system was not recording, the light was extinguished.

5.2.2. Data acquisition equipment

The NDS collected information from various data acquisition systems, including:

- Video and audio recording;
- Mobileye®, and
- Microsoft Kinect™.

This PhD research program used the video and audio recording to explore the role of behaviour in child occupant safety. The Mobileye® and Microsoft Kinect™ were used in the broader ARC Linkage Project to guide sled testing protocol (Arbogast et al., 2016; Bohman et al., 2018; Loeb et al., 2017) and analyse driving performance (Kuo et al., 2016). (See Appendices B, C, A and E, respectively). The data acquisition equipment is discussed in more detail below.

5.2.2.1. Video and audio recording

Eight colour cameras with 150 degree viewing angles were located in the vehicle interior (see Figure 8). Camera 1 was located behind the centre internal rear-view mirror, providing a view of the forward road and traffic scene. Camera 2 was embedded within the internal rear-view mirror (behind a hole, 10mm in diameter), providing a view of the driver and the front seat passenger. Cameras 3 and 4 were positioned in the interior roof of the test vehicle, with the focus on the children in the rear seat. Cameras 3 and 4 were positioned in the unit housing the DVD controls and interior light and thus were not obvious to the rear seat passengers. Cameras 5-8 were QC-3692 CCD Mini Colour Pinhole Cameras. Camera 5 was located at the centre of the rear windscreen and directed to the rear road environment and was housed in a secure box to protect against tampering. Camera 5 provided the rear traffic view. Camera 6 was positioned to provide a view of the console instrumentation. Cameras 7 and 8 were embedded covertly in each of the two side interior handles located above the rear doors, with each handle having a small camera vision hole (approximately 5mm in diameter). Cameras 7 and 8 were positioned to view a child passenger seated on the opposite side of the rear seat. An omnidirectional microphone was embedded in interior roof light panel (50 Hz to 15 kHz). This PhD Research Program utlised the output from the audio recordings and the output from Cameras 3, 4, 7 and 8 that recorded activities in the rear seat of the vehicle. The locations of the cameras that captured child occupant behaviour are highlighted in Figure 9 by green arrows.

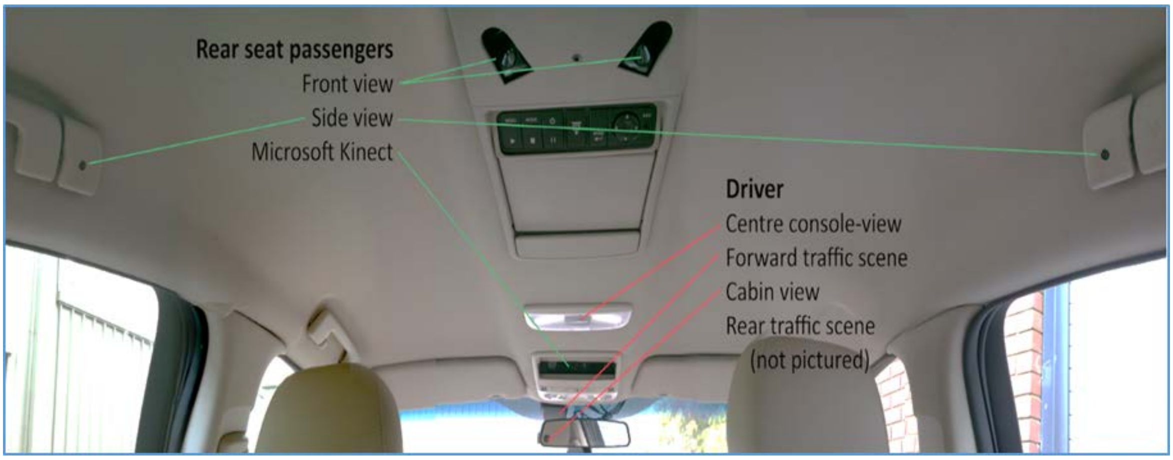

Figure 9. Camera setup, viewed from the rear of the study vehicle

5.2.2.2. Mobileye®

A Mobileye® vision system (see www.mobileye.com) was installed in both study vehicles. The Mobileye® systems are a roadway-facing, monocular device that uses computer vision to detect and warn drivers of lane deviations, headway distance and oncoming pedestrians. The Mobileye® was not utilised in this PhD research program, however, the detection system (warning system switched off) was used to investigate driving performance within the broader ARC Linkage Project (Kuo et al., 2016). See Appendix E.

5.2.2.3. Microsoft Kinect™

In addition to the data acquisition systems that were fitted into both study vehicles, the General Motors Holden Statesman was also equipped with a Microsoft Kinect™ camera and depth sensor (Microsoft, 2011) for motion-tracking of rear seat passengers (see Figure 10). The Kinect™ system was not installed in the Calais due to space constraints in the vehicle trim. The Kinect™ sensor was originally designed as a motion capture device for gaming. The depth sensor consists of an infrared laser projector combined with a monochrome complementary metal-oxide-semiconductor (CMOS) sensor, which captured motion data. The Kinect™ sensor was installed discretely in the ceiling sunglass cavity located near the rearview mirror. The Kinect™ was powered by a separate Windows 7 embedded PC that was located in the boot of the vehicle. In the broader ARC Linkage Project, the Kinect™ was used for logging 3D data of rear seat passengers to understand how children position themselves within their CRS (Arbogast et al., 2016). See Appendix A. The Kinect™ output was not required for the purpose of this PhD research program.

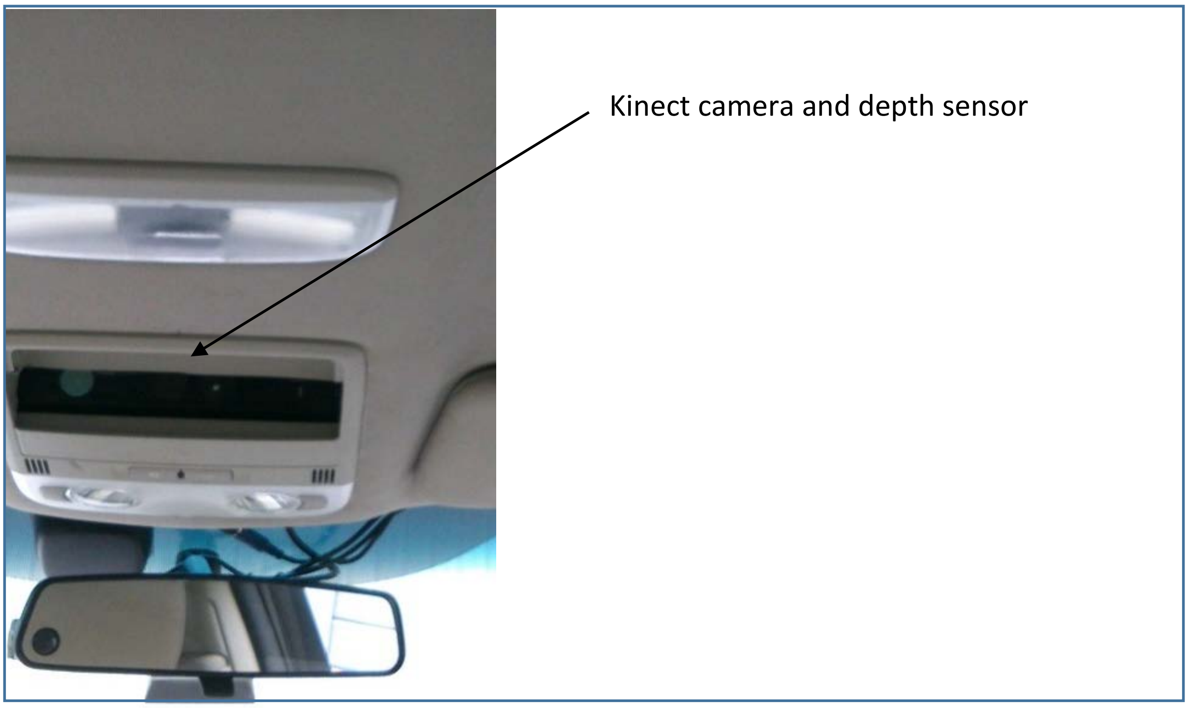

Figure 10. Microsoft Kinect camera setup within the study vehicle

5.2.3. Data storage

All recording devices (with the exception of Kinect™) were controlled by a data acquisition system (Racelogic VBOX®, www.vboxaustralia.com.au) located in the boot of each study vehicle. The VBOX® systems collected all video and audio data. Additionally, the systems collected vehicle performance data from CAN bus (Controller Area Network) and GPS (See Figure 10). All video, audio, CAN bus and GPS data was written to SanDisk (SD) cards. Data was transferred off the SD cards after each participant and stored on a secured drive at Monash University for analysis of the output.

All Kinect™ data was written to an external hard drive (1TB) that was installed into the boot of the General Motors Holden Statesman vehicle.

5.2.4. Data output

All data was viewed in a closed office for the purpose of privacy and confidentiality. Example of the frames that were available for viewing are provided in Figures 11 and 12.

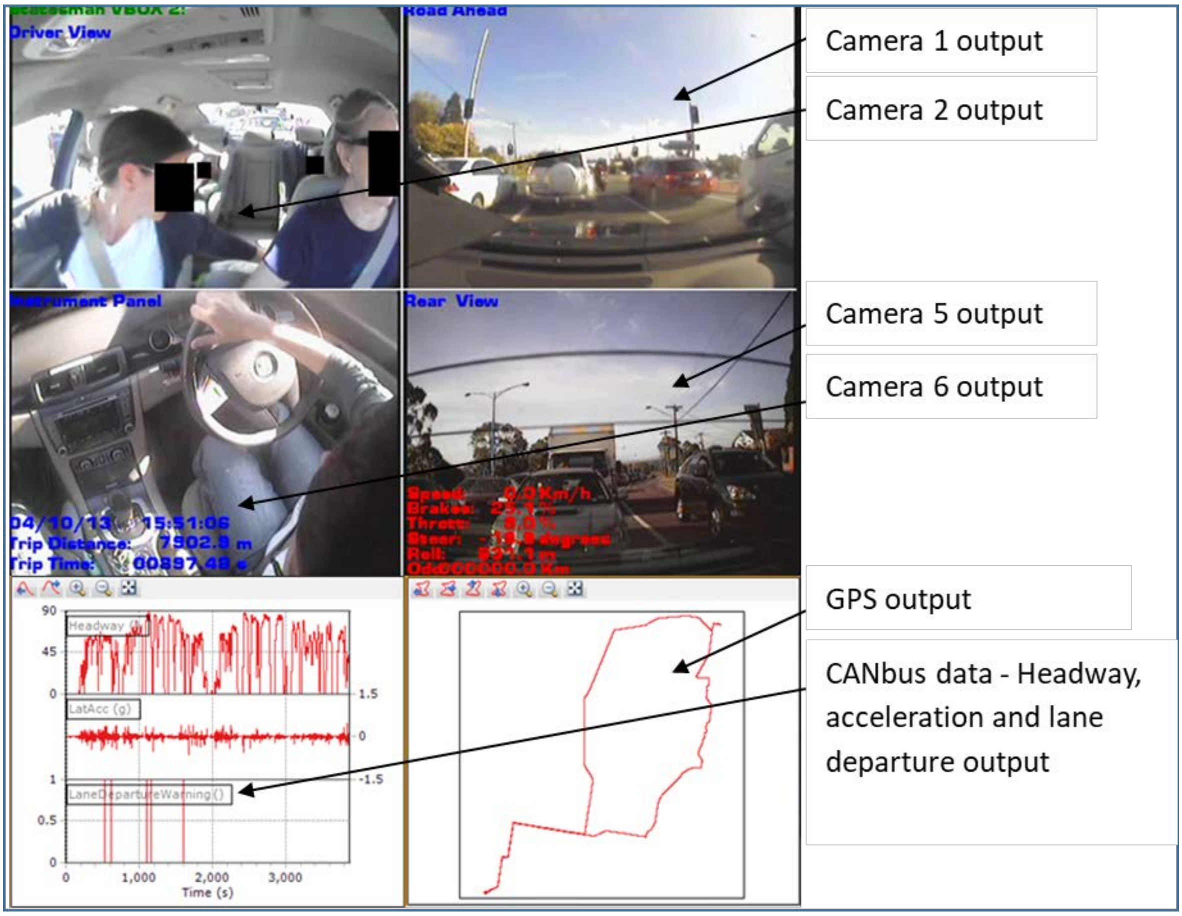

Figure 11. Camera and CANbus data output

Figure 12. Output from Cameras 3, 4, 7 and 8

5.3. Procedure

Participating families were asked to drive one of the study vehicles for a period of approximately two weeks. Parents were instructed to drive the study vehicle on their regular driving trips. Prior to the observation period, the study vehicles were serviced cleaned, filled with petrol, photographed (i.e., standard inspection photos), and fitted with a new hard-drive for data storage. Handover of the study vehicles occurred at the participants' place of choice. A briefing session was conducted by members of the research team at vehicle handover. At this time, parents provided informed written consent for themselves, their spouse/partner and their children under the age of 15 years (see Appendix K). Informed consent of any passengers over the age of 15 years was also obtained in accordance with the institutional ethics requirements (see Appendix L).

A CRS fitting specialist attended the vehicle handover session to ensure that all CRS were fitted correctly, and where possible, checked each child in their restraint system and advised parents about any inappropriate usage. All children used their own CRS or BS within the study vehicles.

Participants were briefed about the operation of the study vehicle and the placement and activation of the cameras and recording equipment. Parents were provided with a 24 hour, 7 days a week mobile phone number to contact the research team if required. A written summary of this information was also provided in the study vehicle. In addition, participants had the option to be taken for a pilot drive in the study vehicle and were instructed to drive the study vehicle as they would normally drive their own vehicle (including safely and responsibly). Study vehicles had a full tank of petrol at handover. As partial reimbursement, petrol vouchers for $80 were given to each participating family.

One week into each observation period the research team checked on the vehicles and participants, provided an opportunity to ask any questions and asked if there were any trip recordings that they wished to have delete for any reason (an institutional ethics requirement). Data was transferred from the SD cards onto the secured Monash University server to free SD storage space for the second week of the observation period.

At the end of the second week, each study vehicle was collected from the participant's choice of location. Participants were asked again if there were any trip recordings that they wished to have delete for any reason. The child/ren's own CRS was fitted back into the family's own vehicle by a CRS specialist (an institutional ethics requirement).

5.3.1. Measures

5.3.1.1. NDS data

The data collected from one randomly selected rear seated child travelling in either a FFCRS or BS was analysed for each trip. Demographic and background data relating to the parents, family and the child occupants was extracted from the DDCROS (see Appendix F) and entered into Snapper computer application software (Webbsoft Technologies, 2007). This provided information such as gender and age of driver, number of children in family, and gender, age, birth order and restraint use of the selected child occupant. The corresponding video and audio data for the randomly selected child occupant for each trip was then imported into Snapper. The images of the four video quadrants from Cameras 3, 4, 7 and 8 provided a time synched, rear seat view for analysis (see Figure 11).

A total of nine 5 second epochs were selected (in two waves) for coding into Snapper due to resource and time constraints. In the first instance, five epochs were purposely selected from throughout the trip at 5%, 25%, 50%, 75% and 95% of the trip time. The selection of 5% and 95%, rather than 0% and 100%, optimised the data available by excluding the times closest to the automated ignition start up and shut down of recording systems, where the potential for missing data was greatest. Analysis of the first set of epochs identified missing data, for reasons such as: body interference bright lighting and darkness (23%, 16% and 3% respectively). Hence, to expand the dataset a further four 5 second epochs were randomly selected through random number generation. The four additional epochs were sampled at 17%, 30%, 53% and 89% of the trip time. Each of the nine 5-second epochs were viewed and the relevant data was extracted manually and recorded into Snapper.

5.3.1.2. Trip variables

The format of the data recorded to VBox provided trip variables. Trip variables were:

- Family ID number (1…42);
- Trip date (DD/MM/YY);
- Trip time of day (00:00…23:59), and;
- Total trip duration (HH:MM:SS).

Notes reported from the trips provided additional information where necessary and included time points where data was not observable and details of any changes observed on scanning video images of each trip for example when changes to driver occurred, periods of stationary vehicle.

5.3.1.3. Vehicle occupant variables

A scan of the video data and corresponding DDCROS demographic and background data (Cross, Charlton, & Koppel, 2017) characterised vehicle occupant variables.

Vehicle occupant variables were:

- Driver gender (male/female);
- Changes to driver (yes/no);
- Front seat vehicle passenger (present/absent);
- Changes to passengers (yes/no);
- Gender of each child occupant (male/female);
- Age of each child occupant (in months);
- Number of child occupants (1..4 or more);
- Birth order of each child occupant (where 1 is first born);
- Restraint type of each child occupant (RFCRS, FFCRS, BS, added H-harness), and;
- Seating location of each child in vehicle (right/centre/left, where right is determined facing the front of the vehicle and located behind driver).

5.3.1.4. Child occupant variables from DDCROS:

One child that travelled in either a FFCRS or BS was coded. If there was more than one child in a trip travelling in either a FFCRS or BS a random number generation (0.0001…1) method was used for the random selection process. The child occupant with the highest number was selected for coding; if data was not observable, the child occupant with the next highest number generated was selected. Vehicle occupant variables that were collected by the DDCROS in Stage 1 of this PhD research program were extracted to be used in the NDS analysis. Refer to Appendix F. The data collected on the selected child occupant was then entered into Snapper (Webbsoft Technologies, 2007) for in-depth analysis.

5.3.2. Coding of child occupant variables:

Snapper (Webbsoft Technologies, 2007) is a performance analysis computer program that allows categorical and time stamped coding of individual's actions and behaviours whilst viewing video content. Snapper enables the collection, identification and analyses of activity type information over a predefined period of time (Webbsoft Technologies, 2007). For the purpose of this PhD research program, the epoch duration (viewing time) was set to 5 seconds. VBox format presented the camera output of all four rear seat cameras (2 side view and 2 front view) to be viewed simultaneously to optimise reliability of coding (for example forward and sideways lean was captured by front view camera and side view camera). Figure 13 presents the screen output that was viewed during the coding process.

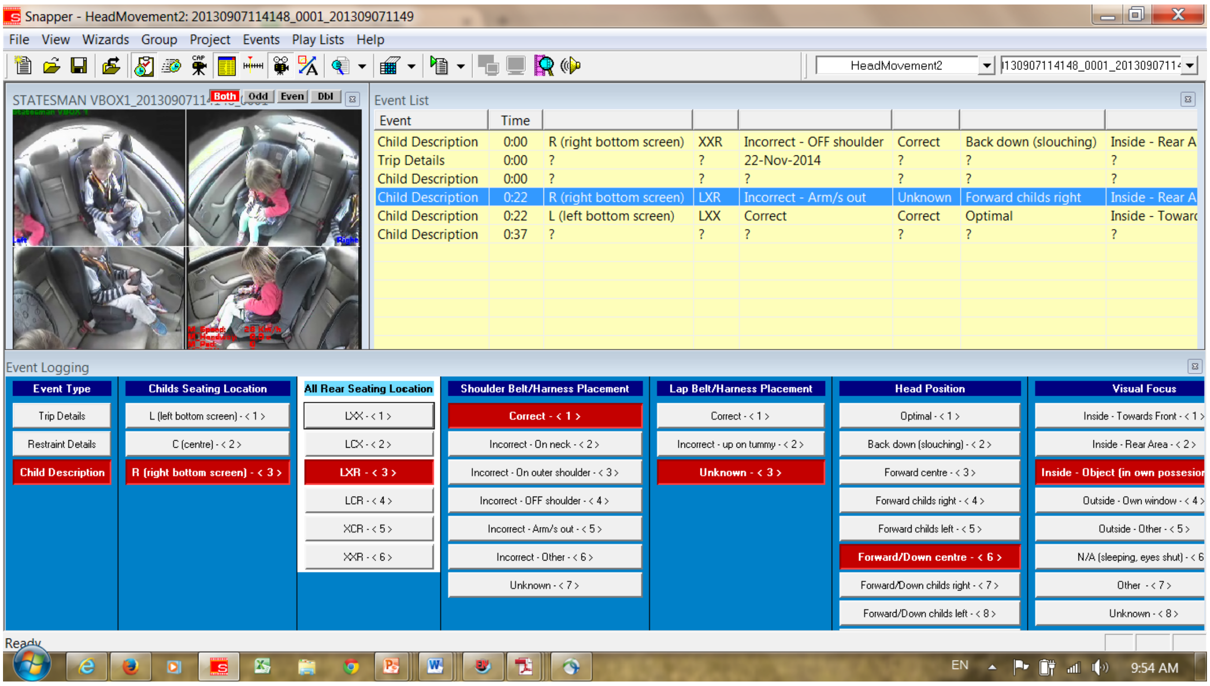

Figure 12. Snapper screen output (Webbsoft Technologies, 2007)

Snapper was used to view and code the following variables:

- Head position (optimal/suboptimal; see Figure 14);
- FFCRS or BS use (correct/incorrect, where incorrect use was defined as twists, routing errors, loose fit, and unfastened belts/harness buckles);
- Interactions (yes/no, where yes included verbal and/or non-verbal interactions occurring within the vehicle);
- Primary activity (looking, conversation, eating/drinking, playing w toy/s, using electronic handheld device, reading, touching/looking at self, crying/fighting, watching DVD, sleeping/drowsy, touching bag, touching vehicle/restraint, other and unknown)
- Secondary activity (e.g., additional activity, as listed above but categorised as secondary as required less cognitive loading);
- Behaviour (passive/active, where passive was defined as still; active was defined as moving), and;
- Affect (positive/negative, where positive was defined as happy and content; negative was defined as unhappy or agitated).

Each of the nine epochs were coded for all variables in chronological order. If a variable was not clearly observable it was categorised as unknown.

Video coded category	Collapsed category	Definition	Head position exemplars	
			Lateral	Fore-aft
Optimal	OptimalVisual reference point: -The fore-aft and lateral position of ears within the protective zone of wing structure of CRS.			
Back-down (slouching)	Suboptimal	Visual reference point: -The position of ears below the protective zone of wing structure of CR and visual. Approximation of 100 mm – 300mm distance from protective zone. Approximation of less than 100 mm from back cushioning of restraint.		
Forward – Centre	Suboptimal	Visual reference point: The fore-aft and lateral position of ears in front of protective zone of wing structure of CRS. Approximation of 100 mm – 300mm distance from protective zone.		
Forward – Child's right	Suboptimal	Visual reference point: The fore-aft and lateral position of ears in front of protective zone of wing structure of CRS and placed to the child's right. Approximation of 100 mm – 300mm distance from protective zone.		
Forward – Child's left	Suboptimal	Visual reference point: The fore-aft and lateral position of ears in front of protective zone of wing structure of CRS and placed to the child's left. Approximation of 100 mm – 300mm distance from protective zone.		
Far-forward – Centre	Suboptimal	Visual reference point: -The fore-aft position of the back of the head extended in front of the protective zone of wing structure of CRS. Approximation of 100 mm – 300mm distance from protective zone.		
Far-forward – Child's right	Suboptimal	Visual reference point: -The fore-aft position of the back of the head placed in front of the protective zone of wing structure of CRS and placed to the child's right. Approximation of more than 300mm distance from protective zone.		
Far-forward – Child's left	Suboptimal	Visual reference point: -The fore-aft position of the back of the head placed in front of the protective zone of wing structure of CRS and placed to the child's left. Approximation of more than 300mm distance from protective zone.		
Other	Suboptimal	Visual reference point: The back of the head placed in any other position outside of the protective zone of wing structure of CRS. E.g. above or rear facing.		

Figure 14. Still images from video output of cameras capturing rear seat occupants' fore-aft and lateral positions (adapted from Bohman et al., 2018).

5.4. Analyses of NDS Snapper data

The NDS provided the output that enabled observation and classification of the characteristics of everyday family travel. Information on child occupant head position, CRS use, interactions, behaviours and activities was coded at different time points or epochs throughout the randomly selected trips and provided objective measures to describe how children behave when travelling in a CRS.

Participating families completed 1,651 driving trips that had a least one child travelling in a CRS. One quarter of these trips (n=414) were randomly selected for detailed analysis - due to time and budget constraints. Random number generation technique was applied to all 1,651 trips. The first quarter of trips from each family was selected for coding. If video data was unclear or unavailable for a trip the next trip was selected. A total of 414 trips were analysed. Trips were 15 minutes average in duration and ranged from 1 minute, 14 seconds to 1 hour, 26 minutes and 46 seconds.

The child occupant variables (see section 3.4.1.4) for the 414 trips were coded at nine 5-second epochs (5%, 17%, 25%, 30%, 50%, 53%, 75%, 89% and 95% of total trip duration). A total of 3,726 epochs were available for analysis.

5.4.1. Reliability

All Snapper manual coding was undertaken by the PhD candidate. Ten percent of all trips were also coded by an independent researcher (CW). The intra-class correlation coefficient (ICC) with 95% confidence interval (95% CI) was used to assess systematic and random error that might affect the relative inter-rater reliability. ICC estimates were calculated to measure inter-rater reliability for child occupants' head position (i.e., optimal vs. suboptimal vs. extreme suboptimal vs. unknown, interactions, child affect and primary activity). The ICC value for head position indicated a moderate level of inter-rater reliability and consistency between the two observers. The ICC value for interactions, child affect and primary activity indicated a high level of inter-rater reliability and consistency between the two observers. Further ICC details are provided in Chapter 4 of this PhD Thesis in the publication: The common characteristics and behaviours of child occupants in motor vehicle travel (Cross, Koppel, Arbogast, Rudin-Brown, & Charlton, In Press).

5.4.2. Analyses for Publication 2

5.4.2.1. Descriptive analyses

Descriptive statistics were used to summarise information on child occupant demographics and the characteristics of the 414 driving trips. These data are presented in Publication 2 to provide an overview of the characteristics of the NDS data.

Descriptive analyses were also conducted for data extracted from the 3,726 epochs that were coded in Snapper, providing an overview of the child variables that were observed from the video and audio data.

5.4.2.2. Comparisons

Chi square analyses were conducted on the selected 414 trips to compare the characteristics with the remaining uncoded trips from the dataset (n=1,237) to ensure that a representative sample was extracted from the full dataset. Findings are presented in Publication 2.

Chi square analyses were also conducted to determine whether there were statistically significant associations between child occupant head position (i.e., optimal or suboptimal) and variables of interest (i.e., restraint type, restraint use, behaviour, affect, interaction and primary activity). With respect to the child occupants' primary activity and associations with child occupant head position, specific comparisons of interest included: engaging in conversation versus lap-based activities (e.g., electronic device use, reading and toys) and other activities (e.g., sleeping, looking out window). These comparison groups were selected because intuitively, they encourage optimal or suboptimal head position (e.g., leaning forward and down to direct attention into the lap area).

5.4.3. Analyses for Publication 3

Variables of interest were selected based on the findings of Publication 2 and previous research on child occupant injury, CRS misuse, injury data relating to gender and CRS comfort. Variables explored were head position, restraint type, shoulder restraint use, child gender, child age category by restraint, birth order, primary activity and interaction.

5.4.3.1. Descriptive Analyses

Epochs were excluded from analysis if variables were not available for coding. A total of 2,158 epochs were available for analysis. Descriptive statistics for the 2,158 epochs were presented in Publication 3 as child factors, trip factors and head position. Head position was defined as either 'optimal' or 'suboptimal' for the purpose of the analyses.

A breakdown of the characteristics of child occupants travelling in FFCRS was presented separately to those travelling in a BS to reveal any differences in each of the variables across restraint types. A variable describing child age by restraint type was created to explore whether child occupants that were older in age for their recommended restraint type have a tendency to adopt different head position to child occupants that were younger in age for their recommended restraint type.

5.4.3.2. Modelling factors associated with suboptimal head position

The relative contributions of factors associated with suboptimal head positions for child occupants when travelling in either a BS or FFCRS were explored through a generalised estimating equation (GEE). The GEE was conducted to accommodate the repeated measures nature of the data where multiple observations were made for a child, within a trip and within a time period. All variables of interest were checked for multicollinearity with Pearsons correlations prior to inclusion in the GEE (see Appendix M).

6. Publication # 2

Cross, S. L., Koppel, S., Arbogast, K. B., Rudin-Brown, C. M., & Charlton, J. L. (In Press). The common characteristics and behaviours of child occupants in motor vehicle travel. *Traffic Injury Prevention.*

6.1. Introduction

The second publication presents the descriptive findings of the NDS. It is represented in Stage 2 of the PhD research program, as highlighted in Figure 15 below.

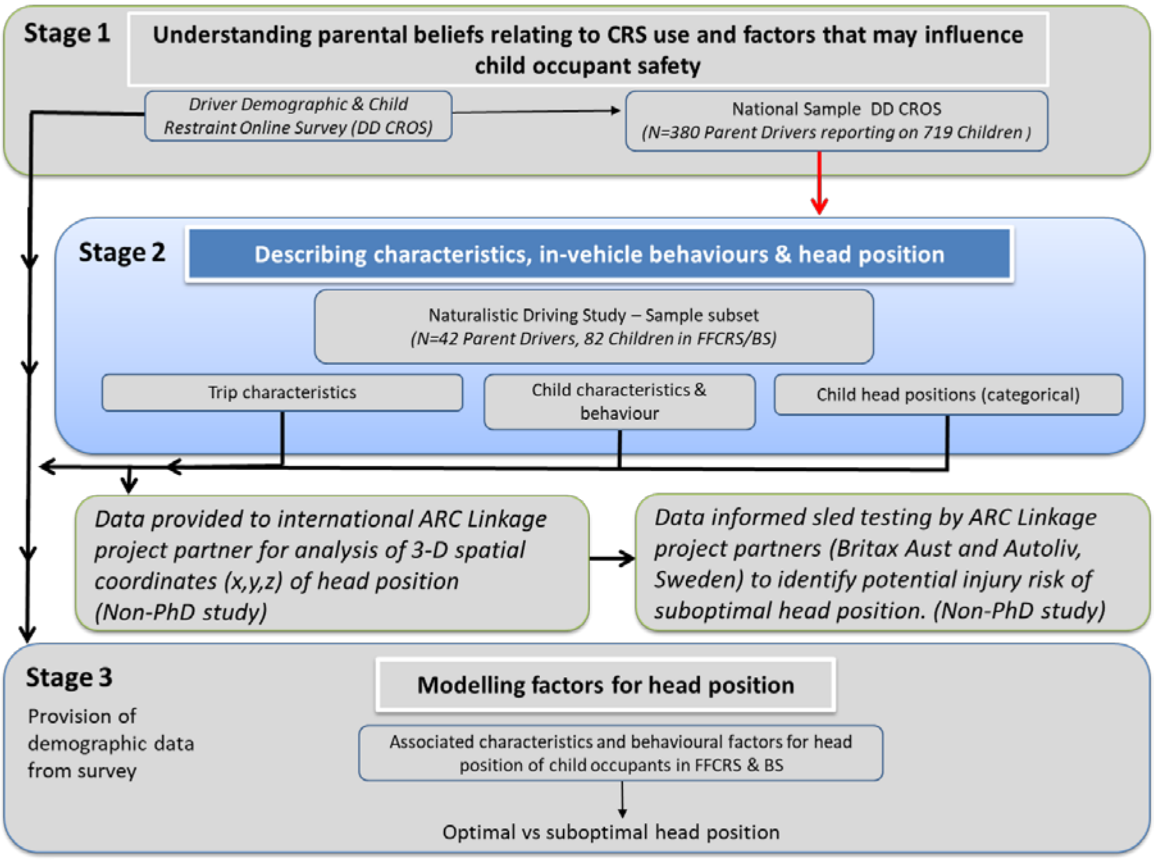

Figure 15. Stage 2 of PhD research program

The overarching aim of this PhD research program was to examine how children were restrained and seated in their CRS (FFCRS or BS) and their behaviour during real-world, everyday motor vehicle trips. The NDS extended previous research (Andersson et al., 2010; Charlton et al., 2010; Forman et al., 2011; Osvalder et al., 2013; van Rooij et al., 2005) by exploring child occupant behaviour and associations with child occupants' head positions during everyday motor vehicle trips.

The aim of the Stage 2 study was to describe the common characteristics and behaviours of child occupants during everyday, real-world motor vehicle travel in a sample of Australian families to identify potential safety implications of observed behaviours and head position within the CRS.

A total of 42 families drove a study vehicle for a period of two weeks. Data was collected by video, audio, Mobileye and Kinect systems for analysis. Demographic data was extracted from the DDCROS conducted in Stage 1 of this PhD research program. NDS video and audio data was imported into a computer program called Snapper that enabled coding of child occupant variables whilst viewing the video data.

The study provided new information on common head positions and CRS use of child occupants, including;

- **Optimal head position of child occupants was observed in the majority of epochs** (74%).
- The most common **CRS misuse** observed in epochs was shoulder seatbelt/harness misuse (88%).
- Child occupant head position was significantly **more likely to be classified as 'optimal' if the child was: restrained in a FFCRS, if their restraint use was classified as being 'correct', if they were behaving passively, and if they were engaged in conversation** (compared with playing with a toy).

These findings raise a number of safety concerns. Suboptimal head position was observed in approximately one quarter of epochs with the distance and direction of head positions likely to place some children at higher injury risk than others. CRS misuse specific to the shoulder seatbelt/harness was observed in most of the epochs and is also associated with elevated injury risk. In contrast, when the CRS shoulder seatbelt/harness was used correctly, optimal head position was more likely to be observed. This information provides valuable insights for improving child occupant safety. It identifies the importance of correct CRS use to improve the safety functionality of the CRS in terms of seatbelt/harness systems and also to increase the likelihood of the child occupant adopting an optimal head position and remaining within the protection zone of the CRS.

On exploring the impact that conversation and playing with a toy had on head position it was revealed that conversation intuitively encourages a safer head position than interacting with an object in their lap. This information has the potential to guide future CRS and vehicle design to improve the safety of child occupants by finding ways for the rear seat environment to accommodate the common behaviours observed during real-world motor vehicle travel. The characteristics of family travel that were observed in this study indicate that more than one factor is likely to influence child occupant head position in any single epoch and further research is recommended to ascertain relative contributions to suboptimal head positions.

Title: The common characteristics and behaviours of child occupants in motor vehicle travel

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Abstract

Objective: Child occupant behaviour and head position when travelling in child restraint systems (CRS) may have an effect on injury risk in the event of a motor vehicle crash. The current study aimed to describe the common characteristics and behaviours of child occupants during everyday, real-world motor vehicle travel in a sample of Australian families to identify potential safety implications of observed behaviours and head position within the CRS.

Methods: Two instrumented study vehicles were used by 42 families for approximately two weeks. Continuous video and audio data were collected across 1,651 trips (over 600 hours). An online survey provided additional parent, familial and child occupant data. The characteristics and behaviours of 72 child occupants (aged 14 months to 9 years) who travelled in a forward-facing CRS (FFCRS) or a belt-positioning booster seat (BS) were observed and recorded by manual review of a sample of the video/audio recordings. One quarter of all trips (n=414) was randomly selected for coding/analysis and, within each trip, one child occupant was selected who was travelling in a FFCRS or BS. Child occupant behaviours, head position within the FFCRS or BS, and other relevant information was coded for each trip during nine discrete five second intervals or 'epochs' (5%, 17%, 25%, 30%, 50%, 53%, 75%, 89% & 95% of trip duration).

Results: In the majority of epochs (74%), child occupants' heads were observed to be 'optimally' positioned within the FFCRS or BS. For more than half of the epochs, child occupants were observed to be: correctly restrained (58%) and involved in an interaction with another vehicle occupant (59%). Bivariate analyses revealed that children travelling in a FFCRS were significantly more likely to be observed to have optimal head positions than those travelling in a BS (78% *vs.* 62%), $\chi 2$ (1) = 86.00, $p < 0.001$. Child occupants who were observed to be 'correctly' restrained were significantly more likely to be observed to have optimal head positions than those who were observed to be 'incorrectly' restrained (80% *vs.* 20%), $\chi 2$ (1) = 10.33, $p < 0.01$.

Conclusions: This is the first naturalistic driving study (NDS) to specifically explore the factors associated with child occupants' head position when travelling in a CRS. Findings from the current

study can be used to inform the positioning of anthropometric test dummies (ATD) in CRS testing, guide improvements to CRS/vehicle design, and develop targeted educational strategies to improve child occupant safety.

Keywords: child restraint systems, road safety, child occupant behaviour, head position

INTRODUCTION

Child occupant travel and child restraint system use

Child restraint systems (CRS) provide specialised protection for child occupants travelling in a motor vehicle and can reduce the risk of injury in the event of a crash by almost 70 percent (Brown, McCaskill, Henderson, & Bilston, 2006; Durbin, Elliott, & Winston, 2003). Although CRS use is over 90 percent in Australia (Koppel, Muir, et al., 2013), motor vehicle crashes remain a leading cause of child fatality and serious injury (Commonwealth of Australia, 2017), with unrestrained child occupants, or child occupants who have been incorrectly or inappropriately restrained within their CRS, at an increased risk of injury (Bilston, Yuen, & Brown, 2007; Brown et al., 2006).

Currently, the safety performance of a CRS is evaluated through laboratory sled testing with child-like anthropometric test device (ATD) (CREP, 2014), where the ATDs are seated in an ideal position (upright and still) within the CRS. There is a growing body of research that shows child occupants frequently move about during motor vehicle trips and assume very different positions than the ideal positions that the ATDs are placed in for conventional performance testing of CRS (Andersson, Bohman, & Osvalder, 2010; Bohman et al., 2011; Charlton, Koppel, Kopinathan, & Taranto, 2010; Forman, Segui-Gomez, Ash, & Lopez-Valdes, 2011; Osvalder et al., 2013). Several different naturalistic driving study (NDS) methodologies have been used to study child occupants' positions during motor vehicle travel such as: real-world, everyday trips across a two-week period (Charlton et al., 2010); predetermined trips in different types of CRS (Andersson et al., 2010; Osvalder et al., 2013), longer night trips (e.g., 75 minutes) (Forman et al., 2011), structured driving manoeuvres (Bohman et al., 2011), or still images every 15 minutes of trips over 60 minutes (van Rooij et al., 2005). Findings from several different NDS have revealed that child occupants are often observed to be in 'suboptimal' positions (i.e., outside of the protective zone of the CRS (Charlton et al., 2010; Khadilkar & Pauls, 1998).).

It should be noted that a diverse range of methodologies and terminology has been used to define suboptimal positions/postures across different NDS. Andersson and colleagues (2010) defined suboptimal positions as the child being positioned without head or shoulder contact with the seat/CRS back. Osvalder and colleagues (2013) focussed on the head and torso position and included movement in lateral (left-right) and sagittal (fore-aft) planes. Bohman and colleagues (Bohman et al., 2011) also reported movement of the head and torso in terms of lateral movement, whereas Forman and colleagues (2011) defined suboptimal positions in terms of the lateral head position. Other studies, measured suboptimal position in terms of the broader child positioning and included information on the placement of the child's head, body and limbs (Charlton et al., 2010; van Rooij et al., 2005). Whilst these studies provide valuable interpretations of child occupant behaviour and guide future research into suboptimal positions, the lack of uniformity in reporting the way in which child occupants are positioned has resulted in wide differences in prevalence estimates of suboptimal positioning, from 25 percent of trip time (Andersson et al., 2010) to 70 percent of trip time (Charlton et al., 2010). A notable gap in the literature is that the detailed positioning of child occupants with respect to position of limbs, head and torso has not been documented. This information will provide valuable insights for t improving research interpretation in terms of injury risk in the event of a motor vehicle crash. Importantly, previous studies have not captured children's behaviour and/or activity that may help understand why these positions are occurring during motor vehicle travel, as well the proportion of time that child occupants adopt suboptimal positions throughout the driving trip. Child occupants may adopt a suboptimal position for a moment within the driving trip (i.e., a child leaning forward to reach for a book) or for most of their driving trip (i.e., a child leaning forward to read a book for a large proportion of the trip).

Child occupant safety research needs a more refined way of classifying suboptimal positions in terms of specific body parts to better assess potential injury risk in the event of a motor vehicle crash. It is also important that the complex factors and interactions present during motor vehicle travel are better understood in relation to child occupant behaviour and positions (e.g., head position). Research has identified that suboptimal positioning in a CRS is associated with an elevated risk of head injury (Bilston et al., 2007; Brown et al., 2006). Given the long term health and economic consequences of head injuries (Bureau of Infrastructure Transport and Regional Economics, 2006; World Health Organization, 2008), there is strong justification for a new research focus to better understand child occupant's behaviour, head position and safety implications for motor vehicle travel.

The aim of the current study was to extend the findings of previous studies on child occupant positioning (Andersson et al., 2010; Charlton et al., 2010; Forman et al., 2011; Osvalder et al., 2013; van Rooij et al., 2005), with a larger study sample and combining NDS and survey methods to provide a more comprehensive understanding of child occupant travel, including child occupants' head positions, restraint type and use, activities, behaviours, affect, and other in-vehicle factors. This research is part of a larger study examining: i) how children behave and how they are restrained and seated during regular everyday motor vehicle journeys, and how this impacts their safety in the event of a motor vehicle crash, and ii) whether child/ren's behaviour and/or their restraint or seating position during regular day-to-day motor vehicle journeys is a distraction to the driver, and if this distraction affects driver behaviour/performance (Arbogast et al., 2016; Bohman et al., 2018; Charlton et al., 2013; Cross, Kuo, Charlton, Rudin-Brown, & Koppel, In preparation; Kuo, Charlton, Koppel, Rudin-Brown, & Cross, 2016; Loeb et al., 2017).

METHODS

Participants

Forty-two Australian families were recruited to participate in the study. Participating families were eligible for inclusion in the study if the driver(s): held a full driver's licence; was aged 25 years or older; resided within 50km of Monash University; regularly drove at least one child occupant aged between one to eight years who travelled in a FFCRS or BS, and were willing to drive the study vehicle for their everyday trips for a period of two weeks. For compensation for their contribution of time, participants were offered an $80 fuel voucher and a free consultation session with a professional CRS fitter. Recruitment was multimodal, including; advertising through the Royal Automobile Club of Victoria (RACV), project partner email distribution, national newspaper, national radio and posters at childcare centres.

Materials

Instrumented study vehicles

Two instrumented study vehicles were used for data collection: a 2006 Holden Statesman and a 2007 Holden Calais. Both vehicles were large size, luxury-model sedans with automatic transmission. Both study vehicles were instrumented with an inconspicuous video/audio recording system. A standard roof mounted DVD player was present in one of the vehicles and remained operational for participants' use.

Eight colour cameras with 150 degree viewing angle were positioned covertly in the vehicle, providing images of the driver, front seat passenger, the console, traffic conditions (front and rear of the vehicle) and the rear-seated child occupants. Four cameras captured the rear seat of the vehicle to enable rear seated child occupant observations; two cameras were positioned inside the vehicle within the DVD player/interior light cavity to capture lateral movement in the rear seat, and two were covertly embedded in each of the two side interior handles located above the rear doors to capture the fore-aft movement and lateral movement in the rear seat. All recording devices were controlled by a data acquisition system in each vehicle (Racelogic VBOX®, www.vboxaustralia.com.au) located in the trunk of the vehicle. All data were recorded onto Secure Digital cards. Vehicle instrumentation was identical within both study vehicles - with the exception of the Kinect™ motion-capture system that was fitted in the Statesman due to vehicle's larger size and Kinect requirements. Consequently, no skeletal data were collected from the Calais vehicle, (Arbogast et al., 2016; Bohman et al., 2018; Charlton et al., 2013).

Online survey

The Driver Demographic and Child Restraint Online Survey (DDCROS) was used to collect information on participating family demographics (see Appendix 1) (Cross, Charlton, & Koppel, 2017). The survey comprised five discrete sections that gathered data related to demographics, driving history, restraint use, safety beliefs and attitudes, and general beliefs and attitudes. Please see Appendix 1 for the full online survey.

Procedure

The study was approved by Monash University Human Research Ethics Committee. Informed consent was obtained from the main driver from each family on behalf of direct family members. The main driver from each participating family also completed the DDCROS online survey prior to participating in the NDS as part of a separate study (Cross et al., 2017). Participants drove one of two study vehicles. The main driver attended a briefing session at the time of study vehicle hand-over. Participants were asked to drive the study vehicle on their regular motor vehicle trips. All child occupants used their regular FFCRS or BS within the study vehicle. A CRS fitting specialist attended the study vehicle briefing session to ensure participants' CRS were fitted correctly into the study vehicle and where possible, checked each child occupant in their FFCRS or BS, and advised parents about any inappropriate use. The CRS fitting specialist also attended, the study vehicle pickup session to ensure correct fitting of the CRS back into the participant's own vehicle.

Data Analysis

Participating families completed 1,651 driving trips that had a least one child travelling in a CRS. One quarter of these trips (n=414) were randomly selected for detailed analysis - due to time and budget constraints. If there was not a child occupant travelling in a FFCRS or BS in a trip with operational video recording, another trip for the family was randomly selected. One child occupant seated in a FFCRS or BS per trip was randomly selected for analysis by random number generator prior to viewing the video. Data from the video/audio recordings were used to quantify and describe child occupants' in-vehicle behaviour. Each five second epoch was viewed and relevant data extracted manually, including:

- child occupant factors;
    - FFCRS or BS restraint use (correct/incorrect, where incorrect use was defined as twists, routing errors, loose fit, and unfastened belts/harness buckles),
    - head position (see Appendix 2 for coded categories/definitions),
    - interactions (yes/no, where yes included verbal and/or non-verbal interactions occurring within the vehicle),
    - primary activity (e.g., conversation that included the child talking or listening to another occupant, playing with toys, eating/drinking etc.),
    - behaviour (passive/active, where passive was defined as still; active was defined as moving), and
    - affect (positive/negative, where positive was defined as happy and content; negative was defined as unhappy or agitated).
- vehicle occupant factors;
    - driver sex (male/female),
    - front seat vehicle passenger (present/absent),
    - child sex(male/female),
    - child age group (1-3 years, 4-6 years, 7 or more years),
    - seating location of coded child in vehicle (right/centre/left, where right is located behind driver), and
    - number of rear seated passengers (right/centre/left).

For each of these selected trips, video and audio recordings were coded for nine intervals or epochs (at 5%, 17%, 25%, 30%, 50%, 53%, 75%, 89% and 95% of the trip). Five of these epochs were selected at regular trip proportions to capture behavioural changes throughout a given trip (5%, 25%, 50%, 75% and 95%). The 5% epoch was chosen to observe behaviour at the start of the driving trip, the 25%, 50% and 75% epochs were chosen to observe behaviours during the driving trip, and the 95% epoch was chosen to observe behaviour at the end of the driving trip. Four additional epochs were randomly selected to be observed to increase the size of the dataset for analysis (e.g., 17%, 30%, 53% and 89%). These epochs were added due to the acknowledgment of potential missing data in the NDS, such as light interference. Epoch time periods of two, five and ten seconds were piloted for manual coding. Based on the pilot study, it was determined that five second epochs allowed the observer(s) to accurately capture the child occupants' behaviour and head position. When longer epochs were trialled, it was more difficult to capture a discrete behaviour/position because child occupant had frequently changed to a new position or activity during this time. If the child occupant was observed to adopt more than one head position during the epoch, the position furthest from the optimal position was coded (see Appendix 2). Video data from one family could not be included due to poor quality (e.g., camera malfunction). This resulted in a final dataset available for randomly selected coding that comprised 41 families (with 81 children and 1,616 trips). Descriptive statistics were conducted to characterise child occupants' positions and/or behaviours. In addition, all head positions were re-grouped (optimal vs. combined suboptimal/extreme suboptimal) as described by Bohman and colleagues (2018) (see Appendix 2). All coding was undertaken by one researcher. Ten percent of all trips were also coded by an independent researcher (CW). The intra-class correlation coefficient (ICC) with 95% confidence interval (95% CI) was used to assess systematic and random error that might affect the relative inter-rater reliability. ICC estimates were calculated to measure inter-rater reliability for child occupants' head position (i.e., optimal vs. suboptimal vs. extreme suboptimal vs. unknown interactions, child affect and primary activity (0.765, 0.834, 0.813 and 0.824 respectively). The ICC value for head position was 0.76 indicating a moderate level of inter-rater reliability and consistency between Observers. The ICC value for interactions was 0.83 indicating a high level of inter-rater reliability and consistency between Observers. The ICC value for child affect was 0.81 indicating a high level of inter-rater reliability and consistency. The ICC value for primary activity was 0.82 indicating a high level of inter-rater reliability and consistency. Bivariate analyses were conducted to explore the relationship between child occupants' head position and other child occupant variables of interest.

RESULTS

Most child occupants were aged between one and seven years (83%) and more than half of the child occupants (61%) were travelling in a FFCRS (see Table 1). Male child occupants were slightly higher (53%) than female child occupants (47%). A summary of the 81 child occupants' demographic characteristics is presented in Table 1.

Table 1. Child occupant demographics (n=81)

Child occupant variables	n	%
Sex		
Female	38	47
Male	43	53
Age		
0 to less than 1 year	3	3
1 year to less 4 years	34	42
4 to less than 7 years	33	41
7 years or older	11	14
Restraint Type		
RFCRS	4	5
FFCRS	49	61
BS	23	28
Adult Seatbelt	5	6

General trip characteristics for the randomly selected sample (n=414) are shown in Appendix 3. Majority of trips were taken during the day (95%), less than 20 minutes in duration (79%) and taken between Monday and Friday (72%). Trip features for the remaining non-selected (un-coded) trips (n=1,237) are also reported, as well as the statistical comparisons. For the majority (4 out of 6) of comparisons there was no statistically significant difference between the selected and the non-selected trips. The number of trips that had two rear passengers in the selected trips were statistically significant, with higher than the non-selected trips, $\chi2$ (2) = 15.38, $p < 0.01$. Trips that were taken during the day (between 08:00-18:00 hours) were also significantly higher in the selected trips than in the non-selected trips, $\chi2$ (1) = 4.34, $p < 0.05$.

A summary of the randomly selected driving trips (n=414) and the characteristics of vehicle occupants is presented in Table 2. The majority of trips had a female driver (63%) and did not have a front seat passenger present (68%). Almost three quarters of child occupants were travelling in a FFCRS (74%). Over half of the trips (55%) had two rear seated occupants. Single rear seated occupants were observed for 37 percent of trips, with the most common seating allocation of single rear seated occupants being on the left side of the bench seat (59%).

Table 2. Summary of trips (n=414) and the characteristics of vehicle occupants

Vehicle occupant variables	n	%
DRIVER		
Sex		
Female	259	63
Male	155	37
FRONT SEAT PASSENGER		
Yes†	129	32
No	285	68
CHILD		
Sex		
Female	168	41
Male	246	59
Age		
1 to 4 years	177	43
4 to 7 years	213	51
7 years or older	24	6
Restraint Type		
FFCRS	307	74
BS	106	26
Seating Location		
R (behind driver)	199	48
L	179	43
C	36	9
Number of rear seated occupants		
1	154	37
2	227	55
3	33	8
Seating allocation of single child occupant trips (n=151)		
Left (kerbside/behind front passenger)	90	59
Centre	10	7
Right (behind driver)	51	34

† Includes presence of front seat passenger for part of the trip.

All epochs (n=3,726) were analysed from the randomly selected trips to explore child occupants' positions and behaviours and are shown in Table 3. The majority of restraint use was observed as being correct (58%). The incorrect restraint use observed consisted of a high proportion of shoulder harness/belt misuse (n=600, 88%) with half of the shoulder belt misuse relating to incorrect shoulder placement. Approximately one quarter of the children's head positions were observed to be suboptimal or extreme suboptimal.

Table 3. Summary data for child occupant restraint use, positions and behaviour for all epochs (n=3726)

Child occupant variables	n	%
Restraint use† (n=1,641)		
All correct	959	58
Incorrect±	682	42
Shoulder misuse	600	88
Belt/harness on outer-shoulder	183	27
Belt/harness off shoulder	153	23
Belt/harness on neck	71	10
Arm/s out of shoulder belt/harness	105	15
Twisted shoulder belt/harness	43	6
Unbuckled belt/harness	4	1
Other shoulder belt/harness misuse (e.g., belt routing error)	41	6
Lap only misuse		

Belt harness misuse (e.g., high on abdomen, loose)	82	12
Head position†† (n=3,515)		
Optimal	2,586	74
Suboptimal	852	24
Extreme suboptimal	77	2
Interactions with others††† (n=3,497)		
Yes	2,076	59
No	1,421	41
Primary activityǂ (n=3,482)		
Conversationǂǂ	1,732	49
Looking	885	25
Playing with toys	190	6
Sleeping/drowsy	181	5
Eating/drinking	159	4
Touching/looking at self	142	4
Watching DVD	48	1
Reading	37	1
Touching vehicle/restraint	36	1
Using electronic h/held device	30	1
Other (e.g. coughing, sneezing, hiccups)	28	1
Crying/fighting	9	1
Touching bag	5	1
Behaviourǂǂǂ (n=3,480)		
Passive	2,760	79
Active	720	21
Affect ǂǂǂǂ (n=3,480)		
Positive	3,385	97
Negative	95	3

± Incorrect use is not exclusive and may include lap or shoulder belt misuse or both.
† Unknown restraint use (n=2,085)
†† Unknown head position (n=211)
††† Interactions include both verbal, non-verbal and both; Unknown interaction/s (n=229)
ǂ Unknown activity (n=244)
ǂǂ All conversation as primary activity is also counted as a verbal interaction
ǂǂǂ Non-classified behaviour (n=246)
ǂǂǂǂ Non-classified affect (n=246)

Child occupants were observed as having optimal head position in nearly three quarters of the epochs observed (74%). Interactions between any vehicle occupants were observed in 59 percent of the epochs and the most commonly classified primary activity that the child occupant was engaged in was conversation (49%).Child occupant head position was significantly more likely to be classified as 'optimal' if the child was: restrained in a FFCRS ($\chi 2$ (1) = 86.00, $p < 0.01$); if their restraint use was classified as being 'correct' ($\chi 2$ (1) = 10.33, $p < 0.01$); if they were behaving passively ($\chi 2$ (1) = 253.38, $p < 0.01$), and if they were engaged in conversation (compared with playing with a toy; $\chi 2$ (1) = 32.28, $p < 0.01$). In contrast, suboptimal head position was significantly more likely if there was an interaction among vehicle occupants, $\chi 2$ (1) = 15.31, $p < 0.01$. There were no significant differences across optimal and suboptimal head positions for child occupants' affect or being engaged in a conversation versus eating/drinking (see Table 4).

Table 4. Summary statistics for analyses of relationships between child occupant head position and other child occupant variables across epochs (n=3,726)†

Child occupant variables	Child occupant head position n (%) Optimal	Suboptimal/Extreme suboptimal	Significance
Restraint Type			
BS vs.	541 (62)	337 (38)	**$\chi 2$ (1) = 86.00, p < 0.01**
FFCRS	2,045 (78)	592 (22)	
Restraint use			
All correct vs.	764 (80)	195 (20)	**$\chi 2$ (1) = 10.33, p < 0.01**
Incorrect	497 (73)	185 (27)	
Behaviour			
Passive vs.	2,199 (80)	556 (20)	**$\chi 2$ (1) = 253.38, p < 0.01**
Active	363 (50)	356 (50)	
Affect			
Positive vs.	2498 (74)	884 (26)	$\chi 2$ (1) = 0 .85, p = 0.35
Negative	64 (70)	28 (30)	
Interactions with others			
Yes vs.	1,468 (71)	597 (29)	**$\chi 2$ (1) = 15.31, p < 0.01**
No	1,094 (77)	326 (23)	
Primary activities			
Conversation vs.	1,233(72)	490 (28)	**$\chi 2$ (1) = 32.28, p < 0.01**
Playing with toys	98 (52)	92 (48)	
Conversation vs.	1,233(72)	490 (28)	$\chi 2$ (1) = 0.22, p = 0.64
Eating/drinking	111 (70)	48 (30)	

Significant at p<0.05

† Unknown variables excluded

DISCUSSION

The current study used NDS methodology to observe and describe common child occupant characteristics and behaviours in a sample of Australian families during everyday, real-world motor vehicle travel. This is the first study to describe the relationship(s) between child occupants' head position within the CRS and other child occupant characteristics and behaviours.

A key finding was that child occupants' heads were observed to be optimally positioned within their FFCRS or BS in 74 percent. This finding falls within the range of suboptimal positions previously reported (e.g., 25 percent (Andersson et al., 2010) to 70 percent (Charlton et al., 2010)). However, it should be noted that this study focussed on head position only, whereas some previous studies have included multiple body parts, or head/torso (Charlton et al., 2010; Osvalder et al., 2013; van Rooij et al., 2005). It is likely that the lack of specificity in defining suboptimal positions has resulted in differences in prevalence estimates of suboptimal positioning

This study is one of a small number of studies in which data regarding the quality of restraint use were collected during dynamic, everyday trips rather than the traditional approach of setup checking stations (Brown, Hatfield, Du, Finch, & Bilston, 2010; Koppel, Charlton, & Rudin-Brown, 2013). During driving trips child occupants were observed to be 'correctly' restrained in their CRS in just over half (58%) of the epochs. The majority of CRS misuse observed related to shoulder belt/harness misuse (85%), with placement of the shoulder belt/harness most commonly observed as being off the shoulder or on the outer-shoulder (50% combined). These findings support the common observation of CRS belt/harness misuse that has been previously reported by Koppel and colleagues from a CRS inspection program (Koppel, Charlton, et al., 2013). Arguably shoulder belt placement off the shoulder or on the outer-shoulder is also associated with potential head injury due to the likelihood of belt slip off during impact or rebound (Bohman et al., 2018). Parents were provided with education relating to inappropriate CRS use by the CRS fitter specialist prior to commencing the study. The high overall frequency of observed CRS misuse (42% of all epochs) may be related to comfort. A previous study by Osvalder and colleagues (2013) found that discomfort and activities can influence sitting posture and seat belt positions when travelling in a CRS. Improving the design of rear seats including CRS could potentially reduce the instances of child occupant movement and belt slip misuse by improving overall travel comfort

The current study provides important new insights on the relationship between head position (i.e., optimal vs. suboptimal) and other child occupant variables. A key finding was that child occupants travelling in a FFCRS were significantly more likely observed as having optimal head positions than those travelling in a BS. A plausible explanation for finding is that the BS uses the vehicle seat belt instead of an integral harness – which allows for a greater range of child occupant movement. In addition, child occupants who were observed as being 'correctly' restrained were significantly more likely to have optimal head positions than those who were observed as being 'incorrectly' restrained

Optimal child occupant head position was also significantly more likely to be observed when a child was engaged in conversation than when the child occupant was playing with a toy(s) (72% vs. 52%). A potential explanation for this is that playing with a toy may mean that the child occupant is leaning their head towards their lap. The association between playing with toys and suboptimal head position is consistent with research previously reported by Osvalder and colleagues (Osvalder et al., 2013), who identified that specific activities influenced the selection of sitting postures, with child occupants observed to adopt a suboptimal head positions for the majority of a driving trip when using an electronic device. Not surprisingly, 'passive' child occupant behaviour was also associated with optimal head positioning; Child occupants who were observed as sitting still were more likely to be observed to have optimal head positions than those who were active. These findings on child occupant behaviour and associated head positioning when travelling in a motor vehicle provide potential insights into how to improve the rear seat environment and CRS for child occupant functionality and comfort.

Several study limitations should be noted. While the unique study design of a NDS allows for a wide range of variables relevant to child occupant safety to be explored, the 'naturalistic' nature of the study means that it is not possible to ensure that all the data were available for all trips. The visibility of the harness or belts was sometimes compromised because child occupants' arms, blankets or toys obstructed observation. The analyses of NDS data also presented a challenge due to the dynamic lighting conditions where video footage was occasionally unable to be clearly viewed due to bright sunlight or street lights. Due to time and budget restraints, the complete set of data were not analysed. From the total trips collected, one quarter (n=414) were randomly selected for in-depth analysis. Several comparisons were made to ensure that these randomly selected trips were not significantly different to the non-selected driving trips. The proportion of trips that had two rear seated passengers in the selected trips was greater than in the non-selected trips. Selected trips are slightly more biased towards families with more than one child (# for 2+ children vs # for 1 child) due to the fact that selected trips required video to be operational for the child that was randomly selected. One family that had a single child was removed from the randomly selected trips for coding due to the inability to view the video data, resulting in removal of 35 single occupant trips for this excluded family. The selected trips also had more trips that were taken during day. This finding may be explained by the fact that the cameras were not suited to capture behaviours that occurred in night/darkness and as a consequence, some recordings of night trips were not usable for the analysis. Another possible limitation of the study is that participants' own CRS were installed correctly into the study vehicle by a CRS fitting specialist. Previous research involving CRS inspections of Australian family vehicles have revealed high levels of CRS installation errors (Brown et al., 2010; Koppel, Charlton, et al., 2013), therefore potential suboptimal head positions associated with incorrectly installed FFCRS or BS may be under-represented in the current study.

The behaviours observed in this NDS study are real-world, everyday behaviours that occur within a complex family motor vehicle environment. The study findings highlighted that there are a number of activities and behaviours which are associated with suboptimal head positions. Although it may not be possible, nor considered necessary, to control or modify all child occupant behaviours, it is nevertheless important that solutions for improved rear seat safety for child occupants are explored. Recent research conducted as part of the broader study has quantified child occupants' suboptimal head positions when travelling in their CRS (Arbogast et al., 2016; Bohman et al., 2018; Loeb et al., 2017). The quantified common head positions of child occupants travelling in BS were also analysed to explore injury implications in event of a motor vehicle crash (Bohman et al., 2018). Findings from sled tests revealed compromised safety when ATDs were placed in common positions observed in the NDS (i.e., suboptimal head positions) for sled impact (Bohman et al., 2018). More specifically, suboptimal head position was associated with the increased likelihood of shoulder belt slip and greater forward head excursion. Taken together, these findings can inform CRS/vehicle design to encourage behaviours and activities that are associated with optimal head position and accommodate or discourage suboptimal head position. The relative influence of the multiple, interplaying travel factors on suboptimal head position demonstrated in this study will be explored in more detail in future research.

CONCLUSION

This is the first NDS to systematically explore factors associated with child occupants' head position when travelling in a motor vehicle. Child occupant head position was significantly more likely to be classified as 'optimal' if the child occupant was: restrained in a FFCRS, correctly restrained, if they were behaving passively (i.e., sitting still), if they were not interacting with other occupants, or if they were having a conversation. This information has the potential to guide future CRS and vehicle design to improve the safety of child occupants by accommodating the common behaviours observed during real-world motor vehicle travel.

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Manuscript Appendices

Appendix 1 – see Thesis Appendix F

Appendix 2 – see Thesis Figure 14

Appendix 3 – Representative of randomly selected sample and all trips collected in NDS

Appendix 3. Summary of trip characteristics of randomly selected and non-selected driving trips and statistical comparisons

	Selected 414 trips n (%)	Non-selected 1,237 trips n (%)	Significance
<20 mins	328 (79)	991 (80)	$\chi 2$ (1) = 0.12, p = 6.97
During the day (06:00-18:00)	393 (95)	1,136 (92)	$\chi 2$ (1) = 4.34, p < 0.05
Weekday	299 (72)	860 (70)	$\chi 2$ (1) = 1.08, p = 0.30
2 rear seated passengers (incl. adults)	228 (55)	549 (44)	$\chi 2$ (2) = 15.38, p < 0.01
Female drivers†	259 (64)	821 (68)	$\chi 2$ (1) = 2.25, p = 0.13
Front seat passenger presence†† (incl. child occupant & partial trips)	129 (32)	328 (27)	$\chi 2$ (1) = 3.33, p = 0.07

Significant at p<0.05
†Driver sex unknown (n=31)
††Front seat passenger unknown (n=29)

7. Publication # 3

Cross, S. L., Koppel, S., Arbogast, K. B., Rudin-Brown, C. M., & Charlton, J. L. (Submitted). Modelling factors associated with head positions of child occupants travelling in child restraint systems. *Accident Analysis & Prevention*.

7.1. Introduction

The third publication presents a GEE model from the NDS data that explores the relative contribution of a number of factors in the prediction of suboptimal head position. It is represented in the PhD research program as Stage 3, as highlighted in Figure 16 below.

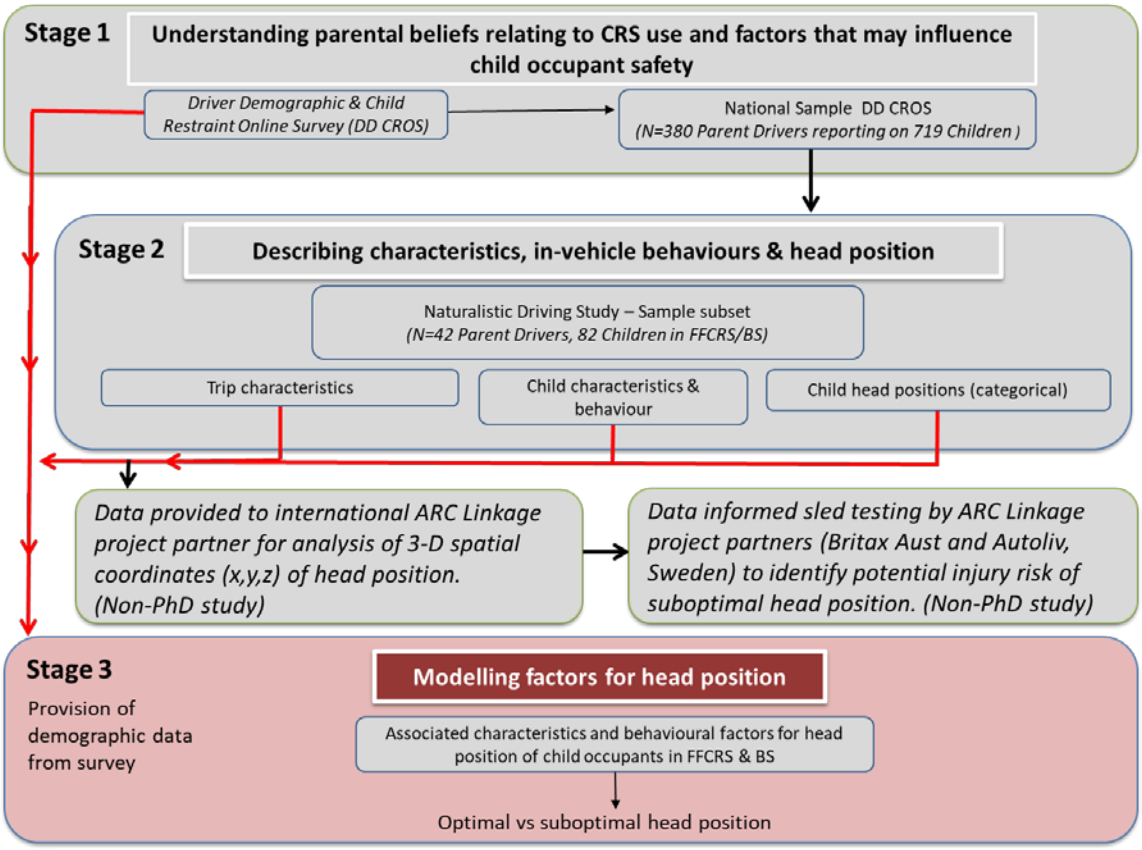

Figure 16. Stage 3 of PhD research program

Many factors may be associated with head positions of child occupants travelling in CRS during real-world, everyday motor vehicle trips. The factors of interest (e.g., familial-, child-, trip-related) that were identified in Stages 1 and 2 of this PhD research program were included in the GEE to identify the travel characteristics associated with child occupant's suboptimal head position when travelling in a FFCRS or a BS during real-world, everyday driving trips.

The findings in this publication identified several factors associated with suboptimal child occupant head positions that may have an effect on their injury risk in the event of a motor vehicle crash, including;

- **Child occupants travelling in a BS were more than twice as likely to adopt a suboptimal head position than child occupants travelling in a FFCRS**. This suggests that the mechanism of restraint offered by BS offers more movement away from the optimal position and has the ability to provide less protection than a FFCRS in the event of a crash.
- **Child occupants that were 'older' for their restraint type were nearly 40 percent more likely to be observed to have a suboptimal head position compared to child occupants that were 'younger' for their recommended restraint type**. This finding suggests that discomfort (associated with outgrowing the restraint type) may increase child occupant movement when travelling.
- **Suboptimal head positions were associated with incorrect FFCRS and BS use**, with suboptimal head position one and a half times more likely if incorrect shoulder belt/harness use was present. Shoulder belt/harness misuse may be allowing the child occupant to move around more within the CRS.
- **Activities of child occupants influenced their head position in their CRS.** Child occupants engaged in lap-based activities (e.g., reading, playing with toys or using an electronic hand-held device) were two and a half times more likely to be observed in a suboptimal head position than child occupants that were engaged in conversation. This suggests that some activities while travelling in a CRS may encourage child occupants to lean forward and be detrimental to child occupant safety in the event of a motor vehicle crash and others may not require movement and may be protective.

The study findings highlighted that there are a number of activities and behaviours which are associated with suboptimal head positions (e.g., playing with toys). Suboptimal head position was also more likely to be observed when CRS misuse was present or if the child was travelling in a BS rather than a FFCRS. Furthermore, separate sled-test research using this dataset confirms that suboptimal head position is associated with the increased likelihood of shoulder belt slip and greater forward head excursion (Bohman et al., 2018). It is not realistic to try and completely remove the desire for a child to engage in an activity or behaviour. It is, however, important that parents are educated on the importance of correct CRS use for every trip to maintain optimal head position and receive best CRS protection in the event of a motor vehicle crash. It is also important that solutions for improved rear seat safety for child occupants are explored. CRS/vehicle design should encourage behaviours and activities that are associated with optimal head position and accommodate or discourage suboptimal head position. Future FFCRS and BS design should also focus on enhancing the travel comfort of the child occupant. BS design, in particular, should explore ways to minimise or discourage the head movement that was statistically more likely to be observed when compared to child occupants travelling in a FFCRS.

Title: Modelling factors associated with head positions of child occupants travelling in child restraint systems

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Highlights

- Child occupants' head position in a CRS may have an effect on their injury risk in the event of a crash
- Naturalistic driving study methodology explored the factors associated with child occupants' head position when travelling in a CRS or booster seat
- Suboptimal head positions were associated with incorrect CRS or booster seat use
- Child occupants in booster seats were more likely to adopt suboptimal head positions
- Child occupant activities influenced their head position in a CRS or booster seat

Abstract

Objective: Child occupant's behaviour and their head position when travelling in a child restraint system (CRS) may have an effect on their injury risk in the event of a motor vehicle crash. The current study aimed to identify the travel characteristics (e.g., familial-, child-, trip-related) associated with suboptimal head positions for child occupants when travelling in a forward-facing CRS (FFCRS) or a booster seat (BS) during real-world, everyday driving trips.
Methods: Two instrumented study vehicles were used by 42 families for approximately two weeks. Over 600 hours of continuous video and audio data was collected from 1,651 trips. One quarter of these trips (n=414) were randomly selected for analysis. Child occupant behaviour, head position within their FFCRS or BS and other relevant information was coded for nine discrete five second intervals or 'epochs' (5%, 17%, 25%, 30%, 50%, 53%, 75%, 89% & 95% of trip duration). The relative contributions of factors of interest were explored through a generalised estimating equation (GEE).
Results: The GEE revealed that child occupants travelling in a BS were twice as likely to be observed to have a suboptimal head position compared to child occupants travelling in a FFCRS. Child occupants were also nearly one and a half times more likely to be observed to have a suboptimal head position if they were in the older age range for the restraint type that they were using (FFCRS or BS), if they had incorrect shoulder belt/harness use, or if they were interacting with other occupants. In addition, when a child occupant was engaged in a lap-based activity, compared to conversation, the likelihood of the child occupant being observed to have a suboptimal head position increased by nearly two and half times.
Conclusions: This is the first naturalistic driving study (NDS) that has explored the factors associated with child occupants' head position when travelling in a CRS. Findings from the current study suggest that a focus on improving BS design and raising parent awareness on behaviours/activities that are associated with optimal and suboptimal head position would be conducive to improving child occupant safety. The finding of the significant association between incorrect shoulder harness/belt and suboptimal head position also highlights the importance of further parent and child education relating to correct CRS use.

Keywords: child restraint systems, road safety, child occupant behaviour, head position

1.0 INTRODUCTION

A CRS provides specialised protection to a child occupant travelling in a motor vehicle by providing s to the growing body and improving the belt positioning (CREP, 2014). A CRS can reduced injury risk i event of a motor vehicle crash by approximately 70 percent if used correctly (Brown, McCaskill, Hen & Bilston, 2006; Durbin, Elliott, & Winston, 2003). Australian research reveals that although the safe benefits of the CRS is widely acknowledged, CRS misuse is prevalent (Bilston, Finch, Hatfield, & Brow 2008; Brown, Hatfield, Du, Finch, & Bilston, 2010; Charlton, Koppel, Kopinathan, & Taranto, 2010; Ko Charlton, & Rudin-Brown, 2013). Importantly, CRS provide additional protection to the developing c (Arbogast, Balasubramanian, Seacrist, Maltese, & García-España, 2009) and misuse potentially elevat child occupant's injury risk in the event of a motor vehicle crash.

1.2 Mechanism of child occupant injury

Anatomical, anthropological and biomechanical changes in the developing child influence their vulnerability to injury (Schmitt, Niederer, & & Walz, 2004). As a child ages, bone ossification and morphological and geometric changes of the spine and pelvic area occur, and relative changes in boc head proportions are observed (Schmitt et al., 2004). These developments provide increased protec against crash forces by altering the kinematics of the child's body in a motor vehicle crash (Arbogast 2009). For example, the anatomical changes occurring at the atlanto-occipital joint potentially influe the degree of head excursion and acceleration in the event of a crash (Arbogast, Cornejo, Kallan, Wir & Durbin, 2002). The types of injuries that are commonly sustained by child occupants involved in cr have been well documented and generally reflect the limited capacity of the developing body to witl biomechanical forces (Arbogast et al., 2009; Arbogast et al., 2005).

Serious injuries are reported to involve the brain, spinal cord and abdomen (Arbogast et al., 2002; Ar et al., 2005; Arbogast & Jermakian, 2007; Arbogast, Locey, Zonfrillo, & Maltese, 2010; Brown, Bilston McCaskill, & Henderson, 2005; Brown et al., 2006; Cameron, Purdie, Kliewer, & McClure, 2008; Natic Highway Traffic Safety Administration, 2010). The mechanism of serious injury of child occupants tra in a CRS often involves excessive head excursion or impact to the head, neck and spine (Arbogast et 2005; Bilston, Clarke, & Brown, 2011; Polk-Williams et al., 2008). Arbogast, Wozniak, Locey, Maltese Zonfrillo (2012) recently analysed data from two crash investigation databases in the United States (the Crash Injury Research and Engineering Network and the Partners for Child Passenger Safety Stud characterised 24 paediatric injuries from child occupants up to 15 years of age that resulted from sid impact crashes. Head injuries were found to be the leading type of injury. Similar findings were repc by Charyk Stewart et al. (2013) who investigated severe injury patterns from all motor vehicle crash resulting in child hospital admissions in Canada. These authors compared a paediatric group of child to 8 years of age with adolescents between 9-17 years of age and found that skull fractures, subdura hematomas, subarachnoid haemorrhage, brain contusions and edema were statistically more comm child occupants in the younger age group (Charyk Stewart et al., 2013). Until the biological transforn is complete in the human child, the additional head-neck support of a CRS is crucial for protection in event of a motor vehicle crash (National Highway Traffic Safety Administration, 2010). Currently, CR tested by placing an anthropometric test device (ATD) in an ideal, upright, still position in the CRS (as the manufacturer's instruction) (CREP, 2014). Safety is ascertained from the data collected from the sensors for head injury criteria (HIC) and neck injury criteria (NIC) obtained from sled tests. However occupants do not behave like ATDs; they do not sit perfectly still and upright while travelling in a veh (Charlton et al., 2010). What is not well understood is the association between the positioning of chi occupants and injury outcomes and in particular, whether head position is compromised when CRS u not ideal. CRS misuse includes inappropriate CRS use and incorrect CRS use. Misuse can take a rang forms as described below.

1.1 Inappropriate CRS use

Inappropriate use is defined as when the CRS is used by a child occupant that is of an age or size oth what the CRS was designed (Ivers et al., 2011; Standards Australia/Standards New Zealand, 2010). Legislated standards provide direction on the best restraint for a child, depending on their age and si

Previous research has revealed that inappropriate use resulting from premature graduation to the next restraint type (i.e., before the child occupant is the appropriate size to be transitioned) is common. These findings are consistent across information gathered by surveys (Bilston et al., 2008; Brixey, Ravindran, & Guse, 2010; Koppel, Charlton, Fitzharris, Congiu, & Fildes, 2008; Lennon, Titchener, & Haworth, 2010) and field observations (Brown et al., 2010; Johns, Lennon, & Haworth, 2012; Koppel et al., 2013). For example, a CRS inspection program of child occupants up to 12 years of age that was conducted in the Australian state of New South Wales (NSW) by Brown and colleagues (2010) identified inappropriate use in more than half of the CRS inspections (51%). These findings have serious implications for child occupant injury. Premature graduation to the next restraint type can compromise child occupant protection and is linked to increased injury risk in the event of a motor vehicle crash (Bilston, Yuen, & Brown, 2007; Brown et al., 2006).

1.3 Incorrect CRS use

Incorrect use is defined as the use of a CRS system contrary to the manufacturer's instruction (Ivers et al., 2011). Incorrect use includes errors such as twists, incorrect routing of belt/harnesses, slack, belt placement on the child occupant and positioning of the child within the CRS. Previous research has shown that incorrect use is common. For example, inspections of 2,674 CRS revealed that the most common forms of incorrect use (41%) were: belt/harness strap errors such as twisted, poorly adjusted, and/or incorrectly positioned CRS (Koppel et al., 2013). This is consistent with findings from Brown and colleagues (2010) who also reported that 51 percent of CRS inspected were being incorrectly used (Brown et al., 2010). Incorrect use has implications in the event of a motor vehicle crash; There is an increased injury risk to child occupants when the shoulder belt/harness is placed incorrectly on the shoulder or arm (Bilston et al., 2007; Bohman et al., 2011).

Another form of incorrect CRS use occurs when the child occupant is not seated as per the manufacturer's instruction (Standards Australia/Standards New Zealand, 2010). This is defined as the child occupant being in a suboptimal position, a shifted position or out-of-position (OOP) and is an interaction between the child occupant and the CRS that places a child occupant in a position other than the preferred, upright and still/optimal position (Andersson, Bohman, & Osvalder, 2010; Arbogast et al., 2016; Bohman et al., 2011; Charlton et al., 2010; Forman, Segui-Gomez, Ash, & Lopez-Valdes, 2011; Khadilkar & Pauls, 1998; van Rooij et al., 2005).

Previous studies have reported suboptimal positions of child occupants travelling in a CRS (Andersson et al., 2010; Arbogast et al., 2016; Charlton et al., 2010; Forman et al., 2011; van Rooij et al., 2005). However, suboptimal positions have been defined in a variety of ways (Cross, Koppel, Arbogast, Rudin-Brown, & Charlton, In Press). For example, some studies focussed on shoulder to booster-back contact and others observed the position or movement of child occupant's head, torso and/or limbs (Andersson et al., 2010; Bohman et al., 2011; Charlton et al., 2010; Forman et al., 2011; Osvalder et al., 2013). .

Different restraints are designed to protect child occupants of different sizes and they function in different ways and allow different ranges of movement for the child occupant (Royal Automobile Club of Victoria, 2019). A FFCRS has a 5-point integrated harness, that when used correctly, should be firmly tightened around the child's shoulders and through their legs for a snug fit (CREP, 2014). Fore-aft and lateral movement is restricted when a FFCRS is used correctly due to the firmness of the belt remaining constant for the complete motor vehicle trip (CREP, 2014). The BS utilises the vehicle seat belt (CREP, 2014). The vehicle seatbelt provides fewer points of restraint (3 point contact with the adult lap and sash seatbelt) (National Highway Traffic Safety Administration, 2013). The seatbelt auto-adjusts the firmness of the seatbelt around the child occupant but can be loosened or moved by the child occupant. This allows the occupant to move about more freely than they can within the FFCRS. The BS provides a contoured structure around the child occupant that limits some lateral movement and provides protection for the child occupant's head in a side impact crash (Neuroscience Research Australia and Kidsafe Australia, 2013) . A recent study by Arbogast and colleauges (2016) reported that the range of fore–aft head position increased from FFCRS to BS to adult seatbelt: 218, 244, and 340 mm on average, respectively. Importantly, suboptimal positions of the head have been shown to have an increased injury risk (Bilston et al., 2007; Bohman et al., 2011; van Rooij et al., 2005).

Bilston and colleagues (2007) confirmed the increased injury risk of sub-optimal positioning by reconstructing eight real crash scenarios of child occupants travelling in BS to compare injury outcomes. Sub-optimally restrained or OOP child occupants who sustained substantial injuries from four crash case studies were compared with four car crashes involving optimally restrained children (Bilston et al., 2007). Simulated crash tests, using the Hybrid III ATD to represent a 3 year old child, were conducted to examine the role of CRS use in injury prevention, with both OOP and optimal dummy placement. This post-hoc crash analysis and reconstruction confirmed the significant contribution of OOP to increased injury risk. However, it should be noted that these findings are drawn from a limited number of events and do not provide information on the behaviours and reasons that lead to child occupant suboptimal positions.

Osvalder and colleagues (2013) provided useful insights on suboptimal positions, as well as self-reported comfort of for six child occupants aged between 7 and 9 years. Child occupants were observed during two separate trips of 60 minutes duration during a predetermined driving route: in a high-backed BS and in an integrated booster cushion (IBC) that was part of the vehicle structure (Osvalder et al., 2013). Self-reported information about comfort was collected from questionnaires that the child occupant completed every 20 minutes within the driving trip. Four video cameras installed in the vehicle captured the child occupants' seating posture (head and torso), seatbelt position and activity information. Findings from the questionnaires revealed that all child occupants preferred the IBC compared to the BS and all child occupants stated that, if given an option, they would have preferred the IBC, a backless BS or none at all. Reasons were due to possibilities to move freely, the absence of torso supports and the design. Most child occupants disliked the side wings on the high-backed BS that reportedly created a 'locked-in feeling'. Interestingly, although they reported that they felt locked-in, the individual variation of movement of head and torso among the children when seated on the high-backed BS was greater than when seated on the IBC. Movement may potentially be due to travel discomfort. Improvements suggested by the child occupants relating to the high-backed BS included softer booster cushion and backrest as well as a wider backrest. A recent video-based observational study by Fong and colleagues (2017) support the suggestion that comfort plays an important role in CRS use. The research team used a count of fidgeting and stabilization movements (such as stretching of neck, stretching of back, shifting weight, leaning forward/backward or to either side, interacting with the sash belt, and kicking or moving of the legs) to quantify discomfort avoidance behaviour (DAB) (Fong et al., 2017). Increases in DAB were associated with increases in the number of CRS use errors among children using BS (errors in use = $3.89 \times DAB - 2.18$, $p < 0.0001$), suggesting that discomfort may be realted to CRS misuse (Fong et al., 2017). The generalised linear regression model also revealed a significant relationship between height of child and errors in use ($p = 0.045$) (Fong et al., 2017). Exploring the association between suboptimal head positions and children from the younger or older age range for their recommended CRS type may provide additional information on improvements in CRS design.

Child occupant position is likely to be influenced by a range of factors when families travel on everyday trips. Particular interactions and activities may be detrimental to travel safety (e.g., touching other occupants, reaching for objects or changing position within the CRS or BS to engage in an activities [e.g., electronic device use]). In our previous research with the same study sample, we observed and described common child occupant characteristics and behaviours when travelling in either a FFCRS or a BS (Cross et al., In Press). Analysis of the video and audio recordings from our previous study revealed that child occupants' heads were 'optimally' positioned for 74 percent of the epochs (Cross et al., In Press). A variety of activities and interactions were observed (e.g., conversing, looking and playing with toys). For more than half of the epochs, child occupants were involved in an interaction with another vehicle occupant (59%). Child occupant's head position was significantly more likely to be classified as 'optimal' if the child was: restrained in a FFCRS (78%) rather than a BS (62%, $\chi2$ (1) = 86.00, $p < 0.01$); if their restraint use was classified as 'correct' (80%) than incorrect (73% $\chi2$ (1) = 10.33, $p < 0.01$); if they were behaving passively (i.e., not moving around) (80%) than sitting still (50%, $\chi2$ (1) = 253.38, $p < 0.01$), and if they were engaged in conversation (72%) compared with playing with a toy (52% $\chi2$ (1) = 32.28, $p < 0.01$). These findings suggest that when analysed independently, the likelihood of a child occupant adopting a suboptimal head position varied across restraint type, restraint use and child occupant behaviours during every-day family travel. Given the evidence for elevated injury risk associated with CRS misuse, further research is needed to identify the relative contributions of factors that are associated with suboptimal head positions.

Consequently, this research specifically aimed to identify the travel characteristics (i.e., familial, child related, trip related) associated with child occupant's suboptimal head position when travelling in a FFCRS or a BS during real-world, everyday driving trips.

2.0 METHOD

2.1 Participants

Forty two Australian families were recruited to participate in the study (Cross et al., In Press). Participating families were eligible for inclusion in the study if the driver(s): i) had at least one child occupant between 1 to 8 years of age who travelled in a FFCRS or a BS; ii) were willing to drive a study vehicle for their everyday trips for a period of two weeks; iii) held a full Victorian driver's licence; iv) was 25 years of age or older, and due to resources, v) resided within 50km of Monash University. For part-compensation for their contribution of time, participants were offered an $80 fuel voucher and a free consultation session with a professional CRS fitter. Recruitment was multimodal, including; advertising through the Royal Automobile Club of Victoria (RACV), project partner email distribution, national newspaper, national radio and from posters displayed at childcare centres.

2.2 Materials

2.2.1 Instrumented study vehicles

Two instrumented study vehicles were used for data collection: a 2006 General Motors Holden Statesman and a 2007 General Motors Holden Calais (Arbogast et al., 2016; Charlton et al., 2013; Cross et al., In Press). Both vehicles were large size, luxury-model sedans with automatic transmission. With the exception of the Kinect™ motion-capture system fitted in the Statesman, instrumentation was identical across both vehicles. Both study vehicles were instrumented with an inconspicuous video/audio recording system, which included eight covert colour cameras with 150 degree viewing angle which provided images of the driver, front seat passenger, the console, traffic conditions (front and rear of the vehicle) and the rear seat child occupants. Four cameras captured the rear seat of the vehicle; two cameras were positioned inside the vehicle to capture lateral movement in the rear seat, and two were covertly embedded in each of the two side interior handles located above the rear doors to capture the fore-aft movement and lateral movement in the rear seat. All recording devices were controlled by two data acquisition systems (Racelogic VBOX®, www.vboxaustralia.com.au) located in the boot of the vehicle. All data was recorded onto Secure Digital (SD) cards. A standard roof mounted DVD player was present in the Statesman and remained operational for participants' use.

2.2.2 Online survey

The Driver Demographic and Child Restraint Online Survey (DDCROS) was used to collect information on participating family demographics (Cross, Charlton, & Koppel, 2017). The DDCROS included questions related to parental beliefs relating to CRS use and child vehicle occupant safety, as well as information relating to parent, family and child demographics.

2.3 Procedure

The study was approved by Monash University Human Research Ethics Committee. The main driver from each participating family read, completed and signed an Explanatory Statement and Consent Form, and completed the DDCROS (Cross et al., 2017) prior to taking possession of a study vehicle (Cross et al, In Press). The main participating driver attended a briefing session at the time of study vehicle hand-over. All child occupants used their regular FFCRS or BS within the study vehicle. A CRS fitting specialist attended the briefing session and vehicle pickup to ensure the FFCRS or BS were fitted correctly, and where possible, checked each child occupant in their FFCRS or BS, and advised parents about any inappropriate use. Participants were asked to drive the study vehicle on their regular, everyday driving trips and use the vehicle as they would their own.

2.4 Data Analyses

Child occupants' head position was categorised as either optimal or suboptimal for the purpose of these analyses. 'Optimal' head position was defined as the head observed in the reference position and within the protective structure of the CRS for the duration of the epoch. 'Suboptimal' head position was defined as the head observed away from the reference position and outside the protective structure of the CRS at any time during the epoch. Suboptimal positions where coded as forward left/right/centre (defined as head observed up to approximately 100mm away from the optimal reference position), far-forward left/right/centre (defined as being observed as approximately 100mm to 300mm away from the optimal reference position) or slouching (head slouched down but not forward from reference position). Further details of head position catergorisation, including exemplars, are provided in previous research (Cross et al., In Press). For the purposes of these analyses, all subptimal positions were combined together.

A generalised estimating equation (GEE) for head position (optimal/suboptimal) was conducted to explore whether selected variables were associated with suboptimal head position. It was necessary to use a GEE to accommodate the repeated measures nature of the data where multiple observations were made for a child, within a trip and within a time period.

A total of 414 family trips were randomly selected from the larger data set - due to time and budget constraints (Cross et al., In Press). For each of these selected trips, video and audio recordings were coded for nine five second intervals or epochs (at 5%, 17%, 25%, 30%, 50%, 53%, 75%, 89% and 95% of the trip). A total of 3,726 epochs were coded for analyses with characteristics reported in previous research (Cross et al., In Press). For this study, 211 epochs containing unknown child occupant head position were removed from the analyses. The characteristics of 3,515 epochs are presented using descriptive statistics. Prior to conducting the GEE, epochs that had missing data for the variables of interest (n= 1,357) were also removed, leaving 2,158 epochs for GEE analysis. A breakdown of the characteristics of child occupants travelling in FFCRS is presented separately to those travelling in a BS to reveal any differences in each of the variables across restraint types.

2.4.1 Selection and definitions of variables

Table 1 lists the variables included in the model and summary data for each category of variable. The repeated measures component of the model was represented by the nested factors of epoch within each trip in the GEE. The variables which indicate the repeated measures in the data are not included as factors in the model. For the purpose of statistical model analyses, the variables of interest that were defined in more detail in eariler research (Cross et al., In Press) have been collapsed into categories as illustrated in Table 1.

Table 1. GEE variable categories (n=2,158)

Variable	Categories	Definition	n	%
Restraint type	FFCRS	Child occupant's own FFCRS	1,642	76
	BS	Child occupant's own BS	516	24
Shoulder restraint use	Correct	No CRS errors	1,561	72
	Incorrect	At least one CRS error (e.g., slack, twists, placement)	597	28
Child sex	Male		1,268	59
	Female		889	41
Child age category by restraint‡	FFCRS – Younger	< 39 months of age	849	52
	FFCRS – Older	≥ 39 months of age	793	48
	BS – Younger	< 71 months of age	280	54
	BS - Older	≥ 71 months of age	236	46
Birth order	First born	First born in family	937	43
	Other	Subsequent birth order in family	1,221	57
Activity±	Conversation	Direct verbal engagement with another occupant	1,109	51
	Lap-based activity	Reading or electronic device or playing with a toy	187	9
	Other	Included but not limited to, eating/drinking, looking around, sleeping	862	49
Interaction	Yes	Interaction with another occupant that was Verbal, Non-verbal or both	130	60
	No	Nil	856	40

‡ Younger and older categories were defined by the nearest 50/50 split of the child occupant's age in months.
± Activity classified as the primary task that the child occupant was involved in for the majority of the 5s.

All data was coded by one researcher. To test for reliability of the video coding, ten percent of epochs were randomly selected and coded by an independent researcher. Intra-class correlation coefficient (ICCs) estimates were calculated to measure inter-rater reliability for child occupants' head position, interactions, child affect and primary activity (0.765, 0.834, 0.813 and 0.824, respectively) (Cross et al., In Press). Correlations of the manual coding revealled strong inter-rater reliability (Gravetter & Wallnau, 2008). Preliminary analyses were also conducted to identify multicollinearity between the variables in the model. Inter-correlations among the variables presented in Table 2 were explored. Variables that were not correlated (< 0.8) were considered independent. No significant multicollinearity was identified in the dataset.

3.0 RESULTS

The characteristics of epochs for child occupants travelling in a FFCRS or a BS are presented in Table 2. The age of that child occupants was categorised for each CRS type and the corresponding age range recommended in Australia (National Transport Commission, 2009).

Table 2. Epoch characteristics

	Total			FFCRS			BS	
	n = 3,515			n = 2,637			n = 878	
	n	%		n	%		n	%
CHILD FACTORS								
Gender								
Female	1,417	40		1,002	38		415	47
Male	2,098	60		1,635	62		463	53
Age (years)			1 to 2	450	17	4 to 5	379	43
			2 to 3	587	22	5 to 6	144	16
			3 to 4	517	20	6 +	355	40
			4 +	108	41			
				3				
Birth Order								
First born	1,654	47		902	34		752	86
Other	1861	53		1,735	66		126	14
TRIP FACTORS								
Shoulder belt/harness use								
Correct	1,581	45		1,217	46		364	41
Incorrect	598	17		443	17		155	18
Missing data	1,336	38		977	37		359	41
Primary activity								
Conversation	1,723	49		1,259	48		464	53
Lap-based activity	416	12		320	12		96	11
Activity (other than conversation & lap-based)	1,333	38		1,022	39		311	36
Missing data	43	1		36	1		7	<1
Front seat passenger								
Adult Female	776	22		599	23		177	20
Adult Male	235	7		190	7		45	5
Child	39	1		29	1		10	1
None	2,465	70		1,819	69		646	74
Total rear passengers								
1	1,327	38		1003	38		324	37
2	1,908	54		1399	53		509	58
3	280	8		235	9		45	5
Interaction								
Yes	2,065	59		1,538	58		527	60
No	1,420	40		1,079	41		341	39
Missing data	30	1		20	1		10	1
Head position ǂ								
Optimal	2,586	74		2,045	78		541	62
Suboptimal	852	24		565	21		287	32
Extreme Suboptimal	77	2		27	1		50	6

± The enrolled participant's partner/spouse was also able to drive the study vehicle, however the age and education level of alternate drivers was not recorded.

ǂ Head position is the outcome variable of this study. Unknown head position epochs (n = 211) were excluded prior to analysis.

Analyses of the 414 trips revealed that the majority of drivers were female (64%), aged between 30 and 41 years (70%) and held a university degree (83%). The majority of trips observed were made by families with two children in the family (69%) and by parents with between 4 and 7 years of parenting experience (62%) with one quarter having more than 7 years parenting experience. The majority of trips (69%) were less than 15 minutes in duration, with the most commonly occurring trip duration being between 5 to 10 minutes (32%).

Overall, child occupant head position was determined to be optimal in the majority of epochs (74%). On comparing epoch characteristics across restraint type, a greater proportion of child occupants travelling in a FFCRS were observed as having an optimal head position (78%) than those travelling in a BS (62%). Overall, correct restraint use was observed in nearly half of the epochs (45%). Overall, restraint use was correct in less than half of the epochs (45%). Correct restraint use was observed in 46 percent of epochs for child occupants of FFCRS and in 41 percent for those in BS. Interaction (verbal/non verbal/both) and conversation were commonly observed across epochs (59% and 49%, respectively). Overall, 59% of epochs observed child occupant interactions. Interactions were observed in 58 percent of epochs for child occupants of FFCRS and in 60 percent for those in BS.

Table 3 presents the factors of interest in the GEE that were associated with child occupant suboptimal head position.

Table 3. Summary results of GEE analysis of factors associated with suboptimal (1) head position of child occupant (n=2,158)

Predictor variables	Coefficient (β)	S. E of estimates (β)	*P* Values	Relative odds	95th%CI on relative odds
Restraint Type					
FFCRS (0)	....	....	....	....	....
BS (1)	2.112	.138	.000*	8.264	5.008-15.91
Child Gender					
Male (0)	....	....	....	....	....
Female (1)	1.072	.108	.520	2.921	2.382-3.758
Child Age (younger/older for each CRS type)					
Younger (0)	....	....	....	....	....
Older (1)	1.351	.103	.004*	3.861	3.016-5.228
Birth Order					
First born (0)	....	....	....	....	....
Other (1)	1.021	.123	.868	2.776	2.230-3.661
Restraint use (Shoulder belt/harness)					
Correct (0)	....	....	....	....	....
Incorrect (1)	1.492	.117	.001*	4.445	3.273-6.534
Activity					
Conversation (0)	....	....	....	....	....
Lap based (1)	2.395	.213	.000*	10.970	1.576-3.639
Other (2)	.708	.189	.067		1.629-2.787
Interaction					
No (0)	....	....	....	....	....
Yes (1)	1.424	.186	.057	4.154	2.688-7.775

*significant at $p<0.05$
Total of Cases excluded with unknown variable/s = 1357
Unknown shoulder restraint use excluded, n=1,336
Unknown activity excluded, n=43
Unknown interaction excluded, n=30

The GEE revealed that child occupants travelling in a BS were twice as likely to be observed to have a suboptimal head position than child occupants travelling in a FFCRS. Child occupants were nearly one and a half times more likely to be observed to have a suboptimal head position if they were in the older age range for the restraint type that they were using (FFCRS or BS) or if they had incorrect shoulder belt/harness use compared to child occupants from the younger age range for their restraint type and child occupants that were observed with correct shoulder/belt harness use. The GEE also revealed an association between child occupant interaction and suboptimal head position (p = 0.057) with the presence of an interaction increasing suboptimal head position by nearly one and half times. However this finding did not reach statisticial significance. Child occupants who were observed to be engaged in a lap-based activity, were nearly two and half times more likely to be observed to have a suboptimal head position compared to child occupants engaged in conversation. No significant relationships were found between child occupant gender, birth order and head position.

4.0 DISCUSSION

This study explored the travel characteristics (e.g., familial-, child-, trip-related) associated with child occupant's suboptimal head position when travelling in a FFCRS or a BS during real-world, everyday driving trips. Importantly, this study has identified a number of key findings that can guide improvements to child occupant safety.

The type of restraint, how it was being used, and the observed behaviours of child occupants when travelling in their CRS were identified as significant contributors to suboptimal head position. These findings are consistent with previous research which has shown that child occupants travelling in CRS adopt suboptimal positions (Andersson et al., 2010; Arbogast et al., 2016; Charlton et al., 2010; Forman et al., 2011; van Rooij et al., 2005). For example, child occupants travelling in a BS were more than twice as likely to be observed with a suboptimal head position compared to those travelling in a FFCRS. This finding supports previous research that has reported that child occupants travelling in a FFCRS tend to move around less within their restraint than child occupants travelling in a BS (Arbogast et al., 2016; Osvalder et al., 2013). A plausible explanation for this is that the BS uses the vehicle seatbelt which provides a 3-point restraint system to secure the child occupant (Osvalder et al., 2013; Transport Accident Commission, 2018) compared to the 5-point restraint system offered by the integrated harness system of the FFCRS. The FFCRS is designed to be adjusted to fit firmly around the occupant for the duration of the trip (Standards Australia/Standards New Zealand, 2010). Another explanation is that the vehicle seatbelt is designed with a retractor mechanism that allows slack for child occupants to move around during a motor vehicle trip and pretensioners that retract the seatbelt and remove any excess slack almost instantly upon sensing a crash (National Highway Traffic Safety Administration, 2013). Unless the pretensioner is retracted in the event of a crash, loosening and movement of the seatbelt is possible in a BS and potentially allows for greater movement of child occupants into suboptimal head positions than child occupants travelling in a FFCRS. Based on the elevated risk of sub-optimal head position associated with BS, it is recommended that a specific focus be made on future BS design and parent/child education initiatives

Another key finding was that child occupants that were classified as 'older' for their restraint type were nearly 40 percent more likely to be observed to have a suboptimal head position compared to child occupants in the younger age range for their recommended restraint type. It is possible that the 'older' child occupants are also larger in size and may be less comfortable and more prone to move within the restraint. This finding supports previous research by Fong and colleagues (2017) that linked discomfort with child movement when travelling. Increased likelihood of movement was also observed in research conducted by Osvalder and colleagues (2013) that recommended CRS structures should be designed with consideration to the comfort that they provide to a child occupant. This research suggests that improvements in child occupant comfort when travelling in a CRS will reduce the likelihood of children moving around and potentially adopting suboptimal head positionsImproved protection for older child occupants might be achieved by a focus on more user-centred CRS design.

Another key finding from this research was that child occupants were approximately one and half times more likely to be observed with a suboptimal head position if their belt/harness shoulder placement was classified as incorrect. Previous research has demonstrated an increased injury risk with such errors including incorrect placement of the shoulder belt/harness on the child occupant's shoulder or arm (Bilston et al., 2007; Bohman et al., 2011; van Rooij et al., 2005). Incorrect use observed in this study included placement of the shoulder belt to the outer shoulder, off the shoulder and loose fit, all of which will allow for greater movement of the upper torso and head of the child occupant. The association between suboptimal head position and incorrect belt/harness shoulder placement could be explained by the misuse allowing the child to move around more if not restrained correctly within the CRS. (e.g. where arms were moved out of shoulder belt/harness allowing the child occupant to move their head forward and away from the protection of the CRS).

In addition to incorrect CRS use, other behaviours frequently engaged in by the child occupant during motor vehicle travel were found to be significant predictors of suboptimal head position. A range of activities were observed including having a conversation, reading, playing with a toy, and using an electronic device such as an iPad, iPod, mobile phone or laptop. Child occupants who were engaging in a lap-based activity were nearly two and half times more likely to be observed in a suboptimal head position than child occupants having a conversation with another occupant. A possible explanation for this finding may be that conversations do not require the child occupant to move their head forward, whilst head positioning for best view of a lap-based activity may intuitively require a forward lean. This finding supports Osvalder's finding (2013) that child occupants were observed to adopt suboptimal positions when leaning forward when using an electronic device use or filling in a paper questionnaire on their lap.

The contribution of gender and birth order as a predictor for likelihood to adopt a suboptimal head position was also explored. No significant associations were observed. The lack of association for gender was unexpected given that previous literature has linked gender with transport injuries (Brown et al., 2005). Brown and colleagues (2005) reported the gender of child occupants from 2-8 years of age that presented to an emergency department of the Children's Hospital, Westmead, New South Wales, Australia. Males consistently represented 60 percent of patients and females represented 40 percent (Brown et al., 2005). Child occupant birth order was of interest in understanding if child occupant head position is influenced by a parents' history of CRS use and prior skills and knowledge relating to CRS safety knowledge for each child. It was expected that birth order from first child onwards may be associated with a decreased likelihood of the child occupant being oberved with a suboptimal head position due to parent's accumulating experience from one child to the next.

Limitations of this study are acknowledged. The voluntary recruitment of participants may have resulted in a sample that is likely to be more travel safety conscious than the general population which may bias findings towards best CRS practice. The sampling procedure resulted in fewer observations of child occupants travelling in a BS (25%) than in a FFCRS (75%). The study vehicle handover process did not require the child occupant to be available. Child occupant interviews/surveys were not viable to collect information on their perceptions of travel safety and comfort. Child occupant perceptions and suggestions should be researched further.

5.0 CONCLUSION

This study explored child occupants' familial factors, activities and interactions occurring at the time of suboptimal head positions. This research has identified several key factors that are significantly associated with child occupants' suboptimal head position. Based on these findings, child occupants travelling in a BS, child occupants observed with incorrect use of the shoulder belt/harness and child occupants engaged in lap-based activities were more likely to be observed to have suboptimal head position and hence, are potentially vulnerable to the associated increased injury risk in the event of a motor vehicle crash. To address these factors, targeted education and design strategies should aim to reduce suboptimal head positions of child occupants that: travel in a BS, that are older for their restraint type and that are engaged in lap-based activities. A focus can be made on BS design by improving comfort and limiting movement into suboptimal head positions. The finding of incorrect shoulder harness/belt and suboptimal head position highlights the importance of further parent and child education relating to correct CRS use.

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8. Discussion

The final chapter presents an overview of the aims of the PhD research program. This is followed by a discussion of the main findings, contributions, implications and limitations of the PhD research program. Last, a summary consolidates the research findings before the researcher provides conclusions and future child occupant safety recommendations.

8.1. Overview of aims and research questions of the PhD research program

This PhD research program explored the role of in-vehicle behaviour in child occupant protection in three complementary stages. The primary aims and research questions were to:

- Understand Australian parents' beliefs, knowledge, and attitudes relating to CRS (FFCRS and BS) use and child occupant safety (Stage 1). Research question: *What are the parental beliefs relating to CRS use, travel safety and other factors that may influence child occupant safety? (Stage 1)?*
- Describe and quantify the head positions, behaviours and activities of child occupants when travelling in a FFCRS or BS during real-world, everyday driving trips (Stage 2). Research question: *What are the common characteristics (e.g., familial-, child- and trip-related factors) of child occupant travel during real-world, everyday driving trips?* (Stage 2)? And, lastly;
- Identify the characteristics and behaviours that can help predict child occupant head positioning when travelling in a CRS during real-world, everyday driving trips (Stage 3). Research question: *What behavioural factors and characteristics are associated with child occupant's head position when travelling in a FFCRS or BS during real-world, everyday driving trips?* (Stage 3)?

Two methodologies (i.e., an online survey and a NDS) were used to explore these PhD research program aims:

1. Online survey: Collected information on parental characteristics, beliefs and perceived influences relating to CRS use from a national sample. The survey collected information from 380 Australian parents relating to 719 child occupants, and contributed to the recruitment of participants the NDS;

   NDS: The NDS comprised 42 families with a least one child occupant travelling in a FFCRS or BS. The NDS collected information relating to in-vehicle behaviours for child occupants during real-world, everyday driving trips. It also identified significant relationships between child occupant head position and the factors of interest (e.g., familial-, child-, and trip-related).

The specific aims and main findings of each of the three stages are discussed. Significant innovations and contributions, as well as limitations, of the PhD research program are considered and future directions for research are identified.

8.2. What do parents say, think and believe about CRS use and child occupant safety?

What parents say, think and believe about CRS use and child occupant safety was explored in Stage 1; Publication 1. The information collected in the DDRCROS revealed a number of interesting and important findings regarding CRS-related knowledge and beliefs relating to child occupant safety. Whilst most Australian parents had some understanding of child occupant safety, there were still significant gaps in parents' knowledge about laws (National Transport Commission, 1999) and best practice guidelines (Neuroscience Research Australia and Kidsafe Australia, 2013) on CRS use and some misconceptions relating to child occupant safety when parents answered questions relating to CRS use and child occupant safety as either True or False responses.

Most parents were correctly informed that: i) their child occupants are safest when travelling in the rear seats in the vehicle (97%); ii) the most appropriate type of CRS for child occupants aged between four and seven years is a BS (95%); iii) correct CRS use for each individual trip requires the adjustment of FFCRS harnesses for maximum safety (91%), and iv) the use of BS sash guides is to encourage correct placement of sash seatbelt (89%).

Another finding was that three quarters of parents (75%) were able to correctly identify that transition recommendations from a FFCRS to a BS were guided by CRS shoulder height markers. This suggests that campaigns that were launched following the legislation changes in 2009 have been reasonably effective in providing messages to parents about the recent introduction of Australian Standards (ASNZS 1754:2010, Australian Standards, 2019) for shoulder markers to guide decisions on transition from FFCRS to BS. Examples of campaigns delivering this information include; the information provided to the public by RACV such as the 'Using restraints, getting it right every trip' campaign and the 'Using restraints video series and information' (Royal Automobile Club of Victoria, 2014), the Kidsafe 'Child Restraint' webpage content and information sessions including information on CRS best practice guidelines (Kidsafe, 2019; Kidsafe Australia, 2014) and the online accessible guidelines on best CRS practice (Neuroscience Research Australia and Kidsafe Australia, 2013). Yet a quarter of parents were not aware of the shoulder height markers to guide FFFCRS to BS so further research is recommended to identify if there are particular target groups to guide additional efforts and messages to reach these parents.

Most parents were also familiar with the recommended minimum height to transition from a BS to an adult seatbelt. For example, most parents recognised that a 145cm standing height is the recommended height to safely transition their child occupant from a BS to an adult seatbelt (85%). However, more than half of the parents (59%) incorrectly stated that this minimum recommended height would be reached by most child occupants by the age of seven years. Indeed, previous research has shown that most Australian children do not reach a 145cm standing height until approximately 11 years of age (Anderson, Hutchinson, & Edwards, 2007). Anderson and colleague's research suggests that children's 'height for age' is not a reliable guide for transition to an adult seatbelt. Rather, an emphasis should be placed on referring parents to the visual shoulder markers on the BS, as outlined in the recent safety standards (Standards Australia/Standards New Zealand, 2010) and the guide 'Keeping Children as Safe as Possible While Travelling in Motor Vehicles' (Neuroscience Research Australia and Kidsafe Australia, 2013) as a guide for the best transition time.

The exploration of the relationship between CRS-related knowledge and parental and familial characteristics also revealed that parents with at least one child aged less than four years were significantly more likely to be in the high CRS-related knowledge score group than parents who did not have a child who was aged less than four years. One potential reason for parents with younger children having higher CRS-related knowledge scores than parents with older children could be that they have been more recently exposed to child occupant safety information from maternal health care providers such as doctors, hospitals and maternal health care nurses. Parents with young children in Australia are provided with a free government operated Maternal and Child Health (MCH) service (Victorian State Government, 2019). The service aims to help families care for babies and young children. It consists of regular visits to/from healthcare professionals to monitor health and provide parents with advice and support (Victorian State Government, 2019). Future efforts should be explored to develop similar public health initiatives to improve knowledge of parents of older children who are transitioning to different restraint types.

Successfully addressing CRS-related knowledge gaps identified in this PhD research program requires an understanding of the potential receptiveness of parents on future travel safety campaigns. The theoretical constructs of the HBM (Rosenstock et al., 1988) and LOC (McDonald et al., 2004; Montag & Comrey, 1987; Rotter, 1954; Wallston et al., 1978) were explored to gain an insight into parents' perceptions relating to child occupant safety.

In applying the HBM construct of 'susceptibility to risk', parents were asked to rate their level of concern for being involved in a motor vehicle crash. Parents reported that they were 'not at all' (6%), 'somewhat' (53%), 'quite' (29%) or 'extremely' (12%) concerned about being involved in a motor vehicle crash. These findings indicate that around 94 percent of parents were at least 'somewhat' concerned about their susceptibility to risk. This is an important finding - with implications for these parents and their openness to safety messaging. Specifically, research that applies the constructs of the HBM has demonstrated that individuals with a higher perceived susceptibility to risk (in this instance, a level of concern about being involved in a motor vehicle crash) have improved receptiveness to behaviour change (Rosenstock, 1974; Rosenstock et al., 1988). Improving parents' awareness of the injury risk relating to the potential of being involved in a motor vehicle crash, and the elevated injury risk if CRS is not used or misused, will help motivate behaviours conducive to recommended (i.e., correct and appropriate) CRS use practices.

The LOC (i.e., the attribution of responsibility to self or others) can also explain the likelihood of individuals being receptive to behaviour change. Hoyt's seminal research demonstrated this effect in a road safety context, confirming an association between high internal LOC and seatbelt use in motor vehicles (Hoyt, 1973). This PhD research program was the first to explore parents' attribution of responsibility to internal and external factors of child occupant safety in Australia, as well as exploring parents' LOC scale scores with respect to parents' perceived influence over more general outcomes.

As reported in Publication 1, the attribution of responsibility was examined across four internal child occupant safety factors and four external child occupant safety factors. When asked to report on factors of influence for child occupant safety, the majority of parents attributed the responsibility of child occupant safety to internal factors, or elements over which they had personal control. The predominant perception of internal control evidenced in the current study supports previous findings (Hoyt, 1973). Importantly, this finding highlights that the majority of parents are likely to be receptive to further safety education and behaviour change initiatives to address the knowledge gaps identified in this research and ultimately improve child occupant safety (Hoyt, 1973; Rotter, 1954).

In addition to the analyses that were conducted for Publication 1, analyses were also conducted to explore differences in mean scores between parents' CRS-related knowledge score groups (low and high) and parents' i) attribution of responsibility to each of the eight attributions of responsibility regarding child occupant safety factors (4 internal/4 external scores), and; ii) total scores on each of the broader LOC scales that are not specific to child occupant safety (McDonald et al., 2004; Montag & Comrey, 1987; Wallston et al., 1978). T-test analyses revealed no significant relationship between the CRS-related knowledge score groups (high/low) and: i) parents' attribution of responsibility to child occupant safety factors, or; ii) parents' total scores on the LOC scales (see Appendix J). It was expected that parents in the high CRS-related knowledge group would be more likely to attribute responsibility to internal factors, or to general scenarios, compared to parents in the low CRS-related knowledge group – however there were no significant differences (see Appendix J).

The LOC theory suggests that parents are more receptive to the uptake of messages if they attribute the responsibility to themselves rather than others (Hoyt, 1973). Internal attribution was reported by most parents who participated in this PhD research program (Publication 1). According to LOC theory, parents should therefore be receptive to travel/child occupant safety initiatives. However, receptiveness to child occupant safety initiatives was not translated into CRS-related knowledge scores. The evidence of gaps in CRS-related knowledge that have been identified in this PhD research program suggest that yet unidentified factor/s other than internal attribution play a role in explaining what parents know about correct CRS use. Perhaps the ways that child occupant safety messages are currently communicated to parents such as child occupant safety and CRS related information that are currently publically and easily accessible online from many reputable sources are somewhat confusing and not as effective in reaching all parents as they could potentially be, additional initiatives to support the communication of these valuable messages are recommended.

While attribution of responsibility using both general and driving-specific LOC scales did not account for differences in parents' CRS-related knowledge scores, several other parent and familial characteristics identified in this PhD research program were shown to account for some variance. The analyses that were conducted and reported in Publication 1 suggest that demographics such as parental age, sex and the age of child occupants in a family are significantly related to parents' CRS-related knowledge scores. For example, parents aged less than 39 years, who were women, and who had children aged less than four years were more likely to have higher CRS-related knowledge than parents who were aged more than 39 years, who were men, and who did not have a child aged less than four years. This information can have a powerful influence in targeted safety messaging as it points to specific parent groups who might benefit most from future child occupant safety campaigns.

8.3. Contributions and limitations of the survey

The contributions of Stage 1 of this PhD research program that relate to what parents say, think and believe about CRS use and child occupants' safety are two-fold. Firstly, the survey findings contribute to the body of child occupant research by identifying specific gaps in parents' knowledge about CRS use. Secondly, it provides evidence regarding parental beliefs that are conducive to the success of child travel safety initiatives, supporting investments in future campaigns (Cross et al., 2017).

Critical success factors for dissemination of the survey were the collaboration and marketing of the DDCROS by project partners, particularly the Australian automobile clubs and General Motors Holden through their frequented websites and company media, including electronic newsletters. Social media was unexpectedly the most common recruitment pathway (34%; see Figure 6). This social media interaction from parents suggests that social media could be considered as a low cost recruitment method for future research involving parents, perhaps due to convenience of access in an often busy family schedule. It also suggests that social media may be useful mode for delivery of key safety messages.

Limitations of the DDCROS included unanswered responses resulting in missing data on variables and exclusion of participant data if unanswered responses were critical to the analyses. Another limitation was the requirement for a basic level of understanding of English language and the exclusive use of an online delivery mode and computer access, knowledge and skills. This limitation may have restricted participation of some nationalities, cultures and diversity of beliefs.

In reviewing the format of the survey, one particular area of interest which might warrant re-framing and further research is the focus on parents' perceived control over their children's safety. The LOC questions on attribution of responsibility (internal and external factors) were presented to participants in a 0-100% slider scale format. In this research, parents assessed all child occupant safety factors independently for their attribution to child occupant safety rather than collectively. These questions may have been better posed if all factors were presented to the parents together in one question rather than individually. To accommodate this shortfall in design, the approach used here, was to classify 'strong attribution' if parents responded to *any* of the questions with 80 percent or more attribution of responsibility.

Another limitation of the survey methodology was that the demographic background of participants may not accurately reflect the general driving population in the Australian state of Victoria on several measures. Parents with university level education were over-represented in the sample compared to general population statistics. Around two-thirds of parents in the survey had a university level education compared to only 27 percent in the general population between 35-54 years of age with a university level education (Australian Bureau of Statistics, 2019). On other demographic measures, the survey sample were representative of population data. For example, the study successfully recruited 69 percent metropolitan participants and 31 percent rural participants which is consistent with recent Victorian data (Australian Government, 2019).

While a systematic endeavour was made to recruit parents who were representative of the broader community, inevitably in a survey of this kind, it is possible that our volunteers were likely to be a more travel safety conscious sample. Hence, the level of CRS knowledge identified in this sample of parents may be greater than that of the general population. Furthermore, previous research indicates that parents may have had a tendency to bias their reports towards more positive child occupant safety behaviours (Bilston et al., 2008; Roynard et al., 2014).

The approach attempted to reduce social response bias by providing participant anonymity. Nevertheless, participants may still have been more likely to answer questions in the manner that would be viewed favourably by others (Ledesma, Tosi, Poó, Montes, & López, 2015; Wåhlberg, Dorn, & Kline, 2010; Williams, 2003). On balance, the limitations associated with the recruitment approach for the survey were regarded as acceptable when weighed against the time and cost effectiveness of the online survey.

8.4. How child occupants actually behave in their CRS?

Stages 2 and 3 (Publications 2 and 3) of PhD research program employed a NDS methodology to observe what parents and child occupants do during their real-world, everyday motor vehicle travel. The survey information (Stage 1) provided an important understanding of parents' underlying travel safety beliefs and gathered demographic information on participants. However, self-reported knowledge and attitudes on travel safety may deliver different findings than what may be observed during every day travel, such as correct CRS use. As noted above, previous research indicates that parents have a tendency to bias their reports on child occupant safety behaviours by responding with more socially desirable answers, such as reporting that they "always" restrain their child occupant correctly when travelling (Koppel, Muir, et al., 2013) while field observations static and roadside inspections suggest otherwise (Brown, Hatfield, et al., 2010a; Koppel & Charlton, 2009). This bias towards safety may also be due to parents' over-confidence in CRS use - thinking their knowledge of CRS use is correct when it is not (Bilston et al., 2008; Roynard et al., 2014). The data collected from the NDS (Stages 2 and 3) provides data from observations of common characteristics and behaviours of child occupants during real-world travel in motor vehicle travel.

Stages 2 and 3 of this PhD research program focus specifically on child occupant head position. The motivation for this emphasis on understanding factors influencing head position was based on the strong evidence for head injury as the most common type of serious injury sustained by child occupants from motor vehicle crashes (Arbogast et al., 2012; Brown et al., 2006; Stewart et al., 2013). Child occupant head position and behaviour was analysed from 414 family trips using continuous travel video and audio data. The data analysed from the NDS extends the findings of previous studies (Andersson et al., 2010; Charlton et al., 2010; Forman et al., 2011; Osvalder et al., 2013; van Rooij et al., 2005), by reporting not only on *frequency* of child occupant suboptimal head position, in particular (rather than body position in general), but also provides an in-depth analysis of characteristics associated with suboptimal head position.

A key finding from Stage 2 (NDS study) was that child occupants' heads were observed to be optimally positioned within their FFCRS or BS for almost three quarters (74%) of the epochs observed. That is, child occupants were commonly restrained with their head within the protective zone of the CRS (see Chapter 5, Figure 14). This suggests that child occupants' head positions were often similar to the ideal, upright position that ATDs are placed in during the safety testing of a CRS, and therefore positioned in a way that affords the best safety protection from the CRS structure in the event of a motor vehicle crash. Notwithstanding the relatively high frequency of optimal head position, of concern was the finding that suboptimal head position of child occupants was observed in 26 percent of epochs. Observations were recorded at nine time points throughout each trip (epochs selected from 5% to 95% of trip duration). Importantly, the research suggests that CRS misuse would likely result in elevated injury risk in the event of a motor vehicle crash (Bilston et al., 2007). Research conducted in the broader ARC Linkage Project confirmed this and found compromised outcomes for the suboptimal head positions that were tested in simulated crashes (Bohman et al., 2018).

The review of crash injury data presented in Chapter 2, revealed that head injuries are not only the leading type of serious injury sustained by child occupants in motor vehicle crashes (Arbogast et al., 2012; Brown et al., 2005; Durbin et al., 2003; Howard et al., 2004), but have serious implications to the injured individual, their families, community and the economy with long term health and economic implications (Bureau of Infrastructure Transport and Regional Economics, 2006; Mitchell et al., 2017; World Health Organization, 2008). The prominence of paediatric head injuries and the profound implications of such injury make real-world, everyday travel behaviours of child occupants the focus of this PhD research program.

Previous studies report higher prevalence of child occupant suboptimal position than observed in this NDS as they have included multiple body parts, such as head/torso, limbs (Charlton et al., 2010; Osvalder et al., 2013; van Rooij et al., 2005). The study of child occupants travelling in a BS on a test route by Andersson and colleagues (2010) also focused on the prevalence rates of child occupant suboptimal head position (25%), with comparable findings to those presented in this PhD research program (24%). Andersson and her research team defined suboptimal position as when the child occupant was positioned without head or shoulder contact with the seat/CRS back. Together, the similar suboptimal prevalence rates identified in both studies suggest that suboptimal head positions also occur on the much shorter trips analysed in this PhD research program (15 minutes average in duration; range: 1 minute, 14 seconds to 1 hour, 26 minutes and 46 seconds) as well as longer trips (40 to 50 minutes in duration) studied by Andersson and colleagues (2010), during which boredom and tiredness might occur**.**

While child occupant suboptimal head position has been reported in previous research for BS occupants (Andersson et al., 2010; Forman et al., 2011; Osvalder et al., 2013), a point of difference with the PhD research program, was the inclusion of child occupants travelling in FFCRS (75%) and BS (25%). This allowed for the important comparison of suboptimal positions across restraint types. Importantly, the current research identified that suboptimal head position is not isolated to BS child occupants but also occur in FFCRS. Moreover, a key finding was that child occupants travelling in a FFCRS were significantly more likely to be observed as having optimal head positions than those travelling in a BS. A plausible explanation for the observed differences is that the BS uses the vehicle seat belt rather than integral harness – which allows for a greater range of child occupant movement.

Stage 2 research also provided an in-depth analysis of other child occupant characteristics and behaviours when travelling in a BS or FFCRS. Factors observed included: restraint use, interactions, activities, behaviour and affect. During driving trips, child occupants were observed to be 'correctly' restrained in their CRS in just over half (58%) of the epochs. The majority of CRS misuse observed related to shoulder belt/harness misuse (88%), with placement of the shoulder belt/harness most commonly observed as being off the shoulder or on the outer-shoulder (50% combined). Previous Australian research using static inspections of CRS use also reported belt misuse findings similar to those observed in this NDS (Koppel, Charlton, et al., 2013). In a separate study, Bohman and colleagues (2018) confirmed that shoulder belt placement categorised as 'off the shoulder' or 'on the outer-shoulder' was associated with potential head injury and was likely to be explained by belt slip off during impact or rebound (Bohman et al., 2018).

Existing safety campaigns were already highlighting the need to check and adjust CRS belts and harnesses for each trip during the time this research was conducted, for example the 'Using restraints, getting it right every trip' campaign (Royal Automobile Club of Victoria, 2019). The PhD research program findings suggest extending educational campaigns and addressing the target groups that had lower CRS-related knowledge that were identified in Stage 1 of this research (males, parents older than 39 years of age and parents with children older than 4 years of age) to encourage parents to routinely check and adjust belts and harnesses for each trip.

Stage 2 also provided detailed observations of child occupant activities. The primary activity was coded for each five second epoch observed. Where two or more activities were present, the primary activity was categorised as the activity with the most cognitive load. The activities explored in this PhD research program were: conversation, looking, playing with toys, sleeping/drowsy, eating/drinking, touching/looking at self, touching, watching DVD, others, and unknown (see Section 5.3.2). Overall, the descriptive analyses revealed that conversation (49%) and looking around (25%) were the most common activities. The data also afforded the opportunity to explore associations between these and other behaviours, and head position. Optimal child occupant head position was significantly more likely to be observed when a child was engaged in conversation than when the child occupant was playing with a toy(s) (72% vs. 52%). A potential explanation for the higher levels of suboptimal position when children are playing with a toy, is that they are naturally drawn to position themselves closer so they can observe the interaction more closely (Bremner & Wachs, 2010). These findings were consistent with Osvalder's findings (Osvalder et al., 2013) where a tendency to lean forward when using electronic devices was observed.

An important implication of the observations from the PhD research is that suboptimal head position has been shown to be associated with an elevated injury risk in the event of a motor vehicle crash, as evidenced through mathematical modelling based on child occupant positions (van Rooij et al., 2005), real world crash data (Arbogast et al., 2012), and ATD kinematics in sled testing including recent simulated crash test research based on data from the PhD research program (Bohman et al., 2018; Stockman et al., 2013a, 2013b). For example, as part of the broader research, Bohman and colleagues (2018) used the child occupant head position information collected in the NDS to evaluate the injury risk from suboptimal head positions. The study used frontal and oblique crash configurations, with Hybrid III (HIII) 6-year-old child anthropometric test device (ATD) restrained in BS and positioned in the observed child passenger postures from the NDS. Results showed that in suboptimal positions, the total (forward) head excursion of the ATD increased up to 210 mm compared to the reference/optimal position, increasing the potential for head strike to the (front) seat back (Bohman et al., 2018). Research by Arbogast and colleagues (2016) from the broader ARC Linkage Project, which plotted 3-D spatial (head) position, also confirmed that variability in head position was greater for child occupants who were restrained in BS and adult seatbelts than for those in FFCRS. This PhD research program added to the broader research by showing that child occupant suboptimal head position is not only more variable (i.e. greater divergence from reference point, in fore-aft and lateral planes) for BS occupants (Arbogast et al., 2016; Bohman et al., 2018) but that suboptimal head positions also occur at a higher frequency for BS occupants than child occupants travelling in a FFCRS. Together these findings draw attention to the need to understand ways that BS travel can be made safer.

Findings from Stage 2, highlighted a need for a more detailed analysis to understand potential reasons for the observed suboptimal head positions. Hence, the focus of final stage of the PhD research program, Stage 3, was to identify the travel characteristics (e.g., familial-, child-, trip-related) associated with suboptimal head positions for child occupants when travelling in a FFCRS or BS. These findings are discussed in the following section.

8.5. Travel characteristics associated with suboptimal head positions

This component of the PhD research program (Stage 3) provides a detailed analysis of the familial-, child-, and trip-related factors of interest gleaned from the NDS data observations, as well as parental demographic characteristics from the DDCROS. The previous Stage of this PhD research program (Stage 2) identified a number of important findings on child occupant behaviour and associated head positioning when travelling in a motor vehicle. Previous research has provided some insights about specific factors that contribute to differences in observed child occupant head positions. Previous research, however, investigated head position in relation to specific factors, such as side wings (Andersson et al., 2010; Forman et al., 2011) and vehicle manoeuvres (Bohman et al., 2011). For example, different CRS types have been shown to be associated with a propensity for child occupants to assume different head positions, depending on whether trips were taken in the day time or night time. Larger wings on CRS were associated with a tendency for child occupants to lean forward and sometimes outside of the protective area of the CRS during the day (perhaps to improve their view). However, the larger wings have also been shown to provide support within the protective zone of the CRS for children's heads during the night (Andersson et al., 2010; Arbogast et al., 2016; Forman et al., 2011; Osvalder et al., 2013).

Information from the two studies were combined to identify the predictors of suboptimal head position of child occupants (Stage 3), using a GEE. The GEE methodology (Liang & Zeger, 1986) enables the analyses of correlated data that otherwise could be modeled as a generalised linear model (GLM). In this research, a GEE allows for the analysis of various child occupant data (e.g., restraint type or activity) in the prediction of suboptimal child occupant head position. Importantly, the GEE adjusts for repeated measures within the data (within-subject child participant data and epoch data from the same trip).

More specifically, a GEE was conducted to identify the travel characteristics that predict suboptimal head positions of child occupants when travelling in a FFCRS or a BS during real-world, everyday driving trips. The analysis revealed several unique findings. In summary, the results showed that child occupants were more likely to be observed to have a suboptimal head position if they; were travelling in a BS, were in the older age range for the CRS type that they were using (FFCRS or BS), had incorrect shoulder belt/harness use or were engaged in a lap-based activity.

Child occupants travelling in a BS were twice as likely to be observed to have a suboptimal head position than child occupants travelling in a FFCRS. Child occupant movement when travelling in a BS allows for a change in the placement of the belt across the body and potential incorrect use. This finding supports other research approaches that have reported that child occupants travelling in a FFCRS tend to move around less within their restraint than child occupants travelling in a BS (Arbogast et al., 2016; Osvalder et al., 2013). Arbogast and colleagues used heat map analysis to reveal more for-aft spread of positions adopted by child occupants travelling in a BS than a FFCRS (Arbogast et al., 2016). The findings of this PhD research program add to this safety concern by providing evidence relating to frequency of child occupant suboptimal head positions for BS and FFCRS. Child occupants travelling in a BS are not only observed with more range of movement but are also more likely to be observed in a suboptimal head positions when compared to child occupants travelling in a FFCRS. A plausible explanation for these findings are that the BS uses the vehicle seatbelt which provides a 3-point restraint system to secure the child occupant (Osvalder et al., 2013; Transport Accident Commission, 2018) compared to the 5-point restraint system* offered by the integrated harness system of the FFCRS that was observed in this NDS[2]. The FFCRS is designed to be adjusted to fit firmly around the occupant for the duration of the trip (Standards Australia/Standards New Zealand, 2010). In comparison, the seatbelt that is used with a BS is designed with a retractor mechanism

[2] A G-type 6-point harness was recently approved by Australian Standards (2014) but was not used by any participating families.

(allowing slack for child occupants to move around during a motor vehicle trip) and pretensioners that retract the seatbelt and remove any excess slack almost instantly upon sensing a crash (National Highway Traffic Safety Administration, 2013). Unless the pretensioner is retracted in the event of a crash, loosening and movement of the seatbelt is possible in a BS and, as observed in the current study, potentially allows child occupants to more readily assume suboptimal head positions than those travelling in a FFCRS (Cross et al., Submitted).

Child occupants with incorrect shoulder belt/harness placement were also nearly one and a half times more likely to be observed to have a suboptimal head position compared to child occupants observed with correct shoulder belt/harness use. This finding is not surprising given that poor shoulder belt/harness placement would likely allow the child more freedom to move around more (e.g., arms moved out of shoulder belt/harness would allow the child occupant to move their torso and head forward and away from the protection of the CRS). This finding has serious implications for child occupant safety, with previous research demonstrating an increased injury risk with such errors (Bilston et al., 2007; Bohman et al., 2011; van Rooij et al., 2005). As noted above, our sled test study based on the same NDS data confirms that injury risk is increased with belt misuse (Bohman et al., 2018).

Another finding from the GEE analysis was that child occupants were nearly one and a half times more likely to be observed to have a suboptimal head position if they were in the older age range for the CRS type that they were using (i.e., FFCRS or BS). A possible reason is that the 'older' child occupants may also be larger in size, and hence may be less comfortable and more likely to move in order to find a more comfortable position. This interpretation is supported by previous research relating to restraint comfort that identifies discomfort as associated with movement (Fong et al., 2017; Osvalder et al., 2013). Future research using NDS methods might usefully explore the role of discomfort in both CRS and BS, particularly for long duration trips. A focus on FFCRS and BS design to maximise comfort and minimize the desire or need for a child occupant to move their head outside of the protective area of the CRS is recommended.

Previous research has unequivocally demonstrated that child occupants do not behave like ATDs (Andersson et al., 2010; Charlton et al., 2010; Forman et al., 2011; Stockman et al., 2013a, 2013b; van Rooij et al., 2005). In the present study, we extend these findings to explore children's interactions and in-vehicle activities which may contribute to understanding why child occupants adopt suboptimal head positions. The GEE revealed that child occupants who were engaged in a lap-based activity were nearly two and half times more likely to have a suboptimal head position compared to child occupants engaged in conversation. It is possible that there is a greater need for forward leaning during lap-based activities in order to observe, explore or read, while on the other hand, a conversation which requires cognitive engagement with another occupant, could be achieved without the need for physical movement. The finding that lap-based activities encouraged child occupants to lean forward and adopt suboptimal head positions supports earlier findings by Osvalder's and colleagues (2013). This highlights a need for further education and CRS/vehicle design to safely accommodate the popular use of electronics by child occupants during travel. In addition to this finding, child occupants engaged in an interaction were nearly one and a half times more likely to have a suboptimal head position than those not engaged inan interaction (29% and 23%, respectively). On face value, this finding appears to conflict with the findings for a positive influence of conversation. A possible explanation for the apparent paradox is that conversations may not require the child occupant to move their head forward (for example if the conversation is with a child occupant in an adjacent seat), whilst interactions, especially those that include verbal as well as non-verbal responses (such as touching or leaning to look) may require an adjustment of head positioning for best view, much like the positions observed for lap-based activities.

8.6. Limitations of the NDS

Although the NDS provided an opportunity to capture the everyday, real-world behaviours of child occupants when travelling in a CRS and allowed for the observation of multiple factors to help predict suboptimal head position, there are a number of limitations associated with this methodology. The nature of a 'naturalistic' study means that it is not always possible to ensure that all the data of interest were available for all trips. In fact, for 72 percent of epochs coded, there was at least one missing variable. The most common reason for missing data was body interference blocking the camera view (23%). This included arms across laps that obstructed the lap belt view, and head/torso leaning to the side that obstructed the shoulder belt view. Sunlight was the next most common singular reason for missing data (16%), and in many cases there were multiple reasons observed (18%). Darkness accounted for a small proportion of missing data (3%) although this is likely to be an underestimate due to the fact that night trips would likely result in lighting conditions where the child occupant head position would be unlikely to be viewed and hence the complete trip would be excluded from the analyses. By way of explanation, if data was not viewable for the main variables of interest (head position and restraint use) the next trip in the random order was selected. Future research using infrared cameras which can record in darkness would be beneficial to further explore child occupant behaviours during night trips**.**

Due to time and budget restraints, the complete set of data was not able to be analysed. From the total trips collected (n=1,651), one quarter (n=414) were randomly selected for in-depth analysis and the 414 trips collected were analysed at nine 5-s epochs. To address this potential limitation, several comparisons were made between the full and extracted data subsets. The findings confirmed that the randomly selected trips were representative of the full data collected (see Publication 2; Appendix 3, p 104).

Another limitation was that the focus of the NDS was on child occupants who usually travelled in either a FFCRS or a BS. The behaviours of child occupants travelling in a RFCRS were included in the present study only for the purpose of analysing in-vehicle interactions with the child occupants travelling in a FFCRS or BS. Head position of child occupants travelling in a RFCRS were not analysed due to: i) reduced mobility of children within their first year of life when travelling in a RFCRS, and ii) it was not possible to fully capture these children with the cameras installed in the study vehicles. The finding that interactions within the vehicle encourage suboptimal child occupant head positions when travelling in a CRS warrants further research into the influence that adjacent passengers in the rear seat may have on suboptimal head positions.

The NDS sample were volunteers and therefore potentially a travel safety conscious cohort compared to the general public. Whilst the observations revealed that participants generally displayed normal travel behaviours, such as driver passing food or drink and talking with child occupants during travel, it is possible that they may at times, have recalled that they were being observed or discussed the cameras with the child occupants prior to travel and adjusted their behaviour to be more socially acceptable. The suggestion that the findings may be drawn from more conservative travel characteristics from the families than their usual everyday (private) travel characteristics equates to a greater need for future initiatives to be developed to improve child occupant travel safety.

Both the survey and the NDS were comprised of parents with an education level that was higher than the general public. Most participants in the survey and the NDS had a university level education (67%, 83%, respectively). This is not representative of the education level for the general public with only 27 percent in the general population between 35-54 years of age with a university level education (Australian Bureau of Statistics, 2019). To explore this potential limitation, analyses were conducted to compare frequency of child occupant suboptimal head position for parents with/without university education. The analysis did not reveal any significant difference ($\chi 2$ (1) = 5.93, $p > 0.05$). Therefore the frequency of the suboptimal head position observed in this NDS can be considered to be a reasonable representation of what might be observed in the general population. Nevertheless, it is possible that the sample of volunteers were a highly travel safety conscious group which other may have led to an inflated level of observed characteristics for some measures. For example, CRS misuse, interactions in vehicles, and child occupant activities which can all elevate injury risk, may be more prevalent in the general population than were observed in the sample studied in this PhD research program.

8.7. Summary of contributions of the NDS

This innovative PhD research program addressed a significant gap of understanding relating to the dynamic environment of real-world, 'everyday' child occupant travel. It addressed two critical elements for injury prevention: i) the surveillance that identifies the problem, and ii) the risk factor identification that identifies the protective and risk factors. In particular, the research redressed the paucity of research relating to the role of behaviour in child occupant protection.

This PhD research program used video and audio recordings to explore the role of behaviour in child occupant safety. Other components of the NDS set-up such as the Mobileye® and Microsoft Kinect™ were used for data collection for the broader ARC Linkage Project (Arbogast et al., 2016; Bohman et al., 2018; Charlton et al., 2013; Loeb et al., 2017). Specifically, findings from the PhD research guided positioning of ATDs for sled test crash simulations exploring potential injury risk of commonly observed suboptimal/shifted positions (Bohman et al., 2018). The information collected in the survey and NDS stages were also analysed to explored driver distraction and driving performance (Kuo et al., 2016).

The NDS provided an innovative method to capture real-world, everyday behaviours that occur within a complex family motor vehicle environment. It utilised several integrated data acquisition systems to collect and record data on in-vehicle behaviours of families as they go about their everyday life and family trips. This research identified that for the majority of the sampled observation periods, child occupants' head position was optimal (74%) when travelling in a CRS, however, in the remaining quarter of epochs (26%), protection from the CRS would have been compromised due to suboptimal head positions. The research also confirmed that CRS shoulder belt/harness misuse was prevalent in the study sample. The CRS shoulder belt/harness misuse observed in around half (42%) of the epochs, also highlights the potential for decreased protection in the event of a crash. Stage 3 provided a combined analysis of the data collected in the previous stages of this PhD research program (Stages 1 and 2) to identify factors that predict suboptimal head positions of child occupants: Child occupants were more likely to be observed to have a suboptimal head position if they were: i) travelling in a BS, ii) observed with incorrect shoulder belt/harness placement, iii) in the older age range for the CRS type that they were using (FFCRS or BS) or engaged in a lap-based activity rather than engaged in conversation.

Overall, the NDS collected information on 690 factors of interest. Factors relating to the role of behaviour in child occupant behaviour and suboptimal head position were analysed in this PhD program through epoch data sample selection. The findings presented here provide an important platform to guide future in-depth analyses, including analyses of full trips that contain behaviours of interest (e.g., CRS misuse, electronic device use and interactions) observed in our epoch-based analyses.

Future research is also recommended to explore in more depth the relationship between child occupant behaviours and factors relating to the driver, front seat passengers and vehicle. One particular question of interest, is whether the factors that encourage suboptimal head position may also compromise driver performance, for example by influencing driver inattention/distraction.

The findings of this PhD research program have highlighted the need for a multidisciplinary approach for improving the safety of child occupants. Child occupant travel safety efforts need to encourage travel characteristics that promote optimal child occupant head position and discourage suboptimal head position when travelling in a CRS. Findings on CRS misuse and the increased likelihood of suboptimal head position of child occupants travelling in a BS suggest that improvements to BS design and instructions may also be an integral component of a complex solution to improve child occupant safety (Bilston et al., 2011; Fong et al., 2017; Gras et al., 2017; Hall et al., 2018; Osvalder et al., 2013; Stockman et al., 2013a, 2013b). Future designs for vehicle rear seat and CRS should also consider solutions to improve the comfort of child occupants and include provisions to safely accommodate the head positions commonly adopted during lap-based activities. Given the trend observed in this study for child occupants being entertained with electronic devices when travelling, CRS design may need to adopt a more user-centred design approach to safely accommodate these kinds of lap-based activities.

The gaps in parents' knowledge, as well as the misuse of CRS and suboptimal positions observed in the PhD research program also highlight a role for education. Policy makers play a pivotal role in improving child occupant safety by educating parents of the increased injury risk associated with CRS misuse. Findings from the present research point to the need for awareness raising for the checking of harness/belts for each individual trip and discouraging lap-based activites such as electronic devices until these can be safely accommodated by improved CRS design. To improve the uptake of educational initiatives, solutions should address the HBM construct of 'perceived risk' (Rosenstock et al., 1988) and communicate the increased injury risk associated with CRS misuse in the event of a motor vehicle crash clearly to parents.

8.8. Conclusions

This PhD research program has made a significant and innovative contribution to the existing body of child travel safety research, using both conventional survey methods to elucidate parents' knowledge and beliefs about their children's safety, as well as innovative NDS methods which afforded unprecedented observations of everyday behaviours to understand factors associated with child occupants' head position when travelling in a motor vehicle. A key finding was that parents believed that they were largely responsible for their children's travel safety. This attribution of responsibility for safety suggests that parents would be receptive to behaviour change strategies to address the identified gaps in CRS related knowledge. Findings from the NDS also revealed that child occupant head position was significantly more likely to be classified as 'optimal' if the child occupant was: restrained in a FFCRS, correctly restrained, behaving passively (i.e., sitting still), engaged in a conversation, or not interacting with other occupants. This information has focused attention on two important safety solutions. First, the findings highlight the potential need for improved designs of CRS and vehicles to more effectively and safely accommodate the common behaviours observed during real-world motor vehicle travel. Second, the findings can also inform child occupant travel safety initiatives, for example, educational campaigns to improve parents' CRS skills and emphasise the importance of correct CRS misuse.

8.9. Recommendations

Based on the findings of the DDCOS and NDS, this PhD research program recommends targeted educational safety campaigns and improvements to CRS and vehicle design to improve child occupant safety. Recommendations include:

- Information relating to the various types of CRS misuse that were associated with suboptimal head position and increased injury risk, including: correct harness/belt use guidelines, the necessity to adjust harness/belt for each trip and the child occupant's position within the CRS;
- Information relating to the CRS visual shoulder marker guides, rather than age alone, for the safest time to transition individual child occupants to the next restraint type;
- Information relating to CRS use and child occupant safety with a focus to reach the target groups identified (i.e., parents aged more than 39 years, men and parents with children aged more than four years);
- Review of CRS / vehicle design to extend the range of movements safely afforded by CRS structures. This might include, for example, a design that accommodates forward leaning which lead to the forward suboptimal head position commonly observed when child occupants were engaged in lap-based activities such as using electronic devices, and;
- Review of CRS design to improve child occupant travel comfort, particularly for older child occupants who are travelling in their recommended restraint type.

In review, motor vehicle crashes remain a leading cause of childhood death and injury in Australia and in most developed countries (Commonwealth of Australia, 2018a; World Health Organization, 2008, 2015). While CRS provide specialised protection to child occupants in the event of a motor vehicle crash, the level of protection that the CRS can provide in a motor vehicle crash depends on how the CRS is being used (Standards Australia/Standards New Zealand, 2010). This innovative PhD research program provided findings on how CRS are being used in Australia and parent's beliefs relating to child occupant travel safety. The PhD research program identified existing gaps in parents' CRS-related knowledge and also identified travel factors that are associated with child occupant suboptimal head positions when travelling in a CRS. Importantly, in terms of translation from research to effective application of future travel safety initiatives, the PhD research program also identified parents' internal attribution of responsibility to child occupant safety, suggesting that parents will be receptive to key safety messages and the uptake of any future efforts guided by this PhD research program. Finally, the NDS provided a unique opportunity to also observe the characteristics of real-world, everyday travel of Australian families, with recommendations to encourage optimal child occupant head position and discourage those behaviours that predict suboptimal head positions through future educational campaigns and CRS/vehicle design.

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10. Appendices

Appendix A – Arbogast, K. B., Kim, J., Loeb, H., Kuo, J., Koppel, S., Bohman, K., & Charlton, J. L. (2016). Naturalistic driving study of rear seat child occupants: Quantification of head position using a Kinect™ sensor. Traffic injury prevention, 17(sup1), 168-174. doi:10.1080/15389588.2016.1194981

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Naturalistic driving study of rear seat child occupants: Quantification of head position using a Kinect™ sensor

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ABSTRACT

Objective: Restraint performance is evaluated using anthropomorphic test devices (ATDs) positioned in prescribed, optimal seating positions. Anecdotally, humans—children in particular—assume a variety of positions that may affect restraint performance. Naturalistic driving studies (NDSs), where cameras and other data acquisition systems are placed in a vehicle used by participants during their regular transportation, offer means to collect these data. To date, these studies have used conventional video and analysis methods and, thus, analyses have largely been qualitative. This article describes a recently completed NDS of child occupants in which their position was monitored using a Kinect sensor to quantify their head position throughout normal, everyday driving trips.

Methods: A study vehicle was instrumented with a data acquisition system to measure vehicle dynamics, a set of video cameras, and a Kinect sensor providing 3D motion capture at 1 Hz of the rear seat occupants. Participant families used the vehicle for all driving trips over 2 weeks. The child occupants' head position was manually identified via custom software from each Kinect color image. The 3D head position was then extracted and its distribution summarized by seat position (left, rear, center) and restraint type (forward-facing child restraint system [FFCRS], booster seat, seat belt).

Results: Data from 18 families (37 child occupants) resulted in 582 trips (with children) for analysis. The average age of the child occupants was 45.6 months and 51% were male. Twenty-five child occupants were restrained in FFCRS, 9 in booster seats, and 3 in seat belts. As restraint type moved from more to less restraint (FFCRS to booster seat to seat belt), the range of fore–aft head position increased: 218, 244, and 340 mm on average, respectively. This observation was also true for left–right movement for every seat position. In general, those in the center seat position demonstrated a smaller range of head positions.

Conclusions: For the first time in a naturalistic setting, the range of head positions for child occupants was quantified. More variability was observed for those restrained in booster seats and seat belts than for those in FFCRS. The role of activities, in particular interactions with electronic devices, on head position was notable; this will be the subject of further analysis in other components of the broader study. These data can lead to solutions for optimal protection for occupants who assume positions that differ from prescribed, optimal testing positions.

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Child restraint; child occupants; naturalistic driving study; head position; head injury

Introduction

Vehicle and restraint safety devices have largely been optimized through laboratory-based or computational test programs using anthropomorphic test devices (ATDs) intended to mimic the human occupant. Most of the test protocols evaluate restraint performance with ATDs placed in ideal positions (e.g., ATD against seat back, perfectly upright) and under these conditions, the majority of restraints perform very well.

Recent real-world evidence has suggested, however, that the ideal test conditions do not always reflect actual conditions and despite being seated in the correct restraint system for their age and size, an unacceptable number of children die or are seriously injured in real-world crashes. For example, previous research has demonstrated the mechanisms of injury for children who died as a result of interaction with frontal passenger airbag deployments (Winston and Reed 1996). Rather than being seated ideally, these children were in the path of the airbag when it deployed and the energy associated with the air bag deployment was transferred to the occupant, resulting in serious injuries or death. With this information about actual position of child occupants in these crash scenarios, laboratory test procedures that more closely mimicked actual positions of occupants were designed and the federal motor vehicle regulation was upgraded, resulting in improved, safer designs for airbags for children (Arbogast et al. 2005; Braver et al. 2008; Graham et al. 1998; Olson et al. 2006).

Anecdotally, human occupants have been observed to assume a variety of positions typically not considered in vehicle crash tests that involve changes in posture and alterations in seat belt placement and geometry. Naturalistic driving

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studies (NDSs), where cameras and other data collection modalities are placed in an instrumented vehicle used by participants during their regular transportation, offer means to collect this data. An extensive line of research focused on studying the naturalistic behaviors of drivers has revealed important findings on both physical movements and behavioral response of drivers during the driving process and in advance of an impending crash or near-crash (e.g., Dingus et al. 2006).

For child occupants, there have been similar efforts to describe position and postural changes using naturalistic, observational methods. Original studies demonstrated the limited time that children are in the ideal position while seated in vehicles but provided little quantitative data needed by industry on how to improve the testing protocols or safety products (Charlton et al. 2010; Meissner et al. 1994; van Rooij et al. 2005). More recently, efforts have been directed to evolve the analyses of these NDS studies to be more quantitative by utilizing time-intensive video analysis methods to categorize the postures that children assume during controlled maneuvers (Bohman et al. 2010; Stockman et al. 2013) or during on-road drives (Andersson et al. 2010; Jakobsson et al. 2011; Osvalder et al. 2013). These efforts have generally confirmed a range of lateral positions that is greater for those in seat belts compared to those in booster seats and an upright position without head and shoulder contact with the seat back, resulting in a head position that is further forward from the seat back compared to ATD seating procedures (Bohman et al. 2010).

Though these important studies documented the need for direct and naturalistic observations of children in vehicles to define actual positions and use of restraints, the studies were limited by small sample sizes, restricted ages, or restraint types and were largely qualitative, lacking the quantitative detail needed to improve test protocols. To address this gap, in 2012, an international collaboration was initiated to conduct a comprehensive NDS of children in the rear seat of cars with the intent to enhance the data collection and analysis methods such that quantitative values of head position could be obtained (Charlton et al. 2013). This larger scale project encompasses the broad aim of reducing the incidence of death and serious injury to child vehicle occupants by quantifying the positions and posture of children as rear seat occupants of vehicles and their interaction with the driver. This article describes initial results from that study—in particular, results derived from utilizing a Kinect sensor in order to quantify rear seat child occupants' head position throughout normal, everyday driving trips.

Methods

Vehicle instrumentation

Two study vehicles were instrumented for the NDS data collection: a 2006 Holden Statesman and a 2007 Holden Calais. Both vehicles were instrumented with a dedicated vehicle-based data acquisition system as well as a set of conventional video cameras (Figure A1, see online supplement). Data presented herein are only from the Statesman vehicle, which was equipped with the motion tracking system described below. Two Global Positioning System–enabled VBOX (Racelogic Ltd., Buckingham, UK) data acquisition systems were installed in each vehicle in the trunk to provide vehicle position data and information on vehicle speed, acceleration, and braking.

In order to collect 3D information about the position of the rear seat occupants, a Microsoft Kinect system, composed of an RGB camera and depth sensor, was installed above the rearview mirror in the 2006 Holden Statesman (Figure A2, see online supplement). The depth sensor consists of an infrared laser projector combined with a monochrome complementary metal-oxide-semiconductor (CMOS) sensor, which captured motion data. Both the raw data stream as well as the built-in skeletal tracking mode were available. The system has the ability to detect and record the 3D location of the head, neck, and shoulders for up to 2 seated rear row occupants. In the targeted range of 1.5 m, the Kinect has an x/y (lateral and vertical) resolution of 3 mm and a z depth resolution of 1 cm appropriate for this application.

Customized software was developed to initiate data collection for the Kinect system and automatically log various streams of data. A configuration file allowed the researchers to specify the relevant settings for the application (listed below). The application was developed in the C++ language using Microsoft Visual Studio 2012 and the Kinect SDK v1.7 for Windows.

Specifications for the Kinect-based data acquisition system used in this study were as follows:

- Set to operate in near mode providing a range of 500 to 3000 mm.
- Set to operate in seated mode.
- Raw color images were recorded at a frequency of 1 Hz and a resolution of 640×480 pixels.
- Depth images were recorded at a frequency of 1 Hz and a resolution of 640×480 pixels.
- Accelerations along the x, y, and z axes were recorded at a frequency of 10 Hz.

A key aspect of the data collection was the automation of the technology. The system was set to start automatically without any driver operation at ignition on. The application associated with the Kinect-based data acquisition system was executed on an Advantech ARK-2150 fanless embedded PC (Intel Core i7, 8GB RAM, Windows 7) installed in the trunk of the vehicle. The embedded PC was powered via an uninterruptible power supply with regulated +12 V. The Kinect-based data acquisition system software application was customized so that all relevant settings (frame rate, resolution, seated mode) were read from the predefined configuration file. Output was written to a 1TB external hard drive via USB 3.0. When vehicle ignition was turned off, the uninterruptible power supply informed the PC via USB that external charging was disconnected and shutdown occurred.

Participant recruitment and study procedures

Data collection started in November 2013 and ended in October 2014. Forty-two volunteer families (with 81 children) were recruited. Participants (drivers) were eligible for recruitment if they

- had 1 to 3 children, ages 1 to 8 years, who usually traveled in a forward-facing child restraint seat (FFCRS) or booster seat in the rear rows of their vehicle;
- held a valid and full car driver's license valid in the state of Victoria, Australia;
- were aged over 25 years;

- drove, on average, at least 100 km per week with their child/children in the car;
- lived within a 50-km radius from Monash University, Clayton in Victoria, Australia;
- had normal hearing and vision; glasses and contact lenses were allowed to be worn;
- had no known medical conditions that may affect their driving; and
- had no known problems with substance abuse (alcohol, drugs, etc.).

Participating families were recruited using a variety of strategies including their participation in a previous on-line child safety survey, Royal Automobile Club of Victoria websites and magazine, and social media methods.

Participants were asked to drive the instrumented vehicle on their regular trips for a period of 2 weeks. Handover of the study vehicle occurred at the participants' houses at a briefing session conducted by members of the research team. At this time, parents' informed consent was obtained in accordance with Institutional Ethics Committee requirements. Parents also completed a brief questionnaire including demographic information, travel patterns, driving behavior, and children's car travel behavior. Participants were briefed about the operation of the vehicle and the recording equipment. All children used their regular child restraint seat, booster seat, or seat belt. Participants were taken for a pilot drive for familiarization with the vehicle. They were instructed to drive the vehicle as they would normally drive their own vehicle.

Head position data processing and analysis

Kinect Version 1.0—the hardware version utilized in this study—was equipped with a built-in skeletal tracking algorithm designed to provide accurate and automated tracking of 10 skeletal joints including the head, shoulder center, shoulder left, shoulder right, elbow left, elbow right, wrist left, wrist right, hand left, and hand right. The version of the software code utilized (SDK 1.7) had recently been upgraded to provide better tracking of a seated occupant with improved near-mode resolution. Initial analysis strategies attempted to utilize the built-in algorithm to track the head. In order to assess the reliability by which the Kinect native skeletal tracking algorithm accurately detected the head location of the rear seat occupant, a subset of trips was randomly selected for a validation effort. For a random subset of 81 trips (a 5% sample of the total data set), the 2D (x–y) location of the head identified by the Microsoft skeleton recognition was superimposed on the corresponding depth image. A calibration technique was then used to translate this location to a 2D location on the color image. Analysts reviewed these color images on a frame-by-frame basis and recorded whether the head location was successfully identified or not. Successful identification was defined as a 2D location anywhere on the face of the child occupant. If a frame was determined to be unsuccessful, the reason or circumstance was recorded. We determined that the skeletal data was present 68% of the time and, of those trips with data present, 3D head position of the child occupant was successfully detected in approximately 41% of them. The remaining trips with skeletal data present had suboptimal outcomes by incorrectly identifying components of the restraint or vehicle as the head.

As a result of the limited ability of the skeletal tracking system to accurately detect the child's head, we developed our own algorithm, which utilized a 2-step process. First, every other Kinect color image, representing an image approximately every 2 s, was manually reviewed by data analysts to record the 2D image coordinates (x: left–right and y: up–down) of the head. In order to streamline the process, custom software was utilized so that analysts could quickly process a large number of images. They were instructed to click on the nose as the target point of interest or, if the nose was not visible, the centroid of the circular projection of the head. With this click, the x–y coordinates of that pixel, in image space, were obtained and the corresponding depth (fore–aft) of that pixel (in millimeters) was automatically extracted from the Kinect depth image. Second, the x–y coordinates were converted from image space to a dimensional coordinate system using a formula based on a pinhole camera model and adjusting the angle at which the Kinect sensor was tilted to the horizontal plane (Langmann et al. 2012). The origin of this coordinate system was the central point of the depth sensor of the Kinect.

Interrater variability of this process was assessed using Lin's concordance correlation coefficient (CCC; Lin 1989), which reflects the degree of the correspondence of results across different analysts, with a value of 1.0 indicating perfect reliability. In this study, a total of 3 analysts were used for the primary processing of the data. A fourth analyst reprocessed a sample of 5 trips from each of the primary 3 analysts and CCC was calculated. Generally a CCC of 0.7 is satisfactory for studies focusing on group-level differences; for this study, we used that cutoff as a threshold of sufficient reliability. Using this approach, the interrater reliability was high (CCC $= 0.911 \pm 0.192$).

Two different graphical representations—histograms and heat maps—show the distribution of the head position for all child occupants. Histograms show the one-dimensional distribution and frequency of left–right and fore–aft position while heat maps combine the 2 histograms to provide a visual representation of the 2-dimensional distribution of head position as viewed from above. Both histograms and heat maps were divided by seat position (left rear, center rear, right rear) and restraint type (FFCRS, booster seat, and seat belt). The distributions depicted graphically are summarized quantitatively by calculating the median, 50th percentile range (interquartile range, IQR), and 95th percentile range of both the fore–aft and left–right positions by seat position and restraint type.

Results

Twenty-one participant families were enrolled using the Kinect-equipped vehicle. Kinect-based data collection system errors resulted in no valid data for 3 families so data are presented for 18 families and 37 children. Limiting the data set to trips with children and those in which the vehicle was driven at least 200 m, to exclude those instances where the vehicle was turned on but did not travel anywhere, resulted in 582 trips and 135.5 h for analysis. The average age of the child occupants was 45.6 months and 51% were male. Twenty-five children were restrained in FFCRS, 9 in booster seats, and 3 in seat belts.

Left–right and fore–aft head positions are summarized in Table 1 for each restraint type–seat position combination. The distribution of fore–aft and left–right head positions by restraint type and seat position are shown in Figures 1 and 2, respectively.

Table 1. Median, IQR, and 95th percentile range of fore–aft and left–right head positions by restraint type and seat position. The origin of the coordinate system was located where the Kinect was positioned above the rearview mirror.

		Fore–aft head position (mm)				Left–right head position (mm)			
Restraint	Seat position (*n*)	Median	95% Range	50% Range	IQR	Median	95% Range	50% Range	IQR
FFCRS	All (25)	987	879–1,097	954–1,015	61		N/A		
	Left	992	886–1,110	957–1,016	59	−447	−534 to −359	−473 to −417	56
	Center	969	860–1,003	923–983	60	−18	−91 to 51	−36 to 2	38
	Right	996	859–1,086	956–1,021	65	376	247–500	330–431	101
Booster seat	All (9)	996	861–1,105	957–1,026	69		N/A		
	Left	1,007	877–1,120	959–1,043	84	−466	−549 to −327	−500 to −431	69
	Center	994	847–1,048	968–1,017	49	−12	−99 to 84	−46 to 15	61
	Right	992	856–1,103	955–1,023	68	351	196–466	301–394	93
Seat belt	All (3)	1,001	787–1,127	961–1,036	75		N/A		
	Left	1,012	892–1,125	976–1,042	66	−488	−578 to −282	−523 to −431	92
	Center	968	729–1,090	921–992	71	−16	−102 to 184	−43 to 32	75
	Right	1,027	828–1,095	990–1,043	53	365	121–456	326–406	80

In Figure 2, which depicts the left–right position of the head, the skewness of the distribution is indicated. A negative skewness means that the distribution is skewed left and vice versa. The histograms for the left-seated children all have positive skewness and right-seated children have negative skewness, indicating inboard leaning. The magnitude of skewness is largest for those restrained in seat belts—that is, those who have the most freedom of movement. The pairs of histograms are combined in Figure 3 to provide a 2-dimensional quantification of head position distribution.

Discussion

These analyses quantified for the first time, using novel Kinect technology as part of an NDS, the position of rear seat child occupants' heads during normal, everyday driving trips, and how that varied by seat position and restraint type. As restraint type moved from more to less restraint (FFCRS to booster seat to seat belt), the 95th percentile range of fore–aft movement increased, 218, 244, and 340 mm on average, respectively. This observation was also true for the 95th percentile range of left–right movement for every seat position and restraint system. This is perhaps to be expected because booster seats and seat belts allow much more freedom of movement and, from these data, this appears to result in greater displacement from the optimal position.

There was variability across the seat position, with the center seat position demonstrating the smallest range of head positions. This could be attributed to several reasons. First, several of the center-seated occupants had adjacent occupants,

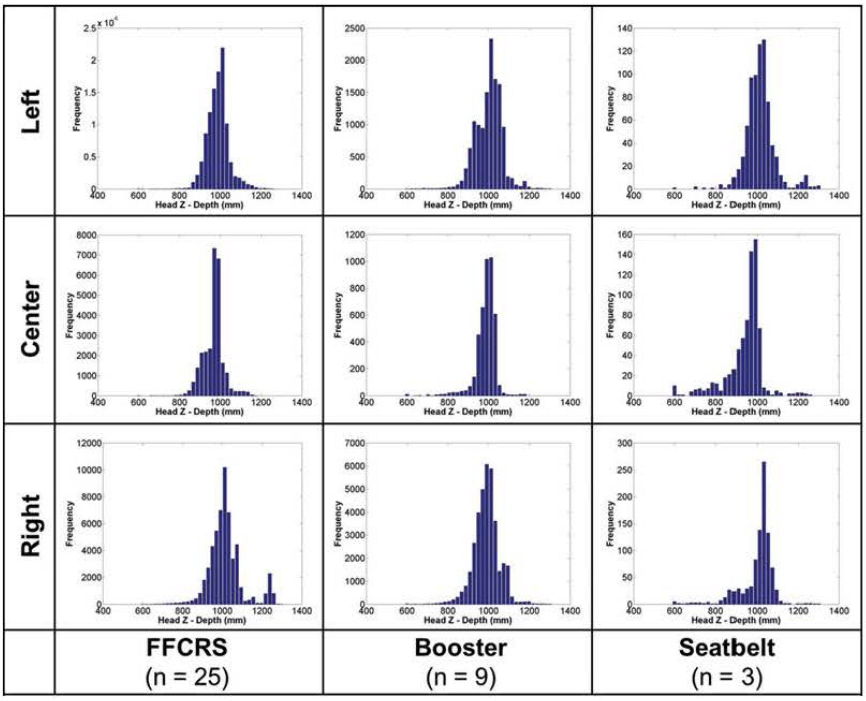

Figure 1. Distribution of fore–aft position of the head by seat position and restraint type. Smaller values on the x-axis represent head positions closer to the front of the vehicle.

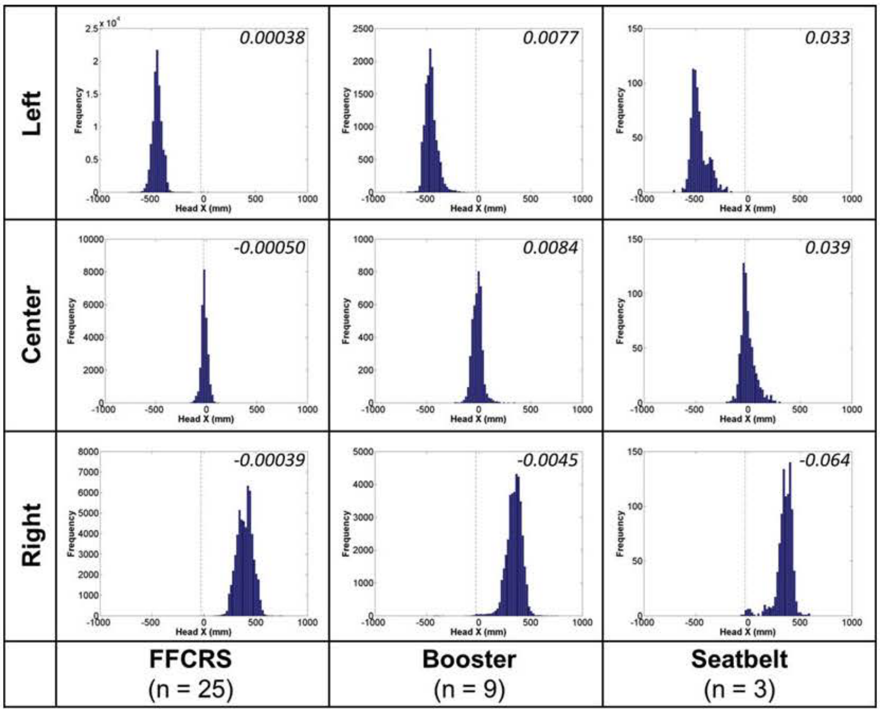

Figure 2. Distribution of left–right position of the head by seat position and restraint type as viewed from the rear of the vehicle. The center line of the vehicle corresponds to a value of −27 mm. Note that the right side of these graphs represents the seat position behind the driver (right-side drive in Australia). The skewness of the distribution is shown in the top right corner of each panel.

thus limiting their ability to move left–right. In contrast, the other center-seated occupants were alone in the rear seat and perhaps were less likely to move because there was no one to interact with. Last, as can be seen from the heat maps and calculation of skewness on the left–right position histograms, there was a tendency for the occupant to move inboard rather than outboard, potentially to see out the front of the vehicle and/or watch the DVD player placed in the vehicle roof and centralized in front of the center-seated position. This need is obviated for the center-seated occupant.

A second, more qualitative observation from examining the still images and video was the types of activities children engage in that influence their posture. Most notable was the role that electronics play in a more forward head position. Even for those

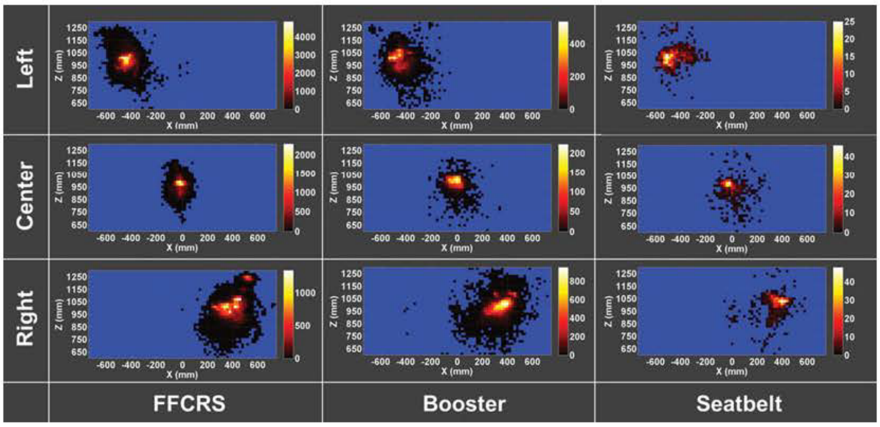

Figure 3. Two-dimensional distribution of head position (as viewed from above) by seat position and restraint type. The colors represent the frequency of specific positions with the range of values being distinct for each graph.

whose backs are against their FFCRS or booster seat, the desire to utilize a smart phone or a tablet causes their shoulders to move forward off the seat back and their head to angle downward. Future strategies to help children avoid these positions or protect them while in these positions are in need of development. Additionally, it was noted that for some of the children in booster seats, it was the actual position of the booster seat rather than the position of the child within the booster that resulted in a noncentered left–right position. The booster seat itself was offset inboard and therefore the head position of the child was also inboard from the central line of the seat. Lastly, this vehicle had a DVD player centrally positioned in the roof, which contributed to inboard leaning of several children on their FFCRS/booster seat wings.

It is relevant to consider these observed positions of the child occupants relative to standard positioning of an ATD. A child ATD positioned according to standard procedures generally has shoulder contact with the seat back. Because the ATD pelvis is pushed into the seat back as part of the positioning procedure and the ATD has limited flexibility to the spine, the head is normally not in contact with the seat back. The distance between ATD's head and seat back may differ by a few centimeters depending on booster seat model (Bohman et al. 2010). There are 2 aspects of the observed child positions that differ from this. When awake and active, the children were more likely to choose a more upright and forward leaning position, with limited shoulder contact. When resting, the children were more likely to lean their head all the way back such that the head was in contact with the seat back or laterally in contact with the side wings. This child positioning was also observed in laboratory. Reed et al. (2006) quantified the position of 5- to 11-year-olds seated on a rear vehicle bench seat and compared their preferred sitting position with child ATDs. They found that children slouched their pelvis forward compared to ATDs' standard position, resulting in a more rearward head location compared to the ATDs.

In addition to the findings, this study represents the first attempt to utilize Kinect technology to obtain rear seat occupant position data and several observations are important for future development of this methodological approach. Because of the nature of this study, where the child occupant is in a complex environment much more challenging for skeleton recognition than a typical Kinect game application, rates for skeleton recognition were considerably lower than what can be achieved in a laboratory setting. Our validation study revealed that skeletal data were present 68% of the time and, of those trips with data present, 3D head position of the occupants was successfully detected in approximately 41% of them for an overall accuracy of 28%. The remaining trips with skeletal data present had suboptimal outcomes because it misidentified the head, often for other circular or elliptical shapes such as the curved head side wings of the child restraint or the head restraint of the vehicle. This was especially true when sunlight glare was on the child occupant of interest or when there were multiple occupants in the rear seat. Although the Kinect is programmed to identify up to 2 skeletons, it appeared that in this application, the presence of more than one proved problematic. As a result, we were forced to develop our own algorithm, which was a combination of manual and automated steps.

Future development in this area is promising, however, as a new version of Kinect technology (v2) has been released that provides substantially improved resolution in both the depth and color data streams (1,920 × 1,080 vs. 640 × 480 for color and 512 × 424 vs. 320 × 240 for depth), a wider field of view that improves near-distance detection (<2.5 m), advanced motion processing algorithms, and improved ability to see in all lighting conditions. Based on unpublished preliminary work, we anticipate improved skeletal recognition capabilities. In addition, novel analytic approaches using body shape models in a postprocessing step are being developed that leverage quantitative knowledge of anthropometric relationships between body segments (Park et al. 2015).

There are several limitations to this study that must be discussed. The first and most important is the manual identification of the head position by analysts. As described in the Methods, the analysts were instructed to click on the nose of the occupant or, if the nose was not visible, to click on the center of the 2-dimensional elliptical image that outlined the head. Therefore, the depth values reported are not head center of gravity measures and, in practice, likely represent a variety of head landmarks across participants. Through our interrater reliability study, we were able to confirm that variability across analysts was small. However, future work should be directed toward taking the depth measures that represent a measure of the surface of the head/face and, using quantitative knowledge of the shape of the human head, convert those data into head center of gravity measures more typically used in occupant kinematic analyses. Second, these data were collected in a specific vehicle with particular geometry—a common family sedan used in Australia. It is likely that this general seat design is also present in Europe and the United States; Australian seat strength and vehicle crash tests are fully harmonized with Europe and no differences are present that would specifically affect seat geometry. However, one cannot assume that the data presented in this study represent distribution of head position in a vehicle with a different size or geometry. It is likely that rear seat occupants alter their behavior—or are forced to because of lack of space to move around—in vehicles with smaller rear seat occupant spaces.

As with any NDS, the breadth and depth of data represent a somewhat infinite list of analyses of interest. Herein we presented head position by restraint type and seat position as a first examination of these data. Future work will continue these analyses and analyze head position by parameters such as trip length, time into the trip, and occupancy patterns. Another area of focus will be on the interaction between the driver and rear seat occupants, specifically linking driver and child behaviors with the environmental context at the time of extreme position through sophisticated models. These analyses will give insight into the circumstances and conditions that lead to the suboptimal positioning and identify opportunities for intervention.

It is important to consider the ultimate application of these data. From an engineering perspective, these data provide valuable information for further advances in the design and testing procedures for child occupant protection technology. When one considers improvements in this field, 3 broad areas come to mind: improved biofidelity of pediatric ATDs and injury criteria;

improved replication of crash circumstances in laboratory settings; and improved positioning of ATDs for crash tests to replicate actual positioning of child occupants. The last decade has seen a tremendous increase in fundamental knowledge of pediatric biomechanics that is being incorporated into ATD design (Crandall et al. 2012; Yoganandan et al. 2014), and advances in regulatory and consumer information test procedures are expanding to consider other crash directions than full frontal to more closely mimic crash types occurring in the real world. Data such as those presented herein represent that third area. Previously we have used laboratory assessments of child occupant positioning to influence ATD positioning procedures (Park et al. 2015); however, one could argue that those are not fully biofidelic because the children know they are being studied in the artificial environment of the laboratory and they may not choose positions in the lab that they would have done during a real drive. The opportunity to use NDS data on child occupants to understand real human positioning represents an evolution of that thought.

In addition, by providing quantitative assessments of the range of head positions, we can help guide design of active safety technology to minimize such motion and influence restraint design that during the crash phase accounts for these displacements of occupant state. Ultimately, however, it is important to understand whether these positions correlate to increases in injury risk by simulating some of the common seating postures in crash tests with pediatric ATDs or human models and quantify changes in injury metrics. The positions described in these results are not static positions; the occupant has some kinematic movement that places him or her at that position at a moment in time. The relationship of these positions to injury risk is dependent not only on the position itself but the path the occupant took to get there and where they are moving from that position. Human body models may be useful to understand this complex dynamic event.

These results are part of a fundamental shift in the principles of protecting occupants in crashes by defining how child occupants actually position and reposition themselves during motor vehicle trips. These findings will provide the basis for the development of solutions for optimizing protection for rear seat occupants.

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Appendix B - Bohman, K., Arbogast, K. B., Loeb, H., Charlton, J. L., Koppel, S., & **Cross, S. L.** (2018). Frontal and oblique crash tests of HIII 6-year-old child ATD using real-world, observed child passenger postures. Traffic Injury Prevention, 19(sup1), S125-S130.

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Frontal and oblique crash tests of HIII 6-year-old child ATD using real-world, observed child passenger postures

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ABSTRACT

Objective: The aim of this study was to evaluate the consequences of frontal and oblique crashes when positioning a Hybrid III (HIII) 6-year-old child anthropometric test device (ATD) using observed child passenger postures from a naturalistic driving study (NDS).

Methods: Five positions for booster-seated children aged 4–7 years were selected, including one reference position according to the FMVSS 213 ATD seating protocol and 4 based on real-world observed child passenger postures from an NDS including 2 user positions with forward tilting torso and 2 that combined both forward and lateral inboard tilting of the torso. Seventeen sled tests were conducted in a mid-sized vehicle body at 64 km/h (European New Car Assessment Programme [Euro NCAP] Offset Deformable Barrier [ODB] pulse), in full frontal and oblique (15°) crash directions. The rear-seated HIII 6-year-old child ATD was restrained on a high-back booster seat. In 10 tests, the booster seat was also attached with a top tether. In the oblique tests, the ATD was positioned on the far side. Three camera views and ATD responses (head, neck, and chest) were analyzed.

Results: The shoulder belt slipped off the shoulder in all ATD positions in the oblique test configuration. In full frontal tests, the shoulder belt stayed on the shoulder in 3 out of 9 tests. Head acceleration and neck tension were decreased in the forward leaning positions; however, the total head excursion increased up to 210 mm compared to te reference position, due to belt slip-off and initial forward leaning position.

Conclusions: These results suggest that real-world child passenger postures may contribute to shoulder belt slip-off and increased head excursion, thus increasing the risk of head injury. Restraint system development needs to include a wider range of sitting postures that children may choose, in addition to the specified postures of ATDs in seating test protocols, to ensure robust performance across diverse use cases. In addition, these tests revealed that the child ATD is limited in its ability to mimic real-world child passenger postures. There is a need to develop child human body models that may offer greater flexibility for these types of crash evaluations.

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Introduction

Child restraint systems (CRSs) are effective in reducing the number of fatal and severely injured children in motor vehicle crashes. For child passengers aged 4–8 years, the risk of injury was 55% lower for those restrained by a booster cushion compared to those restrained by a seat belt on the seat bench (Arbogast, Jermakian, et al. 2009). Analysis of real-life cases pointed to the occurrence of head injuries as a result of contact with the vehicle interior as a common injury scenario (Bohman et al. 2011). When developing and evaluating booster seats, child anthropometric test device (ATDs) are placed in ideal positions for crash test simulations, with the pelvis and shoulder in contact with the seat back and centralized in the seat, according to FMVSS 213 (NHTSA 2005). Recently, some seating protocols have been modified to replicate real-world postures. For example, Reed et al. (2006) have shown that children often assume a more slouched sitting posture; consequently, the seating protocol of FMVSS 213 has been modified by adding a spacer of 20-mm thickness behind the child ATD's pelvis to better mimic this posture. A similar approach has been adopted by the European New Car Assessment Programme (Euro NCAP) for the seating protocol of the Q10. However, even with these modifications, child ATDs are not positioned in a way that reflects all child passenger postures that are commonly observed during real-world driving trips. For example, naturalistic driving studies (NDSs) have shown that child passengers sit in a variety of positions during real-world trips. Indeed, Charlton et al. (2010) conducted an NDS with 12 families and reported that child passengers spent 70% of the trip out of the protection zone of the CRS or out-of-position (OOP). Similarly, in a driving study with 6 child passengers traveling in 2 different booster seats for 1 h each, Andersson et al. (2010) found that child passengers were influenced by the size of the side wings of the booster seat, resulting in a more forward leaning position in a booster seat with large side wings compared to one with smaller side wings. Child passengers interacting with tablets or smartphones have

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also been observed to sit in positions with no shoulder contact with the seat back and their head bent downwards (Osvalder et al. 2013). Extreme OOP, such as leaning forwards or sideways to pick up something on the floor or far side seat bench, is less frequent and of limited duration, about 5–10% of the trip. As child passengers change position, it has also been observed that the shoulder belt changes position, moving from mid-shoulder toward the neck or moving further out, away from the mid-shoulder position (Andersson et al. 2010; Jakobsson et al. 2011; Osvalder et al. 2013). If the belt is too far out on the shoulder, the belt may slide off during an impact, compromising the torso restraint and increasing the risk of excessive head excursion and increased injury risk (Reed et al. 2013).

Recent research by our group has analyzed the data from an NDS conducted with 42 families and 81 child passengers aged 1–8 years (Charlton et al. 2013). Each family drove an instrumented study vehicle for 2 weeks. Study vehicles captured vehicle dynamics and film views of the rear-seated children by 4 continuous cameras: side views of rear seat passengers from the left and right and angled views of rear seat passengers from forward-left and forward-right. Cameras were embedded in the study vehicle trim to remain discreet. For a subset of 18 families (including 35 child passengers), a Kinect camera captured motion data from which head position coordinates were derived (Arbogast et al. 2016). Comparing child passengers restrained in forward-facing CRS, in booster seats, and on the seat bench directly, the authors demonstrated clustering of common head positions with less frequent, more extreme OOPs varying with the different restraint types and sitting postures.

Findings from the NDS to date have shown that child passengers choose a greater range of sitting postures than the ideal child ATD position. There is a need to understand the injury consequences if there is a crash when child passengers choose different positions compared to ideal child ATD sitting posture. Thus, the aim of the current study was to evaluate the consequences of frontal and oblique crashes when positioning a Hybrid III (HIII) 6-year-old child ATD using real-world child passenger postures observed in the NDS.

Methods

The study included 2 phases. First, common child passenger sitting postures and several OOPs for booster-seated child passengers aged 4–7 years were identified from the NDS (Arbogast et al. 2016). The second phase involved a series of frontal and oblique sled tests with the HIII 6-year-old using the postures identified in the first phase.

Defining sitting postures

In total, 5 child passenger sitting postures were identified. The reference position was defined by the FMVSS 213 ATD seating protocol. The other postures were based on information derived from the NDS (Arbogast et al. 2016). From this study, 2D "heat maps" showed the frequency and location (lateral/fore–aft) of the head positions of 9 booster-seated child passengers. For each child passenger, the most common head position was identified on the individual heat map. By inspecting the comparable video images, an upright position of the child was confirmed, with shoulder contacting the booster seat but head not necessarily making contact.

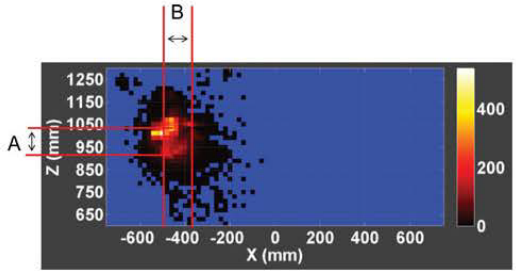

Figure 1. Example of one heat map of one booster-seated child on the right side of the vehicle from the NDS study (Arbogast et al. 2016). Measure A is the range from the most common position to the most common forward-leaning position. Measure B is the range from the most common position to the most common lateral inboard position.

Next, the range of most common forward-leaning positions relative to the most common head position was ascertained from the heat maps (see Figure 1). The range varied between 60 and 120 mm, with an average of 90 mm (see measure A in Figure 1). The measurement was repeated for the lateral inboard leaning position and the range varied between 60 and 160 mm (see measure B in Figure 1) and the average distance was 120 mm. Based on this analysis, the second position (pos2) was called the "common forward-leaning" position, putting the ATD 100 mm straight forward-leaning from its reference position (see Figure 2). Similarly, the third "common forward and laterally leaning" position (pos3) placed the ATD 100 mm straight forward-leaning and 100 mm laterally inboard leaning from its reference position (Figure 2).

For the 2 last positions, more extreme positions were chosen. The fourth position (pos4) was called the "extreme forward" position; the ATD was positioned 300 mm forward from the reference position. Position five (pos5) was called the "extreme forward and lateral" position; the ATD was positioned 300 mm forward-leaning and 100 mm lateral inboard leaning (Figure 2).

Still-frame pictures of the child passengers in the 5 selected heat map positions were extracted from the Kinect data and qualitatively reviewed, in order to position the ATD in postures similar to those of the child passengers. Examples of child passengers' sitting postures are provided in the Appendix (see online supplement). Because the ATD cannot twist its upper body or flex its thoracic spine, the target head position could only be reached by tilting the ATD forward at the pelvis, tilting it sideways by lifting its buttocks, or shifting the ATD forward or sideways. The positions were reached by tilting the ATD, trying to maintain the pelvis in a centralized position on the booster seat. In pos3 and pos4, a foam block was positioned behind the ATD's back in order to ensure that the ATD maintained a forward-leaning position prior to the crash.

For all positions, the shoulder belt was positioned such that the belt fell naturally on the ATD torso, taking the shortest path between the booster seat shoulder belt guiding loop to the buckle.

Sled test setup

The HIII 6-year-old was restrained with a 3-point belt on a booster seat in the rear seat of a mid-sized vehicle body. A Britax Hi Liner booster seat (Britax, Australia) was used. Though families in the NDS study used their own booster seats, the

Figure 2. Side view and front view of the HIII 6-year-old in the 5 different positions tested, from top to bottom: reference, pos2, pos3, pos4, and pos5.

Britax Hi Liner booster seat was chosen for the sled tests because it is a common booster seat in Australia. The seat back height of the booster seat was adjusted and the seat belt was snug against the ATD according to the manual. The booster seat was positioned centrally within the outboard position on the seat bench, with the back initially in contact with the seat back in all tests. For ATD positions pos2, pos3, pos4, and pos5, the booster seat was in the same position as the reference test.

Seventeen sled tests were conducted at 64 km/h, using a generic sled pulse reaching 34 *g* (Appendix A1, see online supplement) corresponding to a Euro NCAP Offset Deformable Barrier (ODB) test in 64 km/h. Two impact directions were tested, full frontal 0° and oblique 15°. In the oblique tests, the ATD was positioned on the right side, resulting in inboard motion during the impact. In 10 sled tests, the booster seat was also attached with a top tether (to meet Australian standards). In the other, no tether was used as is typical for U.S. and European configurations. A standard 3-point seat belt was used, without a pretensioner or load limiter. The sled test matrix is detailed in Table 1. All tests, except tests 6–9, were run with an HIII 6-year-old on the right side. Tests 6–9 were run with an additional HIII 6-year-old on the left side.

The recorded data included linear acceleration to the head, chest, and pelvis; upper neck forces and moments; chest displacement; and lap and shoulder belt forces. Hardware information is detailed in Table A1 (see online supplement). The data acquisition system (Kistler) has a built-in anti-aliasing filter (2,900 Hz 6-pole Bessel). The sampling rate was 20,000 Hz. All data were filtered according to SAE J211 (Society of Automotive Engineers 1995). Each test was captured by digital high-speed cameras (Roper Scientific HG 2000, 1,000 frames/s, Germany) including front, side, and top views.

The head injury criterion (HIC_{15}) and chest acceleration were compared to injury assessment reference values (IARVs) in FMVSS 213 (NHTSA 2005). The neck tension and chest deflection were compared to IARVs reported by Mertz et al. (2003).

Shoulder belt position was reported at the time of maximum head excursion as “close to neck,” “mid shoulder,” “stuck in gap,” or “slip-off.” *Stuck in gap* refers to when the shoulder belt became jammed in the ATD’s gap between the shoulder and the arm. Forward head excursion was measured from the side view, at the center of gravity (COG). In some cases, the head had rotated inboards such that the target at the COG was not visible; in these cases the mid-face position was used as measurement point for the head excursion. The head excursion is presented as both relative to the starting position and the total excursion from the reference position. The head excursion measurement accuracy was ±10 mm. The head excursion in the oblique test was underestimated (3.5%) compared to the tests in the full-frontal tests, because the vehicle buck was rotated relative to the rails and the head excursion was calculated perpendicular to the vehicle.

Results

A total of 17 sled tests were conducted. The loading to the ATD, belt forces, shoulder belt position, head excursion, and head impact are presented in Table 2.

Table 1. Sled test matrix.[a]

Test no.	Position	Description of position	PDOF (°)	Top tether
1	ref	Reference	0	Yes
2	pos2	Common forward-leaning	0	Yes
3	pos3	Common forward- and lateral-leaning	0	Yes
4	pos4	Extreme forward	0	Yes
5	pos5	Extreme forward and lateral	0	Yes
6*	pos2	Common forward-leaning	0	No
7*	pos3	Common forward- and lateral-leaning	0	No
8*	pos4	Extreme forward	0	No
9*	pos5	Extreme forward and lateral	0	No
10	ref	Reference	15	Yes
11	pos2	Common forward-leaning	15	Yes
12	pos3	Common forward- and lateral-leaning	15	Yes
13	pos4	Extreme forward	15	Yes
14	pos5	Extreme forward and lateral	15	Yes
15	ref	Reference	15	No
16	pos2	Common forward-leaning	15	No
17	pos3	Common forward- and lateral-leaning	15	No

Tests marked with an asterisk were run on the left side; the other tests were run on the right side.

Table 2. ATD loading and kinematics from all sled tests.

Test no.	HIC 36 ms	Head 3 ms clip (g)	Upper Neck *Fz* (N)	Chest clip 3 ms (g)	Chest deflection (mm)	Pelvis 3 ms clip (g)	Shoulder belt (N)	Lap belt (N)	Head excursion (relative) (mm)	Head excursion (total) (mm)	Shoulder belt position	Head impact
IARV	1,000	80	1,810	60	31	—	—	—	—	—	—	
1	1,374	83	2,549	50	46	53	5,440	3,075	343	343	Mid-shoulder	None
2	961	68	2,047	52	47	49	5,311	3,551	367	467	Stuck in gap	Knee/rebound
3	1,001	68	2,199	53	44	47	5,260	3,150	330	430	Slip-off	None
4	441	48	1,625	47	43	48	4,774	NA	252	552	Stuck in gap	None
5	493	52	1,665	50	44	50	4,471	2,662	247	547	Stuck in gap	Knee/rebound
6	786	68	2,223	54	46	53	5,406	3,537	311	411	Mid-shoulder	Knee/rebound
7	925	71	2,307	59	44	51	5,758	3,755	288	388	Mid-shoulder	Arm
8	460	55	1,680	46	39	50	4,826	2,536	233	533	Stuck in gap	Seat back
9	577	74	1,778	49	44	52	4,752	3,140	222	522	Stuck in gap	Seat back
10	1,167	78	2,510	48	48	51	4,982	3,822	397	397	Stuck in gap	Knee/rebound
11	788	69	2,289	48	50	51	4,979	3,981	351	451	Stuck in gap	None
12	864	73	2,471	46	49	49	5,663	3,776	327	427	Stuck in gap	None
13	370	54	1,694	47	60	48	4,737	3,755	251	551	Slip-off	None
14	356	53	1,765	50	48	54	4,113	2,978	266	566	Stuck in gap	None
15	1,277	81	2,407	46	47	51	5,659	3,289	409	409	Stuck in gap	Arm
16	941	74	2,514	48	52	48	5,705	3,668	314	414	Stuck in gap	Knee/rebound
17	907	73	2,337	47	53	54	5,510	3,488	322	422	Slip-off	Arm

The HIC exceeded the IARV (750) in 3 tests. In test 15, the increased HIC was associated with head contact with the arm. The 3-ms head resultant stayed below 80 *g* in all tests, except in the full-frontal and oblique reference tests, which reached 83 and 81 *g*. The head accelerations were 30–44% lower in pos4 and pos5 compared to the reference positions, and those tests were associated with slipping out of the shoulder belt. There was head impact to the front seat back in 2 full-frontal tests, pos3 and pos4 without tether, but the contact did not result in a head acceleration different from the other tests with no head contact. Those were tests with the ATD positioned on the left side, where the front seat back was flexing less forward during impact compared to the right front seat back, resulting in less space for head excursion. In the other sled tests, there was no seat back contact with the head, though there was extensive head excursion in some tests. In some tests, the head impacted the knees of the ATD during the rebound, but the acceleration associated with that contact was always less than the maximum acceleration the head reached during the forward excursion.

Upper neck tension ranged from 1,625 to 2,510 N, exceeding the IARV (1,890 N) in more than half of the tests. It was more common that the upper neck tension was below the IARV in pos3 and pos4 compared to the other positions; this was associated with the shoulder belt slipping off the shoulder. Chest acceleration was below the IARV (60 *g*), whereas chest deflection exceeded the IARV (31 mm) for all tests. Pelvis acceleration varied across a limited range of 48–57 *g*, and no trends were observed that might be explained by changes in either occupant position or impact angle.

In the majority of sled tests, the shoulder belt either slipped completely off the ATD's shoulder or jammed in the gap between the shoulder and the arm (see Figure 3). The shoulder belt remained on the shoulder in 3 out of 17 tests: In the reference test in full-frontal with tether and in pos2 and pos3 in full-frontal without tether.

Total head excursion compared to the reference position increased with forward-leaning position and increased in sled tests where the shoulder belt slipped off the shoulder in all tests except in the oblique test without tether when the ATD was positioned in pos2 (compared to tests 15 and 16). Those 2 tests had the same amount of head excursion.

Discussion

Recent NDS have shown what many parents are already aware of; That child passengers do not sit like ATDs during real-world driving trips (Arbogast et al. 2016; Charlton et al. 2010, 2013; Jakobsson et al. 2011; Osvalder et al. 2013). Our analyses to date suggest that extreme OOP accounts for a very limited portion of the driving trip (Arbogast et al. 2016). This study has evaluated the kinematics and loading to the HIII 6-year-old positioned in common child passenger postures and in more extreme OOPs identified from NDS data (Arbogast et al. 2016). The sled tests showed that the shoulder belt slipped off the shoulder in most of the tests. Furthermore, the more forward-leaning the ATD

Figure 3. Test 2: Side view and top view of HIII 6-year-old in pos2, at 0 ms (first row), at 80 ms (second row), and at maximum head excursion at 103 ms (third row). Note the shoulder belt slippage into the gap between the shoulder and arm in the pictures in the right column.

starting position, the greater its forward excursion relative to the reference position.

There is a trade-off between ATD kinematics and loading and, as a result, a trade-off between head excursion and neck loads. The neck tension was reduced in the more extreme forward-leaning positions (pos4, pos5) compared to other positions (ref, pos2, pos3), but in those extreme starting positions, the head had the greatest excursion and was closest to the seat back. There may be several reasons for this finding. First, the shoulder belt force was slightly lower, because the shoulder belt slid off the shoulder and did not restrain the torso in the same way as if the shoulder belt stayed on the shoulder, resulting in lower neck loading. Second, when the ATD started with an initial extreme forward position, there was not much space available for travel until it reached its most forward flexed position. As a result, the head had lower head acceleration, thus resulting in lower neck tension.

Head impact with the front seat back occurred in just 2 tests, but in several other tests, the head was very close to the seat back. The 2 tests with head contact were performed with the ATD positioned on the left side where the front seat back flexed less than on the right side. This may indicate that in vehicles with more limited space, the risk of head contact would increase. Furthermore, Arbogast, Balasubramanian, et al. (2009) have shown that children are more flexible than child ATDs in low-severity tests. This may be the case in high-severity crashes as well, increasing the risk of the head impacting the seat back. In real life, there is very likely to be seat belt slack due to clothing and due to poor buckling-up procedures, adding to increased head excursion and the risk of the head impacting the seat back. Hence, though the risk of head injury was limited in these tests as measured by head contact, HIC, and head acceleration, it is likely that for real child passengers, these extreme positions show an increased risk of head injury due to its greater excursion. In addition, in many of the tests, the shoulder belt slipped off the shoulder and became jammed in the gap between the arm and shoulder, restricting the forward motion to some extent. For a real child, which lacks the gap between the arm and the shoulder, it is likely that the shoulder belt would continue to slip off, resulting in the shoulder belt sliding down the arm and providing less restraint of the torso. This would result in even larger excursion than with the ATD in these tests and an increased risk of the head impacting the seat back. Human body model simulations, with models without this nonbiofidelic gap between the shoulder and arm, may confirm these hypotheses.

Given that this is an international collaboration, sled tests were conducted with and without the top tether attached to the booster seat. In this test series, there were no obvious differences in ATD performance between the tests with and without the top tether in terms of keeping the shoulder belt on the shoulder in various sitting postures. Of the 3 tests without shoulder belt slip-off, one test was with the top tether attached and 2 tests were without the top tether attached. However, there was a trend of greater head excursion in tests with the top tether compared to tests without. Further studies are needed to understand whether these differences were within the measurement error or whether there is a real performance difference between booster seats with and without a tether.

The seat back of the booster seat was adjusted according to the manual, which specifies that the distance between the shoulder and shoulder belt guide of the booster back should not exceed 30 mm. Because the height of the booster back can only be adjusted in 22-mm intervals, the seat back height chosen to meet the manual requirements forced the shoulder belt to take a slightly different angle from the shoulder to the belt guide compared to the belt outlet from the retractor to the guide. This meant that the load path was not straight from the retractor outlet over the ATD's shoulder (see Figure 4). In many cases, this led to damage to the booster seat guide during the test as the belt tried to assume a straight line between the retractor outlet and the shoulder. The belt guide could not support belt loads of 5,000 N if the belt did not assume this straight line described above. When the shoulder belt guide broke, it introduced additional belt slack in the shoulder belt that may have contributed to the shoulder belt slip-off. The photos in the right column in Figure 4 show how high (>30 mm) the booster seat back needs to be adjusted in order to have a straight load path for the shoulder belt. This suggests that booster seat performance is dependent on vehicle seat belt geometry and indicates the need for evaluating the booster seat together in an in-vehicle environment.

Figure 4. In the left column, the booster seat back is shown adjusted according to the manual and the added lines emphasize the nonlinear shoulder belt path. In the right column, the booster seat back adjustment is in a higher slot (greater than recommended in the manual) and the shoulder belt path forms a straight line from the retractor outlet to the ATD's shoulder.

The chest deflection exceeded the IARV in all sled tests. Though the shoulder belt slipped off the shoulder, it stayed over the chest, loading the rib cage. This was particularly true if the shoulder belt jammed in the gap between the arm and the shoulder. This generic Euro NCAP ODB pulse is a demanding crash pulse that reaches 35 *g*. In general, to reach full points in Euro NCAP, the majority of vehicles are equipped with load limiters and pretensioners, which help to reduce the chest deflection. In this test series, no load limiter or pretensioner was used.

Limitations

The HIII 6-year-old has not been designed and validated for positions such as the forward-leaning and lateral-leaning positions evaluated in this test series. The HIII ATDs were first developed to be used for frontal airbag static OOP tests (Wolanin et al. 1982). Later, they were also used for dynamic crash tests, positioned in upright positions with shoulder contact with the seat back. The HIII 6-year-old poses a challenge to be positioned like real-world child passengers. In the current sled tests, the head position was achieved by tilting the ATD forward and/or sideways. In the 2 more extreme OOPs, a foam block was positioned behind the ATD's back to ensure that the HIII 6-year-old could maintain this forward-leaning position prior to the impact. Future work should explore the use of child human body models, which may offer greater flexibility in positioning for these types of crash evaluations.

This study evaluated the consequences for child passengers in various real-world sitting postures in frontal impacts, including full-frontal and oblique impact of 15°. In full vehicle tests with a deformable barrier, the impact angles varied between 12° and 20° during the first 100 m of the crash, when the occupant was moving forward (Bohman et al. 2011). In this study, an oblique impact angle of 15° was chosen.

Each configuration was only tested once. Tests where there was no belt slip-off should be tested several times to ensure that it is a stable restraint configuration.

The actual crash dynamics in an oblique impact are more complex than can be simulated in a sled test, and this may influence the kinematics of the occupant. Other impact directions, such as side impacts, should also be evaluated. A child passenger in a forward-leaning position when exposed to a side impact will be out of the side wings of a booster seat; hence, protection benefits will be limited. The integrated safety system of the vehicle, such as inflatable curtains, is in general evaluated for ATDs positioned sitting straight upright with shoulder back contact. Therefore, it is likely that an ATD in a forward-leaning position may not receive optimal benefit from the inflatable curtain.

In some tests, especially those when the shoulder belt slipped off or became jammed in the gap between the shoulder and the arm, the ATD was observed to rotate inboard and, in many cases, the target of the COG of the head was not visible. In addition, in tests without the top tether attached, the back of the booster seat moved forward with the ATD and, in some cases, the side wings hid the target of the COG of the head. In these circumstances, head COG excursion measurements were estimated and not directly measured.

In sum, results of this test series highlighted that real-world child passenger sitting postures may contribute to shoulder belt slip-off and increased head excursion in frontal and oblique crashes, thus increasing the risk of head injury. A trade-off exists between increased head excursion and elevated neck tension, pointing to the need to consider advanced restraint design that simultaneously limits both of these injury metrics. Development of restraint systems should include evaluation across a wider range of sitting postures that encompass common positions that child passengers choose to ensure robust performance. Lastly, ATD structure limits its ability to mimic real-world child passenger positions and thus further advocate for the development of pediatric human body models that may offer greater flexibility for these types of crash evaluations.

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Automated recognition of rear seat occupants' head position using Kinect™ 3D point cloud

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ABSTRACT

Introduction: Child occupant safety in motor-vehicle crashes is evaluated using Anthropomorphic Test Devices (ATD) seated in optimal positions. However, child occupants often assume suboptimal positions during real-world driving trips. Head impact to the seat back has been identified as one important injury causation scenario for seat belt restrained, head-injured children (Bohman et al., 2011). There is therefore a need to understand the interaction of children with the Child Restraint System to optimize protection. *Method:* Naturalistic driving studies (NDS) will improve understanding of out-of-position (OOP) trends. To quantify OOP positions, an NDS was conducted. Families used a study vehicle for two weeks during their everyday driving trips. The positions of rear-seated child occupants, representing 22 families, were evaluated. The study vehicle – instrumented with data acquisition systems, including Microsoft Kinect™ V1 – recorded rear seat occupants in 1120 driving 26 trips. Three novel analytical methods were used to analyze data. To assess skeletal tracking accuracy, analysts recorded occurrences where Kinect™ exhibited invalid head recognition among a randomly-selected subset (81 trips). Errors included incorrect target detection (e.g., vehicle headrest) or environmental interference (e.g., sunlight). When head data was present, Kinect™ was correct 41% of the time; two other algorithms – filtering for extreme motion, and background subtraction/head-based depth detection are described in this paper and preliminary results are presented. Accuracy estimates were not possible because of their experimental nature and the difficulty to use a ground truth for this large database. This NDS tested methods to quantify the frequency and magnitude of head positions for rear-seated child occupants utilizing Kinect™ motion-tracking. *Results:* This study's results informed recent ATD sled tests that replicated observed positions (most common and most extreme), and assessed the validity of child occupant protection on these typical CRS uses. *Summary:* Optimal protection in vehicles requires an understanding of how child occupants use the rear seat space. This study explored the feasibility of using Kinect™ to log positions of rear seated child occupants. Initial analysis used the Kinect™ system's skeleton recognition and two novel analytical algorithms to log head location. *Practical applications:* This research will lead to further analysis leveraging Kinect™ raw data – and other NDS data – to quantify the frequency/magnitude of OOP situations, ATD sled tests that replicate observed positions, and advances in the design and testing of child occupant protection technology.

1. Introduction

Vehicle occupants, and child occupants in particular, constantly move, sleep, or play in the rear seat of vehicles. Previous research has found that child occupants often move from the optimal position prescribed for the efficient functioning of their restraint system throughout the duration of the driving trip (Charlton, Koppel, Kopinathan, & Taranto, 2010; Forman, Segui-Gomez, Ash, & Lopez-Valdes, 2011; van Rooij, Harkema, de Lange, de Jager, Bosch-Rekveldt, & Mooi, 2005). These behaviors may not only impact the effectiveness of the restraint system, but may negatively influence the driver's attention and performance (Koppel, Charlton, Kopinathan, & Taranto, 2011). Quantification of the diversity and frequency of children's positions and out-of- position (OOP) statuses can inform the design of new test programs with Anthropomorphic Test Devices (ATD) that will more closely mimic human vehicle occupants (Arbogast et al., 2013; Bohman, Arbogast, & Boström, 2011; Bohman et al., 2011). These new tests will facilitate a paradigm shift in the advancement of child occupant protection, away from safety technology designed to protect an ideally positioned occupant, and toward dynamic restraint systems that maintain optimal restraint over a range of expected occupant positions and movements in a vehicle, during real-world, everyday driving trips.

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Table 1
Reasons for native algorithm incorrect recognition.

Incorrect target	Child restraint system (CRS) structure
	Another car part
	Occupants' body, other than the head
	Clothing
Technical error	Noise in image due to sunlight
	Dark image due to unidentified reasons
Occlusion	Scene blocked by front seat passengers or belongings of occupants

Naturalistic driving studies (NDS) represent an increasingly useful and sought after resource for understanding real-world behaviors in motor vehicles, including children's OOP trends (Dozza, Bärgman, & Lee, 2013). However, these studies also present difficulties for analysis, as they generate huge quantities of highly heterogeneous data that challenge 'conventional' analytical protocol (Dozza et al., 2013). As a result, exploring novel methods of analysis is critical to realizing the full potential of NDS.

Hence, in order to better understand the diversity and frequency of suboptimal positioning by rear seat occupants, an NDS was undertaken through a multi-disciplinary collaboration of engineers and behavioral scientists in Australia, the United States, and Europe to quantify the differences between optimal and actual posture and position of child occupants in the rear seat (Charlton et al., 2013). For this study, which took place in Melbourne, Australia from August 2013 to October 2014, two study vehicles were instrumented with video cameras and data acquisition systems. Additionally, one of the vehicles was instrumented with a Microsoft Kinect™ system V1, composed of an RGB camera and depth sensors to provide 3D motion capture of rear seat occupants. The study vehicles were loaned to families with young children for a two-week data collection period for naturalistic observation of rear seat occupant behavior during their normal, everyday driving trips.

Another paper, published in 2016 in *Traffic Injury Prevention* (Arbogast et al., 2016), details one method of data analysis utilized for this NDS, as well as that method's preliminary results. This paper provides a detailed account of the study's data collection methodology, as well as three other novel methods of algorithmic assessment for processing the Microsoft Kinect™ data. These algorithms will contribute to the repertoire of analytical methods available to researchers in the future, particularly as NDS increases in prevalence and incorporates new data acquisition systems.

2. Methods

2.1. Vehicle instrumentation

Two study vehicles – a 2006 Holden Statesman and a 2007 Holden Calais – were instrumented for the NDS. Both study vehicles were instrumented with a dedicated vehicle-based data acquisition system, as well as a set of conventional video cameras.

2.1.1. Data acquisition system

Two GPS-enabled VBOX™ (Racelogic Ltd., Buckingham, UK) data acquisition systems were installed in each study vehicle (stored in the trunk) to provide vehicle position data and information on vehicle speed, acceleration, and braking.

2.1.2. Conventional video cameras

The conventional video system was comprised of eight cameras located in the vehicle interior, strategically positioned to gain an overall view of the forward road scene and the interior of the cabin, with minimal disruption to the driver's view and maximum concealment from vehicle occupants. The cameras provided views of the child occupants (both front and lateral views) and the driver, a restricted view of the front seat passenger, and a view of the roadway.

- Camera 1 was located behind the center internal rear-view mirror, providing a view of the forward road/traffic;
- Camera 2 was embedded in the internal rear-view mirror (behind a hole, 10 mm in diameter), providing a view of the driver and the front seat passenger;
- Camera 3 was embedded in the front cabin light enclosure, providing a view of the steering wheel, center radio console, and the driver's lap;
- Cameras 4 and 5 were positioned in the interior roof of the vehicle, within the DVD player/interior light cavity;
- Cameras 6 and 7 were embedded in the handle above the door in the rear passenger compartment, one on left and one on right and
- Camera 8 was located in the rear parcel shelf, providing a view of the road/traffic to the rear.

All cameras were connected to the data acquisition unit stored in the trunk (boot) of the study vehicle. The video system was operated by a microcontroller, programmed to allow for automatic start-up within 60 s of study vehicle 'ignition on.' The recording system could also be de-activated manually by pressing a red button on the dash behind the steering wheel. This feature was necessary to satisfy ethics requirements and allowed drivers to opt out of the study temporarily by shutting down the recording system at the start of, or during, a trip.

2.1.3. Mobileye™ camera

In addition to the conventional video system, a Mobileye™ vision system was installed. This optical vision system, which includes motion detection algorithms, was used to log data on road signs, headway distance, lane departures, and pedestrian detection. Audio warnings to the driver were de-activated during the data collection period.

2.1.4. Microsoft Kinect™ for Windows system

A Microsoft Kinect™ system, composed of an RGB camera and depth sensor, was installed above the rear-view mirror in the 2006 GM Holden Statesman to provide 3D motion capture of the rear seat outboard occupants (Fig. 1). The dimensions of the 2007 Holden Calais did not permit installation of the Kinect™ system. The depth sensor consisted of an infrared laser projector combined with a monochrome CMOS sensor, which captured motion data. Both the raw data stream and built-in skeletal tracking mode, the latter of which was designed to track the 3D location of the head, neck, and shoulders of up to two seated rear row occupants, were available. In the targeted range of 1.5 m (distance between Kinect™ and rear seat back), the Kinect™ was reported to have an upwards and lateral x/y resolution of 3 mm and a depth resolution z of 1 cm. Kinect™ was calibrated to operate in 'near mode' in order to

Fig. 1. Embedded Kinect™ for Windows.

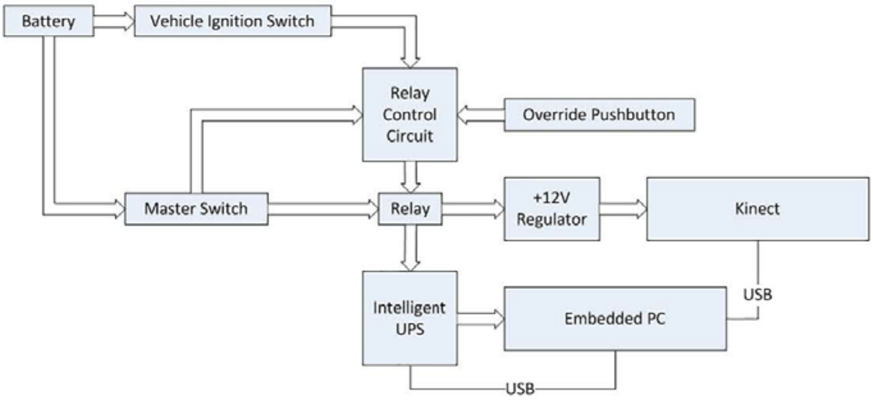

Fig. 2. Embedded Kinect™ auto start configuration.

accurately capture child occupant movement within the dimensions of the vehicle interior. Data from the Kinect™, Mobileye™, and video camera systems were synchronized with the VBOX data by matching the time stamps on each data stream.

Customized software was developed to initiate automatic data collection for the Kinect™ system upon vehicle ignition and log various streams of data. A configuration file allowed the researchers to specify the relevant settings for the application. The application was developed in the C++ language using Microsoft Visual Studio 2012 and the Kinect™ for Windows v1.7 SDK.

These settings included:

- Near mode: Set to operate in near mode providing a range of 500 mm to 3000 mm.
- *Seated mode*: Set to operate in seated mode providing access to up to 10 joints.
- *Color* images: Set to record raw color images at a frequency of 1 Hz and a resolution of 640 × 480 pixels.
- *Depth images*: Set to record depth images at a frequency of 1 Hz and a resolution of 640 × 480 pixels.
- *Skeleton joints*: Set to record 3D location of 10 joints at a frequency of 10 Hz. Ten joints were recorded (Head, Shoulder Center, Shoulder left, Shoulder right, Elbow left, Elbow right, Wrist left, Wrist right, Hand left, Hand right).
- *Accelerometer data*: Set to record acceleration along x, y, and z axis at a frequency of 10 Hz.

2.2. Data collection

2.2.1. Embedded PC

The Kinect™ application was executed on an Advantech ARK-2150 fanless embedded PC (Intel Core i7, 8GB RAM, Windows 7) installed in the trunk of the vehicle. The embedded PC was powered via an Uninterruptible Power Supply (UPS).

2.2.2. External hard drive

Kinect™ output was written to a 1TB external hard drive via USB 3.0. The use of swappable external hard drives allowed for fast turnovers participant check-up at midpoint at the end of the first week and the continuous upload of data to the central server while the study vehicle stayed with the family for a second week.

2.2.3. Auto start

A key aspect of the data collection was the automation of the technology (see Figure 2). All components of the system were set to start automatically (without any driver operation) at ignition. To account for variable system start-up times, all data was timestamped and synchronized post-hoc. Starting the vehicle powered the UPS, which provided regulated +12 V to the Embedded PC. The PC was configured to start Windows when powered on. A shortcut to the Kinect™ application was placed in the Startup folder. The Kinect™ software application was customized so that all relevant settings (described above) were read from the predefined configuration file. Data were automatically recorded on the external hard drive. When vehicle ignition was turned off, the UPS informed the PC via USB that external charging was disconnected. This allowed initiation of the Windows shutdown process. The UPS was programmed to shut down and cut power to the PC after 60 s, allowing a smooth shutdown process.

2.2.4. VBox data collection

Video and vehicle data were recorded via the VBOX data acquisition systems. Data were stored on SD cards to facilitate fast participant turn-over. One VBOX system collated videos of the roadway and driver, while the second system integrated rear seat views. For each vehicle trip, each VBOX system generated a timestamped AVI video file comprising four video views and a synchronized text file integrating CANBUS, Mobileye™, and GPS data.

2.3. Participant recruitment and study procedures

A brief description of the participant recruitment and study procedures are provided here for completeness. 22 participating families were recruited, representing 41 children (42 families with 82 children, but only 22 drove the study vehicle instrumented with the Kinect™ system). Participants were asked to drive the study vehicle on their regular trips for a period of two weeks. Handover of the study vehicle occurred at the participants' house at a briefing session conducted by members of the research team. At this time, parents' informed consent was obtained in accordance with Institutional Ethics Committee requirements, and a briefing on the operation of the study vehicle was conducted.

Contact was made with participants midway through the data collection period to monitor and address any practical issues and to inquire if there were any trip recordings that they wished to have deleted for any reason (an institutional ethics requirement). At the end of the two-week observational data collection period, the study vehicle was collected from the participant's house by members of the research team.

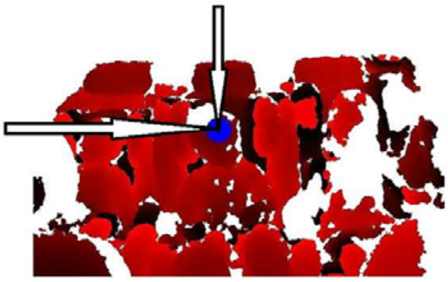

Fig. 3. Kinect™ valid head recognition, with blue dot depicting head native Kinect™ head recognition.

3. Results: Kinect™ data processing

3.1. Native algorithm

In addition to color and depth streams, the Kinect™ has the ability to detect key skeletal landmarks. The classic approach of identifying the passenger's head through a face detection algorithm was considered and a short pilot was conducted. It appeared quickly that the shifting sun reflection on the passengers' heads made this approach very difficult. Manual inspection of results led the team to abandon this approach to better leverage the various sources of data. The research team opted to use the Microsoft skeleton tracking algorithm to quantify the posture and position of rear seat occupants. This built-in algorithm utilizes a machine learning process where body parts are inferred using a randomized decision forest, learned from over 1 million training examples. For this study, the research team was interested in head tracking, so no analysis was conducted on shoulder, elbow, wrist, or hand tracking data. The nature of the study presented challenges: because children were in complex environments more challenging for skeleton recognition than a typical Kinect™ gaming or research laboratory application, skeleton tracking data were successfully collected only on a portion of the total trip time. 22 families (with 41 children) drove the Statesman Holden study vehicle equipped with the Kinect™ system. Skeleton data were logged by the Kinect™ for 662 trips out of the total 1120 trips, yielding a success rate of 59%.

In order to assess the accuracy of the skeletal tracking algorithm for detecting the head location of the rear seat occupant, a subset of the trips was randomly selected for a validation analysis. For this subset of 43 trips (a 2.5% sample of the total data set), the 2D (x-y) location of the head identified by the Microsoft skeleton tracking algorithm was superimposed on the corresponding depth image. This location was then translated to a 2D location on the color image. Analysts reviewed these color images on a frame-by-frame basis and recorded whether the head location was successfully identified or not. Successful identification was defined as a 2D location anywhere on the face of the child passenger. If a mismatch was detected, the source of the error or circumstance was recorded. See Table 1 for examples of reasons of native algorithm incorrect recognition. The manual video review and tabulation of the frames with valid head recognition led to a success rate of 41% (e.g., when head data were present, it was correct 41% of the time). Fig. 3 is an example of a valid head recognition. In this picture, three children passengers are present. The Kinect system recognized a middle passenger and successfully identified his head. Fig. 4 is an example of an invalid head recognition. In the latter example, the vehicle's headrest is mistaken for the head by the Kinect™ system. In this situation there is no child passenger sitting in the middle. The Kinect is unable to discern head rest from passenger head. Reasons for incorrect target detected are tabulated below:

Fig. 4. Kinect™ invalid head recognition, with headrest mistaken for head.

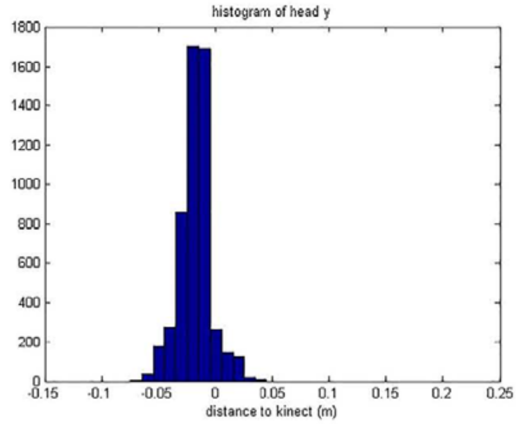

Fig. 5. Histogram of lateral component of head position.

3.2. Preliminary results

As an example to illustrate the value of the skeletal tracking data, data for a single trip for a single rear seat occupant was summarized through histograms of head position in all three axes. (Fig. 5 to Fig. 7). While the x (left-right movement) and y (up-down movement) distributions of head position follow an expected Gaussian distribution, the z (fore-aft) distribution of head position is bimodal. This bimodal

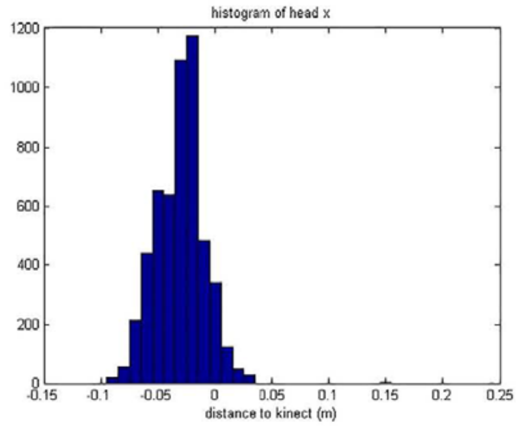

Fig. 6. Histogram of vertical component of head position.

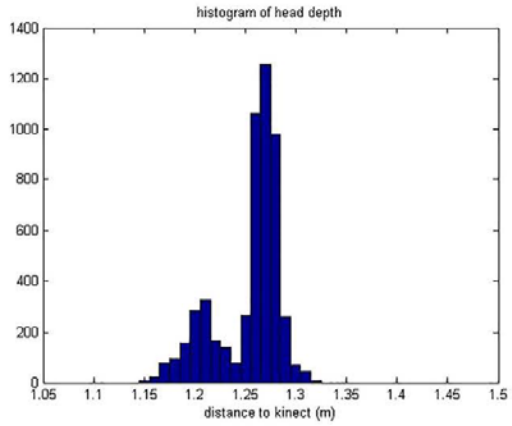

Fig. 7. Histogram of depth component of head position.

distribution represents two general positions the occupant assumes: an initial rearward position (which is the most common and likely the most optimal position and a forward position (which likely represents forward movement of the occupant to look at his/her surroundings). In this example, the forward movement is, on average, 8 cm forward from the nominal position.

3.3. Limitations

NDS are, by their nature, challenging because many elements likely to influence the results are hard to control. In this study, skeletal recognition was especially challenging. First and foremost, direct sunlight prevented the Kinect™ system from logging depth for a large number of points in each frame. These points were logged as white pixels during data collection (Figs. 6 and 7). In addition, external elements – such as the vehicle headrest, with its circular pattern – was often mistaken for the child's head.

In order to leverage the 3D point cloud logged by the Kinect™ system, alternative post processing algorithms were designed to directly process the depth and color images and extract meaningful information.

4. Results: filtering for extreme motion

4.1. Algorithm

The primary analytic objective was to efficiently detect extreme motion by child occupants, where occupants place vulnerable body parts outside the protection area of the CRS. However, given the high level of noise in infrared images due to the sun's reflection, complete automation of the identification of extreme motion epochs is extremely challenging. Therefore, the research team developed a semi-automatic extreme motion filtering process that allowed analysts to quickly sift through the large number of images.

This heuristic process consisted of three steps – reference image selection, detection of frames with extreme motion, and head location extraction (Fig. 8). This process was implemented through custom software written in Matlab (MathWorks, Natick, MA), which provided a user-friendly graphic user interface (GUI) for expedited processing. For the reference image selection, analysts were provided with a window where they could quickly select an image in which every passenger was sitting in the optimal recommended position. This selected reference image was then used for the next step, where the depth images from the rest of the trip were compared against the reference image to identify those that were most different in terms of depth distribution within an

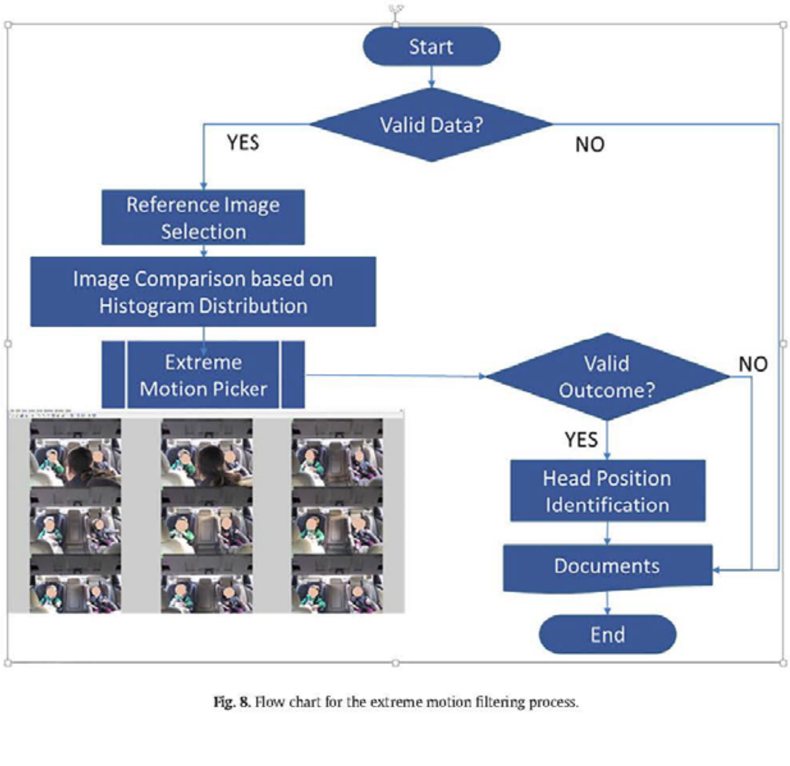

Fig. 8. Flow chart for the extreme motion filtering process.

identified region of interest. This approach extracted images with extreme motion in an automated way. The comparison for the extreme motion detection was enabled by implementation of the histogram comparison based on the Chi-squared distance, which was defined as:

$$C\left(p_i, q_j\right) = \frac{1}{2}\sum_{k=1}^{K}\frac{\left[h_i(k) - h_j(k)\right]^2}{h_i(k) + h_j(k)},$$

where $h_i(k)$ and $h_j(k)$ denote the K bin normalized histogram at p_i and q_j, respectively (Belongie, Malik, & Puzicha, 2002). The greater the chi-squared distance, the higher the image was ranked. With this ranking information, candidate images for extreme motion were systematically presented to analysts, through a process called 'Extreme Motion Picker,' in order to qualitatively validate the filtering process and confirm that these images did indeed represent frames in which the child's head was out of position. Once confirmed, the analysts interactively drew regions of interest around the head, and the algorithm extracted the depth value of the center point of the region of interest. A list of images with extreme motion and 3D coordinates was logged for archive purposes.

4.2. Preliminary results

Fig. 9 shows reference (panel c) and extreme motion (panel a) images of a record set, where histograms (panels b and d) of each time frame were generated within a region of interest around the face. Note that the histogram (b) has two peaks due to fore-aft motion of the occupant in the left. Aforementioned comparison method was then run based on the depth information that was effectively converted using Kinect depth images. Also note that histograms here are only shown to help interpretation of the process, and not needed for the comparison process described previously.

The proposed method allowed the research team to filter out images with extreme motion from the data set (e.g., images where occupants put a portion of their body in potentially dangerous areas). Fig. 10 shows two examples of these extreme motion situations.

4.3. Limitations

Although the described algorithm was effective in identifying images containing extreme motion from the study's large image database, analysts were still required to validate the end result through a final review. This process was achieved through the use of a friendly custom application, which permitted quick sifting of images. Even though the algorithm was successful identifying images with extreme motion, the process has built in limitations in the sense that frames with extreme motion with a lot of noise (sun reflection) would have been missed by the algorithm. The percentage of time a child spends in these extreme motion situations can therefore not be established through this algorithm. In order to quantify the number of false positive and false negatives generated by the algorithm, one would have to review all frames. Given the high number of frames (over 500,000 color images), this was not possible. While we identify examples of extreme motion, additional work would be needed to quantify the amount of time spent by each child in these extreme motion position. In addition,

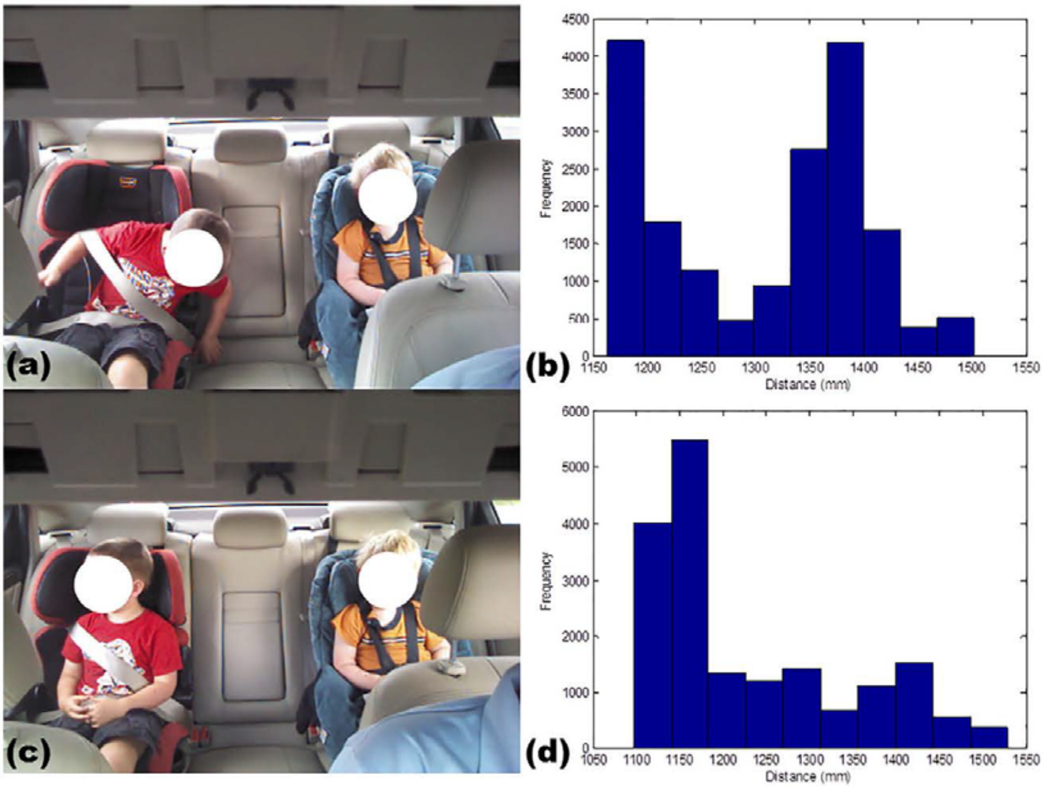

Fig. 9. Extreme motion detection using histogram distribution comparison. Sample frame with extreme motion is shown in (a), the histogram of which is in (b). (c) and (d) represent the reference image of the same trip where occupants are sitting in the optimal position. In panel (b), another peak can be found due to head movement of the child in the left.

Fig. 10. Two examples of extreme motion.

the investigators note fundamental differences between children, which ranged from a very calm and well positioned boy, to a special need child with a wide spectrum of motion.

5. Results: background subtraction and depth-based head detection

5.1. Algorithm

The extreme motion detection approach described above will only identify candidate images of interest but is not an approach to quantify the position of the occupant's head over the entire trip. To further develop this capability and account for limitations of the native algorithm in generating time-series head position data, a third approach was developed. Custom software was developed using OpenCV for the post-hoc analysis of Kinect™ depth stream images. Depth images (rather than RGB) were utilized in order to eliminate varying factors, like passenger clothing choice or changes in ambient lighting, that may have affected object detection in RGB using the native algorithm.

This analysis comprised three steps: background subtraction, morphological transformation, and head detection. First, Eigen background subtraction was implemented to extract a foreground mask of the child passengers and thus minimize the confounding effects of child restraint side wings and vehicle head restraints on automated head detection. The segmented foreground masks were then refined via image erosion (iterations = 2, kernel size = 3) and dilation (iterations = 4, kernel size = 5) to remove artifacts arising from the background subtraction process. Lastly, a decision tree was applied to the masked depth image to locate head shapes based on the area, location, and shape of contiguous depth regions (area > 5000 px, (Arbogast et al., 2016) closest to top of image, height < 150 pixels).

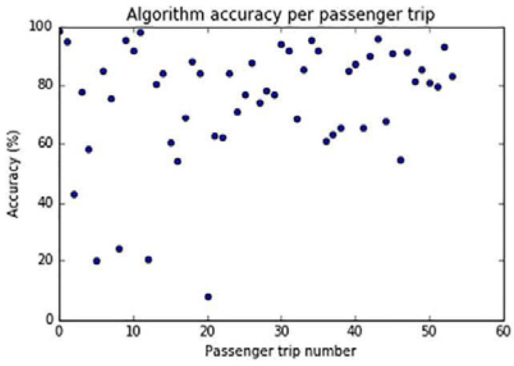

Fig. 11. Algorithm accuracy per passenger trip.

5.2. Preliminary results

Algorithm performance was evaluated per passenger per trip, achieving mean accuracy of 74.73%. The distribution of system accuracy across passenger trips is presented in Fig. 11.

5.3. Limitations

This algorithm was limited by the integrity of the segmented passenger foreground mask. Instances where erroneous segmentation occurred (i.e., when restraint side wings were retained after background subtraction) or where depth data were inadequately captured resulted in errors in the head detection stage. While artifacts in the depth stream are difficult to avoid due to the naturalistic design of the study, these issues can be addressed through the exploration of different background subtraction parameters and the application of feature tracking.

In the head detection stage, basic feature tracking was implemented by checking sequential head positions for large fluctuations in the x and y axes (candidate positions were not recorded if changes in x or y exceeded 10 pixels). The validity of the algorithm, was spot checked through a number of examples. Because of the difficulty to obtain the ground truth, no reliability statistics could be established. The application of more sophisticated tracking methods will likely improve algorithm performance.

6. Discussion

Analysis of NDS of child occupants seated in the rear seat of the vehicle can inform researchers on real-world use of child restraint systems (CRS). This paper presents the first large-scale NDS of child rear seat occupants, the technological choices that were made for car instrumentation, and three distinct data processing algorithms that were developed for analysis. The research team was successful in providing a qualitative and quantitative view of the child occupants' motion in the rear seat.

Moreover, all three algorithms presented produced valuable results, even though limitations were present. Main limitations came from (a) the non-traditional use of the Kinect™ system in a car interior, which limited the efficacy of Kinect™ native algorithm, (b) the presence of bright sun reflections, which interfered with the infrared data collection in many frames, and (c) the difficulty of consistently tracking a child's head when the image can be occluded by toys, the child's arm, or by the child's parents or siblings.

These researchers hope the algorithms outlined in this paper will form the bedrock of analysis for diverse NDS sets in the future, beyond the Kinect™ system and toward other motion-tracking and machine learning data acquisition. The fourth manual/automated method discussed in Arbogast et al., 2016 has limitations, including the difficulty of manual identification of head positions, as do the algorithms outlined in this paper. As all of these analytical methods are/were novel and experimental, it is critical that they be refined, improved, and utilized in future research to ensure that large-scale naturalistic data can be assessed with increasing efficiency and accuracy, particularly driving data. Moreover, because some of these limitations were specific to the data set generated in this study, these algorithms may represent valuable, novel methods of analysis for data sets generated from other types of motion-sensing input devices, facial/gesture recognition technologies, and other machine learning.

Given this, as well as the reliability of both the Kinect™ system and videos in recording the child at all times, the research team will continue to explore and improve alternatives for data processing. Global processing techniques such as machine learning provide a way to analyze noisy pictures and leverage time consistency (from frame to frame). We therefore anticipate that this rich dataset will continue to produce results that will further enhance child passenger safety.

7. Summary

In 2015, almost 700 children under 13 years of age died in motor-vehicle crashes, representing 1 of every 4 unintentional child injury deaths (Insurance Institute for Highway Safety: Highway Loss Data Institute, 2016). CRS reduce fatalities, but research has found that child occupants often move from the optimal position prescribed for their restraint systems (Charlton et al., 2010; Forman, Segui-Gomez, Ash, & Lopez-Valdes, 2011; van Rooij, Harkema, de Lange, de Jager, Bosch-Rekveldt, & Mooi, 2005). These OOP tendencies may decrease the effectiveness of CRS and endanger rear seat occupants.

It is therefore critical that laboratory testing of rear seat CRS incorporate the positions that children frequently take, which are often suboptimal relative to the CRS' prescribed positions. Naturalistic driving studies are extremely useful in understanding OOP situations. To understand common rear seat child positions, this study explored the feasibility of using Microsoft Kinect™ to log this positioning, focusing on child occupants observed in a naturalistic driving study in Melbourne, Australia. This paper briefly summarized initial findings, including that, when head data were present, Kinect™ was correct 41% of the time (for a review of the Kinect™ system data analysis using a fourth analytical method, which combined manual and automated steps, see Arbogast et al., 2016).

Most importantly, this paper provided novel algorithms for assessing the Kinect™ system's raw data, including an algorithm that filtered for extreme motion and an algorithm that utilized depth-based head detection were tested, with useful results – the latter achieved a mean accuracy of 74.73% when head data were present. These algorithms may be useful not only for Kinect™ system data analysis, but other large-scale naturalistic data analysis.

8. Practical applications

This NDS generated significant raw data from the Microsoft Kinect™ system. While additional work is needed to precisely quantify the frequency and severity of various rear seat children's OOP situations (that is, positions that derivate from restraint systems' prescribed positions), qualitative data were used by the investigators to place Anthropomorphic Testing Device (ATD) in children common and extreme positions to assess the impact on protection. Sled tests were conducted at Autoliv, Sweden and the impact on head excursion was confirmed. The results of these sled tests will be presented at the 61st Annual Meeting of the Advancement of Automotive Medicine in 2017.

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Appendix D - Arbogast, K. B., Loeb, H., **Cross, S. L.**, Davydov, J., Mascarenhas, K., Koppel, S., & Charlton, J. L. (2013). Use of Kinect™ for naturalistic observation of occupants in vehicles. Ann Adv Automot Med.,57:343-344.

USE OF KINECT™ FOR NATURALISTIC OBSERVATION OF OCCUPANTS IN VEHICLES

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INTRODUCTION

Restraint performance is evaluated using anthropomorphic test devices (ATD) positioned in prescribed, optimal seating positions. Anecdotally, human occupants, children in particular, have been observed to assume a variety of positions that involve changes in posture and alterations in seat belt placement and geometry which may potentially affect restraint system performance. In our previous research, we have described these position and posture differences using conventional video recording and analysis methods. These efforts, while being critically important for defining the nature and magnitude of the problem, have been largely qualitative, and have identified the presence or absence of out-of-position (OOP) and the direction of OOP (i.e. leaning forward out of the restraint). Furthermore, data analysis has been resource intensive. As a result, there is a need to evolve this methodology to be more quantitative both in order to streamline the data analysis process and to obtain precise body position data that can be used to develop countermeasures to mitigate particularly harmful positions and postures. Thus, the objective of this study was to develop and trial an innovative data collection and analysis method, using Microsoft Kinect™, to determine the naturalistic positions of child occupants while restrained in cars using quantitative techniques.

METHODOLOGY

Techniques were developed to collect quantitative data on child posture and position while restrained in the rear seat of two instrumented study vehicles. The vehicles are large sedans and will be loaned to families for a two week data collection period for naturalistic observation of child behavior during typical driving trips. In addition to conventional data acquisition system and video cameras, the Microsoft Kinect™ system, composed of an RGB camera and depth sensor, was installed into both vehicle environments to provide 3D motion capture of the rear seat outboard occupants. The depth sensor consists of an infrared laser projector combined with a monochrome CMOS sensor, which captures motion data in 3D under any ambient light conditions. The data streams are utilized in a skeletal tracking mode to provide the 3D location (relative to the sensor) of the head, neck, and shoulders of up to two seated rear row occupants. When utilized in the naturalistic environment, data from the Kinect system can be synchronized with the other data streams from the data acquisition system (braking, speed, steering) and video cameras by matching the time stamps on each data stream.

The accuracy of the Kinect™ system in quantifying left/right and fore/aft movements was assessed via the following approach:

- Left/right - Two strings were suspended from the ceiling in the coronal plane relative to the test subject, spaced 63cm apart, and placed directly in front of the test subject. The test subject aligned the center of their nose and body with one string and then moved laterally to the other string and then returned to the initial position. The test was repeated nine times by a single test subject.
- Fore/aft - One string was suspended from the ceiling, 61cm in front of the wall, in the sagittal plane of the subject. Standing upright against the wall, the test subject moved forward to the string, and back against the wall. The test was repeated nine times by a single test subject.

Data from the Kinect™ system was processed using customized software and compared to the known excursions. IRB approval was obtained from Monash University.

RESULTS

The Kinect™ system provided a consistent assessment of initial position – the standard deviation of the initial position ranged from 0.8-1.5 cm. The error between the Kinect™ measured distance and the actual measured distance ranged from 1.2-3.1 cm which corresponded to 2.0-4.9%.

Table 1: Absolute and percentage error of the Kinect™ system

	Initial position as measured by Kinect™ (cm) (Mean±SD)	Ending position as measured by Kinect™ (cm) (Mean±SD)	Total distance as measured by Kinect™ (cm) (Mean±SD)	Absolute Error (cm) (Mean±SD)	% Error (Mean±SD)
Left/right (63 cm reference movement)					
Head	-31.1±0.8	30.6±0.8	61.6±1.5	1.7+1.0	2.7±1.6%
Center of Shoulders	-29.9±1.5	29.9±0.6	59.9±1.7	3.1+1.7	4.9±2.7%
Fore/aft (61 cm reference movement)					
Head	111.5±1.2	174.4±1.2	62.9±1.6	2.2±1.1	3.6±1.8%
Center of Shoulders	110.3±1.6	171.3±0.4	61.0±1.5	1.2±0.75	2.0±1.2%

The primary limitation of this data is the lack of a true gold standard for measurement of reference distance. Although the strings were placed with precision, the movement of the test subject has some variability that is not captured in the data collection. The error reported in the Table above is a combination of the error of the Kinect™ system as well as the variability in the test subject's actual movement.

CONCLUSIONS

Kinect™ can provide a reasonably accurate quantification of movement similar to what would be expected in a vehicle without the need to apply markers to the subject of interest. Errors were less than five percent. Implementation of this novel data collection method will provide acceptable quantitative data on the motion of rear seat occupants in naturalistic riding settings. The motion data can be processed to serve as a screening tool to help researchers identify relevant segments of the video stream for future analysis. As a result, this method will improve the efficiency of naturalistic data analysis for posture and position information and ensure the collection of quantitative data which can complement other qualitative data for the development of countermeasures.

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Appendix E - Kuo, J., Charlton, J. L., Koppel, S., Rudin-Brown, C-M. & Cross, S. L. (2016). Modelling driving performance using in-vehicle speech data from a naturalistic driving study. Human Factors, 58(6), 833–845.

Modeling Driving Performance Using In-Vehicle Speech Data From a Naturalistic Driving Study

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Objective: We aimed to (a) describe the development and application of an automated approach for processing in-vehicle speech data from a naturalistic driving study (NDS), (b) examine the influence of child passenger presence on driving performance, and (c) model this relationship using in-vehicle speech data.

Background: Parent drivers frequently engage in child-related secondary behaviors, but the impact on driving performance is unknown. Applying automated speech-processing techniques to NDS audio data would facilitate the analysis of in-vehicle driver–child interactions and their influence on driving performance.

Method: Speech activity detection and speaker diarization algorithms were applied to audio data from a Melbourne-based NDS involving 42 families. Multilevel models were developed to evaluate the effect of speech activity and the presence of child passengers on driving performance.

Results: Speech activity was significantly associated with velocity and steering angle variability. Child passenger presence alone was not associated with changes in driving performance. However, speech activity in the presence of two child passengers was associated with the most variability in driving performance.

Conclusion: The effects of in-vehicle speech on driving performance in the presence of child passengers appear to be heterogeneous, and multiple factors may need to be considered in evaluating their impact. This goal can potentially be achieved within large-scale NDS through the automated processing of observational data, including speech.

Application: Speech-processing algorithms enable new perspectives on driving performance to be gained from existing NDS data, and variables that were once labor-intensive to process can be readily utilized in future research.

Keywords: naturalistic driving study, driver distraction, speech activity detection, speaker diarization, child passengers

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INTRODUCTION

Passenger-related distractions are one of the most prevalent secondary behaviors engaged in by drivers during the driving task and are a leading cause of all distraction-related crashes (Ghazizadeh & Boyle, 2009; McEvoy, Stevenson, & Woodward, 2007; Sullman, 2012; Young, Rudin-Brown, & Lenne, 2010). Distraction occurs when insufficient attention is directed to the driving task, instead being allocated to behaviors such as conversing with passengers, resulting in impaired driving performance in the form of increased steering and speed variability and an overall increase in the number of driving errors (Horberry, Anderson, Regan, Triggs, & Brown, 2006; Young & Salmon, 2012).

Through the use of vehicles instrumented with video cameras, kinematic sensors and other recording equipment, naturalistic driving studies (NDSs) offer researchers an in-depth and ecologically valid perspective into real-world driving (Eeink, Barnard, Baumann, Augros, & Utesch, 2014; Hanowski, Perez, & Dingus, 2005; Stutts et al., 2005; Van Schage et al., 2011). Analyzing NDS data for the occurrence of specific in-vehicle behaviors is typically a labor-intensive process involving manual review of video or audio data (Koppel, Charlton, Kopinathan, & Taranto, 2011). With respect to growing data set sizes, manual review is increasingly less feasible (Kuo, Koppel, Charlton, & Rudin-Brown, 2014). The automated processing of NDS video data for observable behaviors, such as eye glances, blinking, yawning, and hands off wheel, has received considerable attention in the research literature, with several validated tools actively in use in transport safety research (Kuo et al., 2014; Medina, Lee, Wierwille, & Hanowski, 2004; Tan, Borgstrom, & Alwan, 2010). In contrast, little attention has been directed toward automation of audio data processing in NDSs, possibly because in some jurisdictions, the data cannot be recorded or analyzed due to privacy issues.

Audio processing, or more specifically, speech processing, comprises multiple research areas, including voice activity detection, speaker diarization (identifying unique speakers in a signal), speaker verification (verifying the identity of speakers), and speech recognition (identifying the contents of speech). Within applications such as telephony or broadcast television transcription, where the signal-to-noise ratio is high, significant performance benchmarks for speech-processing measures have been achieved. However, audio recordings made under naturalistic conditions typically feature intermittent speech activity and high levels of background noise and may involve an unknown number of speakers, conditions that greatly increase the difficulty of accurate processing (Ziaiei, Lakshmish, Sangwan, Hansen, & Oard, 2014). Recently, substantial improvements in voice activity detection and diarization performance have been achieved under naturalistic conditions (Sell & Garcia-Romero, 2014; Ziaiei et al., 2014). The application of these methods to NDS audio would facilitate the use of a greater proportion of collected data and increase the replicability and efficiency with which audio data is analyzed.

In-vehicle audio has been used extensively within human factors research for exploring cognitive load, passenger distraction, and mobile phone use (Drews, Pasupathi, & Strayer, 2008; Reimer & Mehler, 2011; Young, Salmon, & Cornelissen, 2013). In experiments in which the level of conversation intensity has been manipulated either by increasing the cognitive load required in forming a response or by increasing the emotional intensity of the conversation topic, researchers have observed an overall decline in driving performance and safety, with increases in reaction times and critical incident involvement (Chen & Chiuhsiang, 2011; Lansdown & Stephens, 2013).

In contrast, findings on the impact of child-related secondary behaviors on driving performance within naturalistic settings have been reported with less consistency. Vehicle crashes are one of the leading causes of death for children in the developed world, attributable to over 5,000 fatalities and 85,000 incapacitating injuries for children under 8 years of age between 1999 and 2008 in the United States alone (Hanna, 2010; UNICEF, 2001). In one of the first NDSs addressing the issue of child-related distraction, Stutts et al. (2005) did not observe an association between child-related secondary tasks and driving impairment indicators. Similarly, no relationship was found between child passenger presence and crash risk in the 100-Car study (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Although child-related trips were examined by both groups, they were not the major focus of the studies. Rather, Stutts et al. examined the prevalence of a range of secondary behaviors, and a key outcome measure of the work by Klauer et al. (2006) included odds ratios for crash and near-crash risk. In particular, Klauer et al. (2006) identified a 2-times-greater odds for crashes and near crashes when drivers look away from the forward roadway for more than 2 s.

Although important insights have been gained from these early studies, they offer limited information on child-related secondary behaviors. Additionally, the application of such broad classes of distractors—"child-related distractions" or "child passenger presence"—is unlikely to adequately account for the wide variety of child-related behaviors and their potential effects on driving. In the same way that cell phone conversations can be distinguished by hands free and handheld (Amado & Ulupinar, 2005), and in-vehicle audio may comprise, for example, radio talk shows and children's stories (Hatfield & Chamberlain, 2008), child-related secondary behaviors encompass a wide range of distinct behaviors.

In a recent observational study examining child occupant behavior and driver distraction (Koppel et al., 2011), drivers were observed to engage in potentially distracting behaviors on 98% of observed trips, with interactions between drivers and rear-seat child passengers representing the second most frequent secondary behavior. In 10% of the child-related secondary behavior epochs, drivers looked away from the forward traffic scene for more than 2 s, a behavioral marker of doubled crash and near-crash risk (Klauer et al., 2006). Notwithstanding the detailed analysis of child passenger behaviors undertaken by Koppel at al. (2011), to date no studies have specifically utilized audio data to examine the impact of these interactions on quantitative measures of driving performance.

Following this body of existing research, the rationale for extending in-vehicle audio analysis to NDS data is clear. The aims of the current study were (a) to describe the development and application of an automated approach for processing in-vehicle speech data from an NDS, (b) to examine the influence of child passenger presence on driving performance, and (c) to model this relationship using in-vehicle speech data.

METHOD

Data Set

We analyzed the Children in Cars (CIC) data set, which has been previously described by Charlton et al. (2013). The CIC data set comprises 690 hr of naturalistic driving data from 42 participant families residing in Melbourne, Australia. Participant families were selected on the basis of regularly transporting at least one child age between 1 and 8 years who traveled in a forward-facing child restraint system (CRS) or a booster seat. Each participating family drove one of two instrumented study vehicles for a period of 2 weeks. Mean age for all participating drivers was 38.43 years with standard deviation of 4.41 years. Although either spouse was permitted to drive the study vehicle, 66% of all trips were undertaken by female drivers. The study vehicles were luxury-model sedans with automatic transmission and instrumented with eight video cameras, interior microphone (omnidirectional microphone insert embedded in interior roof light panel, 50 Hz to 15 kHz), MobilEye (www.mobileye.com) for measuring headway, and VBOX systems (www.vboxmotorsport.co.uk) for recording Controller Area Network (CAN) bus and GPS data.

Outcome Variables

Vehicle performance measures were recorded at 10 Hz. For the current analysis, standard deviation of steering angle and standard deviation of velocity were used as outcome measures. Although microadjustments to steering angle are representative of alert driving, the overall standard deviation of steering angle has been observed to increase with increased distraction (Chan & Singhal, 2013; Engström, Johansson, & Östlund, 2005). Similarly, speed variability has been shown to increase as drivers engage in concurrent tasks (Horberry et al., 2006). For the purpose of this study, epochs where the vehicle was stopped, was traveling slower than 50 km/h, or was engaged in a turning maneuver were excluded from the analysis. This definition provided a clearly defined, straight-driving context for validation purposes, removing the potentially confounding effects that might be associated with stop-start driving in high-volume traffic and turning, where variability in the two dependent measures of interest (steering angle and velocity) would be expected. Segmentation of the driving data into nonturning, >50-km/h epochs was achieved using GPS and CAN bus data.

Predictor Variables

Audio data were recorded from a microphone embedded within the interior roof light panel. In-vehicle speech activity within the audio data was identified and extracted using the harmonic frequency likelihood ratio test method (Tan et al., 2010). Subsequently, for each vehicle trip, speaker diarization was performed in order to cluster the speech-segmented audio data based on who was speaking and to exclude instances of nonpassenger speech (i.e., speech activity from radio, GPS, DVD, electronic handheld devices). This diarization was achieved by (a) deriving *i*-vectors for each second of speech audio, (b) performing principal components analysis (PCA) on the derived *i*-vectors, and (c) performing *k*-nearest-neighbor classification on the first three PCA factors. An overview of these methods can be found in Sell and Garcia-Romero (2014) and Shum, Dehak, Chuangsuwanich, Reynolds, and Glass (2011). Based on this work flow, a grouping variable of speech/nonspeech was created (with the speech condition including all instances of driver/passenger speech regardless of speaker).

In addition to the speech-based grouping variable, epochs were also grouped by the number of child passengers present (zero, one, two, and three). Child passenger count for each trip was determined by manual review of the video data.

TABLE 1: Summary Statistics for Child Passenger and Speech Activity Grouping Variables

	Child Passengers						
	0	1		2		3	
		Speech	Nonspeech	Speech	Nonspeech	Speech	Nonspeech
Number of epochs	2,136	275	1,808	337	2,222	58	333

Analysis

Due to the nested repeated measures structure of the data set, multilevel modeling (MLM) was selected for the analysis. MLM is an extension of the general linear model and is commonly used in transport safety research, where the hierarchical nature of data would otherwise violate the assumptions of independence and normality required for a general linear model. A general example of these violations would be crash data, whereby participants are grouped within vehicles, which are in turn grouped within specific road segments where the crashes occurred (Jones & Jorgensen, 2003). In the present study, individual epochs were nested within trips, per family, per study vehicle. Not accounting for potential correlations among these measures would result in a less powerful model, leading to inaccurate estimates of parameter effects.

In the current study, two MLMs were specified to test the effects of in-vehicle speech activity type and number of child passengers on the outcome measures of steering angle and velocity variability. An autoregressive correlation structure was specified for each trip, per family, per vehicle, to account for the hierarchical structure of the data set. This model was implemented in SAS via the MIXED procedure.

RESULTS

Segmentation of Driving Epochs

Epochs when the vehicle was traveling above 50 km/h and not engaged in a turning maneuver were extracted from the data set to minimize potential confounds for the outcome variables. Three participant families were excluded from analysis due to incomplete data. A total of 6,778 epochs comprising 131.6 hr of driving time were extracted from the initial 690-hr CIC data set, representing 19.1% of all collected trips. Mean and standard deviation of epoch duration was 699 s and 731 s, respectively. The extracted epochs totaled 8,661 km of driving, representing 67.6% of all collected trips (12,808 km total). Mean and standard deviation of epoch distance was 1.3 km and 1.6 km, respectively.

Automated Processing of NDS Audio Data

To evaluate speech activity detection performance in the current data set, three epochs were randomly selected from each of 100 randomly selected trips for manual review of incorrect speech detections. Based on this process, a false-positive rate of 10% was achieved. This manually annotated sample (excluding false positives) was subsequently used as training data for the *k*-nearest-neighbor classifier. Summary statistics for the child passenger and speech activity grouping variables are presented in Table 1. Due to sample size disparity, the three-child condition was excluded from subsequent analyses.

Distribution of epochs and speech activity per participating family are presented in Figure 1, sorted in descending order of epochs. The distribution of epochs per family exhibited negative kurtosis (–0.86, SE = 0.74) and positive skew (0.58, SE = 0.38), and correlated significantly with the distribution of speech activity at alpha = .01 (r = .68, p = .000).

Effect of Child Passenger Presence on Driving Performance

To examine the predictive effect of child passenger presence on driving performance, the number of child passengers per trip was tested as a main effect in both models. Least square means for steering angle standard deviation and velocity standard deviation are presented in Figures 2 and

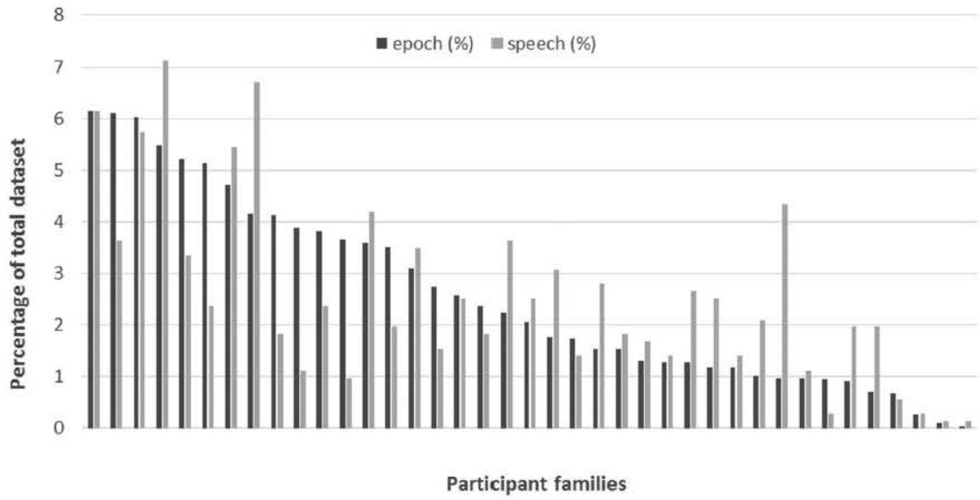

Figure 1. Distribution of epochs and speech activity per participant family, sorted by descending order of epochs.

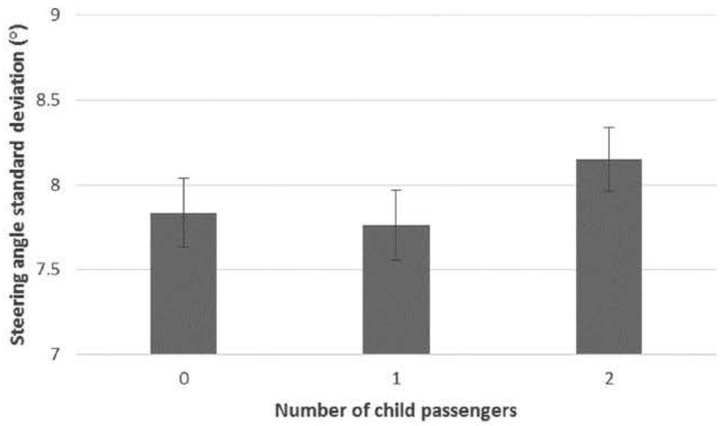

Figure 2. Least square means and standard deviation for steering angle standard deviation per number of child passengers in the vehicle.

3, respectively (least square means derive from a given linear model and are adjusted for the hierarchical structure specified in the MLM).

No significant main effect of child passenger presence was observed for steering angle or velocity variability. Individual least square means also did not differ significantly.

Interactions Between Child Passenger Presence and Speech Activity

A speech/nonspeech grouping variable extracted via automated audio processing was included as an interaction effect to model the impact of speech activity on steering angle variability. A significant main effect of speech presence was observed at $\alpha = .05$, $F(1, 91) = 4.29$, $p = .041$. A plot of least square means contrasts is presented in Figure 4.

The two-child/speech condition was associated with the most steering angle variability, statistically significant at $\alpha = .05$, when compared with all other combinations of passenger presence and speech activity. Full statistical output (fixed-effect solutions and contrasts) for both the steering and velocity models are presented in the appendix.

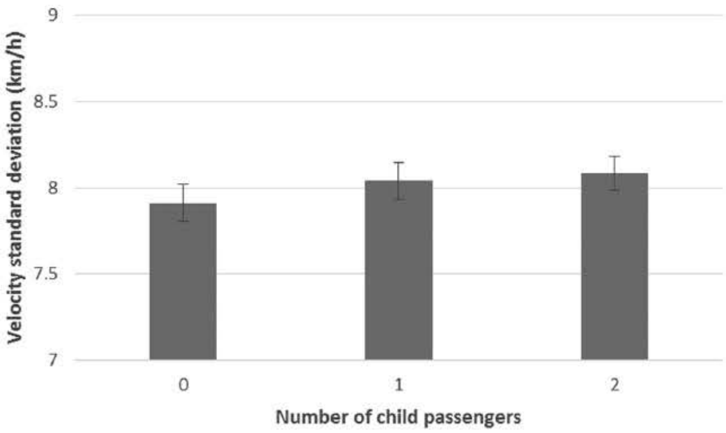

Figure 3. Least square means and standard deviation for velocity standard deviation per number of child passengers in the vehicle.

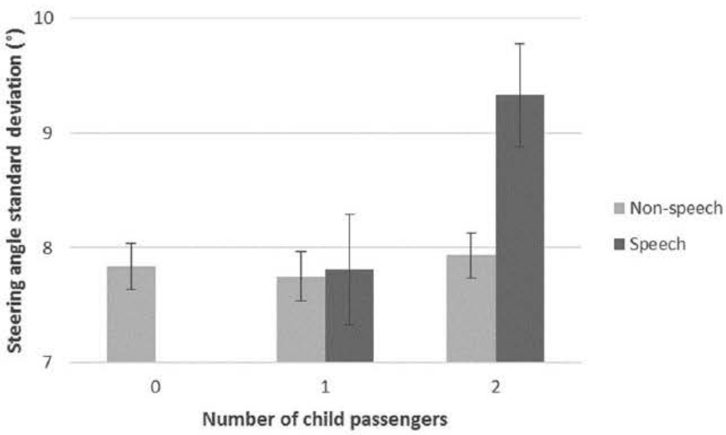

Figure 4. Least square means and standard deviation for number of child passengers and speech activity interaction effects on steering angle variability (standard deviation).

For velocity variability, a significant main effect was observed for speech presence, $F(1, 91) = 7.82$, $p = .006$. A plot of least square means contrasts is presented in Figure 5.

Similar to contrasts for steering angle variability, the two-child/speech group was associated with the most velocity variability, $t(91) = 2.15$, $p = .034$, when compared with the two-child/nonspeech group. The two-child/speech group was also associated with more velocity variability than the control (nonspeech) condition, $t(91) = 2.44$, $p = .017$; one-child/speech versus control, $t(91) = 1.97$, $p = .052$.

DISCUSSION

There is a growing need for automation in analyzing increasingly larger NDS data sets. Working within the problem space of driver distraction and passenger interactions, we aimed to (a) describe the development and application of an automated approach for processing in-vehicle speech data from an NDS, (b) examine the influence of child passenger presence on driving performance, and (c) model this relationship using in-vehicle speech data.

Through the application of state-of-the-art speech-processing methods, audio data from an existing NDS data set were segmented to identify

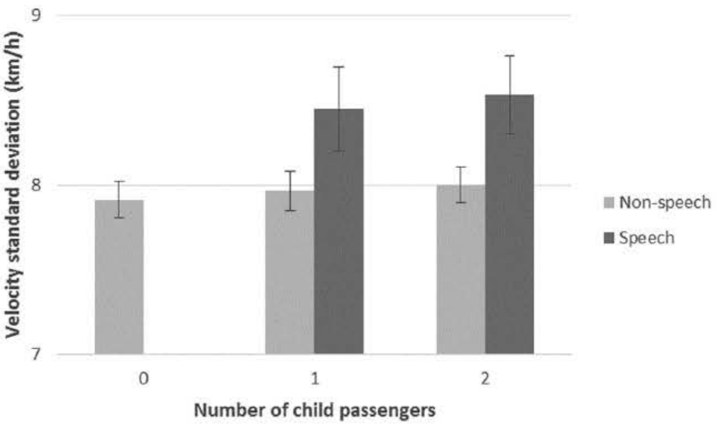

Figure 5. Least square means and standard deviation for number of child passengers and speech presence interaction effects on velocity standard deviation.

epochs that included vehicle occupant (driver and passenger) speech. This was an automated process, achieving a false-positive rate of 10% compared with a manually validated subset of data. A full evaluation of the system, including missed speech and receiver operating characteristic, was outside the scope of the current study—the harmonic frequency likelihood ratio test method and *i*-vector-based diarization performance on a variety of evaluation sets having been previously reported (Sadjadi & Hansen, 2013; Ziaiei et al., 2014). In previous evaluations on similar data sets, a 10% false-positive rate has corresponded with speech detection rates of greater than 95% (Sadjadi & Hansen, 2013; Ziaiei et al., 2014). The application of these methods to NDS audio would facilitate more effective use of data sets and increase the replicability and efficiency with which audio data are processed. These technologies also have broader practical applications in advanced driver assistance systems. The speech-processing protocol used in the current study, for instance, could potentially be applied to the analysis of in-vehicle infotainment usage, cell phone use, or the monitoring of passenger carriage (e.g., for enforcing passenger carriage restrictions under graduated licensing), facilitating human–machine interaction by taking into consideration driver (or passenger) state.

To examine the predictive effects of speech and child passenger presence on driving performance, multilevel models for steering angle and velocity variability were specified. Consistent with previous literature, child passenger presence alone was not a significant predictor. However, incorporating speech into the model revealed that the presence of passenger speech significantly predicted both performance measures. These findings contribute to the distraction and NDS literature by linking child passenger presence and child passenger behaviors to objective measures of driving performance.

Overall, our results indicate heterogeneity within the effects of passenger behaviors on driving performance, with driving performance being variably affected by a combination of the number of child passengers per trip and the presence of speech activity. Examination of least square means showed that engaging in in-vehicle speech activity was generally associated with increased variability in steering angle and velocity, with the effect most pronounced when driving with two child passengers.

One potential explanation for increased variability when speech activity occurs with two child passengers present may be an increase in distraction exposure as a result of the additional passenger—the presence of additional passengers is likely to increase the opportunities for the driver to engage in passenger interactions. However, it is likely that in addition to heterogeneity within child-related secondary behaviors, surrogate measures of driving performance may also be affected differentially. For instance, in the specific context of the nonturning driving epochs sampled, drivers may prioritize lateral control over velocity variability when engaged in potentially distracting behaviors. There may also be temporal effects associated with the duration of epochs or speech behaviors that are not accounted for in the present models. In essence, it is difficult to conclude that passenger speech behavior alone is attributable to impaired driving performance. Rather, the patterns identified in the current study provide a basis on which subsequent experimental research may be conducted.

Large, nonexperimental data sets characteristic of NDSs present a number of challenges to interpretation. First, this research is limited in the extent to which conclusions about causality can be drawn due to the observational nature of NDSs. This limitation is additionally confounded by small effect sizes. Our results are presented instead in the context of an exploratory analysis for which the ecological validity of an NDS design is highly suited. Second, the absence of vehicle crashes in the current data set limited our models to using measures of driving performance. Changes to steering and velocity variance are a valid measure of driver distraction and are a mechanism through which secondary behaviors affect driving performance, increasing the number of driving errors (Young & Salmon, 2012). However, it is not known whether these variables themselves are directly correlated with crashes, and due to the absence of actual crashes in the data, the validity with which inferences about injury risk could be made was constrained. Last, the current data set was limited to self-selected families in Melbourne. Based on the occurrence of non–socially desirable behavior, the observer effect was not likely to have been a significant factor in the data. The ability to generalize our findings outside of this population, however, is inherently limited.

As the focus of the current study was the exploratory use of algorithm-processed NDS speech data in modeling driving performance, a number of other data sources and variables that may have additionally contributed to predicting driving performance were excluded on the basis of preserving clarity. Semantic content within speech, for instance, has been previously used to explore internal factors, such as sentiment and emotional state, which in turn have been shown to affect driving performance (Briggs, Hole, & Land, 2011; Chan & Singhal, 2013; Grimm & Kroschel, 2005; Lansdown & Stephens, 2013). Prior to semantic analysis, audio data must first be transcribed, the time frame for which was outside the scope of the current study. However, given the efficacy with which speech activity detection was achieved, automated transcription processes may be utilized in subsequent studies.

Driver gaze data were not examined in the current study. Secondary behaviors in practice typically involve multiple attentional processes (e.g., passing an object to a child passenger involves visually searching as well as physically handling the item), and the inclusion of driver gaze data would likely assist in further distinguishing instances of in-vehicle speech activity in which the driver was actively involved versus passively listening. The analysis of driver gaze data is the subject of ongoing research.

Additionally, it was unclear whether the novelty of the study vehicle affected the outcome variables of steering and velocity variability. Although the impact of these effects may be expected to diminish over time, the multilevel models used in the current study do not explicitly take into account the participants' familiarity (or changes in familiarity over time) with driving the study vehicles.

External to the vehicle, roadway video and headway data were also present in the data set. In the exploratory analysis of trip metadata, there may have been differences in the nature of the trips driven with one child passenger versus the other conditions beyond the factors captured in the metadata, such as different traffic conditions or the types of roads traveled. Changing road conditions have also been postulated as a potential moderating factor in the degree of cognitive load required by drivers who are responding to passenger-initiated conversation tasks (Drews et al., 2008). Whether these effects apply to child passengers remains untested.

In summary, we demonstrated a novel application of state-of-the-art speech-processing algorithms for the automated processing of NDS audio data. To our knowledge, this study is the first application of automated speech processing to the study of in-vehicle speech in an NDS. Using segmented speech data, the predictive effect of child passenger presence on steering angle and velocity variability was modeled. Consistent with previous research, passenger presence alone was not a significant predictor of driving performance. However, significant differences were observed between the number-of-child-passengers and speech-presence grouping variables, supporting the notion that not all child passenger behaviors affect performance equally. In-vehicle audio data are seldom analyzed at scale—through the interdisciplinary application of automated techniques, new perspectives can be gained from existing data, and variables that were once laborious to process can be readily utilized in future research.

APPENDIX A

Steering Angle Variability

Solution for Fixed Effects

Effect	KNN	Pas	Estimate	Standard Error	*df*	*t* Value	Pr > |t|
Intercept			7.8950	.5542	1222	14.25	<.0001
Pas		2	1.4368	.7111	1222	2.02	0.0435
Pas		1	–0.08330	.2978	1222	-0.28	0.7797
Pas		0	0				
KNN	N		–0.05924	.5160	91	-0.11	0.9088
KNN	S		0				
Pas*KNN	N	2	-1.3391	.7039	91	-1.90	0.0603
Pas*KNN	S	2	0				
Pas*KNN	N	1	0				
Pas*KNN	S	1	0				
Pas*KNN	N	0	0				

Note. KNN = speech activity grouping variable, based on *k*-nearest-neighbor classification; Pas = number of child passengers; S = speech; N = nonspeech.

Type 3 Tests of Fixed Effects

Effect	Num *df*	Den *df*	*F* Value	Pr > *F*
Pas	2	1222	2.66	.0704
KNN	1	91	4.29	.0412
Pas*KNN	1	91	3.62	.0603

Note. KNN = speech activity grouping variable, based on *k*-nearest-neighbor classification; Pas = number of child passengers.

Differences of Least Squares Means

Effect	KNN	Pas	_KNN	_Pas	Estimate	Standard Error	*df*	*t* Value	Pr > |t|
Pas*KNN	N	2	S	2	−1.3983	.4788	91	−2.92	.0044
Pas*KNN	N	2	N	1	0.1810	.2965	91	0.61	.5431
Pas*KNN	N	2	S	1	0.1218	.5234	91	0.23	.8166
Pas*KNN	N	2	N	0	0.09769	.2847	91	0.34	.7323
Pas*KNN	S	2	N	1	1.5793	.4963	91	3.18	.0020
Pas*KNN	S	2	S	1	1.5201	.6575	91	2.31	.0230
Pas*KNN	S	2	N	0	1.4960	.4893	91	3.06	.0029
Pas*KNN	N	1	S	1	−0.05924	.5160	91	−0.11	.9088
Pas*KNN	N	1	N	0	−0.08330	.2978	91	−0.28	.7803
Pas*KNN	S	1	N	0	−0.02406	.5241	91	−0.05	.9635

Note. KNN = speech activity grouping variable, based on *k*-nearest-neighbor classification; Pas = number of child passengers; S = speech; N = nonspeech.

Velocity Variability

Solution for Fixed Effects

Effect	KNN	Pas	Estimate	Standard Error	*df*	*t* Value	Pr > |t|
Intercept			8.3949	.2858	1222	29.37	<.0001
Pas		2	0.1385	.3670	1222	0.38	.7059
Pas		1	0.05276	.1572	1222	0.34	.7372
Pas		0	0				
KNN	N		−0.4810	.2651	91	−1.81	.0729
KNN	S		0				
Pas*KNN	N	2	−0.05166	.3625	91	−0.14	.8870
Pas*KNN	S	2	0				
Pas*KNN	N	1	0				
Pas*KNN	S	1	0				
Pas*KNN	N	0	0				

Note. KNN = speech activity grouping variable, based on *k*-nearest-neighbor classification; Pas = number of child passengers; S = speech; N = nonspeech.

Type 3 Tests of Fixed Effects

Effect	Num *df*	Den *df*	*F* Value	Pr > *F*
Pas	2	1222	0.19	.8250
KNN	1	91	7.82	.0063
Pas*KNN	1	91	0.02	.8870

Note. KNN = speech activity grouping variable, based on *k*-nearest-neighbor classification; Pas = number of child passengers.

Differences of Least Squares Means

Effect	KNN	Pas	_KNN	_Pas	Estimate	Standard Error	*df*	*t* Value	Pr > |t|
Pas*KNN	N	2	S	2	−.5326	.2472	91	−2.15	.0338
Pas*KNN	N	2	N	1	.03409	.1566	91	0.22	.8282
Pas*KNN	N	2	S	1	−.4469	.2705	91	−1.65	.1020
Pas*KNN	N	2	N	0	.08684	.1505	91	0.58	.5654
Pas*KNN	S	2	N	1	.5667	.2575	91	2.20	.0302
Pas*KNN	S	2	S	1	.08574	.3390	91	0.25	.8009
Pas*KNN	S	2	N	0	.6195	.2538	91	2.44	.0166
Pas*KNN	N	1	S	1	−.4810	.2651	91	−1.81	.0729
Pas*KNN	N	1	N	0	.05276	.1572	91	0.34	.7380
Pas*KNN	S	1	N	0	.5337	.2709	91	1.97	.0518

Note. KNN = speech activity grouping variable, based on *k*-nearest-neighbor classification; Pas = number of child passengers; S = speech; N = nonspeech.

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KEY POINTS

- Automated speech-processing algorithms were applied to audio data from a Melbourne-based naturalistic driving study (NDS).
- The predictive effect of speech activity and child passenger presence on driving performance was modeled.
- Child passenger presence alone did not predict performance, but a significant difference between the number of child passengers and speech presence groupings was observed.
- Multiple factors need to be considered in evaluating the impact of child passenger presence on driving performance. Within a large-scale NDS, this goal can be achieved through the automated processing of observational data.

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Sjaan Koppel holds a PhD in psychophysiology and is a senior research fellow at the Monash Injury Research Institute's Accident Research Centre. During her 10 years at the Monash University Accident Research Centre, she has been involved in a range of road safety research projects involving vulnerable road users, such as child road users (e.g., child vehicle occupants, pedestrians, and cyclists), older drivers, and drivers with psychological and/or medical conditions or functional impairments. She has published widely in the area of vulnerable road users and has presented at many national and international conferences.

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Appendix F - Driver Demographics and Child Restraint Online Survey (DDCROS)

(Extracted MS Word format from an interactive online Qualtrics survey).

Welcome and thank you for taking the time to participate in the following driver and child car travel research. This research is being conducted by Monash University Accident Research Centre, Monash University, Clayton as a National effort to better understand Australian travel trends. The survey is part of a larger international study lead by Monash University Accident Research Centre, funded through the Australian Research Council Linkage Scheme in collaboration with;

- the Children's Hospital of Philadelphia Research Institute;
- University of Michigan Transportation Research Institute;
- Chalmers University of Technology,
- Britax ChildCare;
- Autoliv,
- VicRoads;
- Transport Accident Commission (TAC);
- RACV;
- Proquip and;
- General Motors Holden.

Outcomes will be used to optimize vehicle and child restraint design and develop targeted safety education strategies to minimize injury to children in car crashes. The following survey has ethics approval from Monash University Human Ethic Committee. Participant involvement is voluntary and all information is guaranteed to remain completely anonymous unless you choose otherwise. The survey is anticipated to take approximately 15-30 minutes of your time. We ask that prior to starting this survey, you measure the current weight and height of each of your children prior to commencement. All other information that is requested should be readily available to you. Please answer all questions as if the children are travelling with you when you are driving your usual car. Thank you for your valuable participation.

Q1 What is your current age?
❍ 20 (1)
❍ 21 (2)
❍ 22 (3)
❍ 23 (4)
❍ 24 (5)
❍ 25 (6)
❍ 26 (7)
❍ 27 (8)
❍ 28 (9)
❍ 29 (10)
❍ 30 (11)
❍ 31 (12)
❍ 32 (13)
❍ 33 (14)
❍ 34 (15)
❍ 35 (16)
❍ 36 (17)
❍ 37 (18)
❍ 38 (19)
❍ 39 (20)
❍ 40 (21)
❍ 41 (22)
❍ 42 (23)

- 43 (24)
- 44 (25)
- 45 (26)
- 46 (27)
- 47 (28)
- 48 (29)
- 49 (30)
- 50 (32)
- 51 (33)
- 52 (34)
- 53 (35)
- 54 (36)
- 55 (37)
- 56 (38)
- 57 (39)
- 58 (40)
- 59 (41)
- 60+ (42)

Q2 What is your gender? (FORCED RESPONSE)
- Male (1)
- Female (2)

Q3 What is your postcode? (FORCED RESPONSE)
(Please specify) (1)

Q4 Is there a language, other than English, primarily spoken in the home?
- No (1)
- Yes (Please specify language) (2) ____________________

Q5 Were you born in Australia?
- Yes (1)
- No (Please specify how long you have been in Australia in months/years) (2) ____________________

Q6 What is your highest level of education obtained?
- Primary School (1)
- Intermediate (Year 10 equivalent) (2)
- VCE/HSC (Year 12 equivalent) (3)
- Technical or further education institution (including trade certificate/apprenticeship) (4)
- University or tertiary institution (5)
- Higher Degree (6)
- Other (Please specify) (7) ____________________

Q7 What is the yearly household combined gross income (before tax)?
- Up to $30,000 (1)
- $30,000 - $49,999 (2)
- $50,000 - $69,999 (3)
- $70,000 - $89,999 (4)
- $90,000 - 109,999 (5)
- $110,000 + (6)

Q8 What is your current marital status?
- Married/De facto (1)
- Divorced/Separated (2)
- Widowed (3)
- Never married (4)

- ❍ Other (Please specify) (5) ____________________

Q9 What is your current employment status?
- ❑ Working, part- time (2)
- ❑ Working, full- time (3)
- ❑ Unpaid work - Volunteering (4)
- ❑ Unpaid work - carer of child/ren or person with a disability (5)
- ❑ Student, full-time (6)
- ❑ Student, part-time (7)
- ❑ Unemployed (8)
- ❑ Other (Please specify) (9) ____________________

Q10 Are there any conditions or restrictions on your licence (e.g., wearing glasses)?
- ❍ No (1)
- ❍ Yes (Please specify) (2) ____________________

Q11 How many years driving experience have you had on your full licence?
- ❍ 0-5 years (1) ____________________
- ❍ 5-10 years (2)
- ❍ 10-15 years (3)
- ❍ 15-20 years (4)
- ❍ 20+ years (5)

Q12 How many road crashes have you had as a driver in the past two years?
- ❍ 0 (1)
- ❍ 1 (2)
- ❍ 2 (3)
- ❍ 3 (4)
- ❍ 4 (5)
- ❍ 5+ (6)

Q13 Have any of your CHILDREN been involved in any road trauma of any type?
- ❍ Yes (1)
- ❍ No (2)

Answer If Have any of your CHILDREN been involved in any road traum... Yes Is Selected

Q14 Please specify the number of instances that any of your CHILDREN have been involved in each of the following road traumas. (Click cursor onto 0 if nil for any of the types of trauma or use your mouse to drag the cursor to the amount).

______ As a passenger (1)
______ As a pedestrian (2)
______ As a cyclist (3)
______ Other (eg. scooter, skateboard etc. Please specify). (4)

Q15 Over the last two years, have you had any traffic infringement notices, other than parking fines (eg. speeding, not stopping at a stop sign etc.)?

❍ No (1)
❍ Yes (2)

Answer If Over the last two years, have you had any traffic infring... Yes Is Selected

Q16 Which of the following infringements have you had and how many? (Click cursor onto 0 if nil for any of the types of trauma or use your mouse to drag the cursor to the amount).

______ Licensing and registration (1)
______ Speeding (2)
______ Drink/Drug Driving (4)
______ Failure to wear seat belt (6)
______ Distraction or Inattention (eg. mobile phone use, eating, drinking) (7)
______ Safety (eg. Careless Driving) (8)
______ Failing to give way or stop (9)
______ Signally failure or incorrect signal (eg. not indicating to turn) (10)
______ Overtaking (eg. overtaking on the left) (11)
______ Failure to keep left (12)
______ Don't know or can't remember what the infringement type was (14)

Q17 What car do you usually drive when your child/ren are with you?

Make (eg Holden, Toyota) (1)
Model (eg Commodore, Aurion) (2)
Year of Manufacture (3)

Q18 Please select what type of car this is

❍ 2 door sedan (1)
❍ 2 door hatchback (2)
❍ 4 door sedan (3)
❍ 4 door hatchback (4)
❍ Station wagon (5)
❍ 4WD/AWD with 2 rows of seats (6)
❍ 4WD/AWD with 3 rows of seats (7)
❍ People mover/van (8)
❍ Other (Please specify) (9) ____________________

Q19 On average, how many kilometres do you estimate that you drive with your children per week?

❍ Less than 100 km (1)
❍ 101 - 200 km (2)
❍ 201 - 500 km (3)
❍ More than 501 km (4)

Q20 If a trip was defined as turning the engine on to turning the engine off, in a given week, how often would you estimate that you travel with your children in the car for the following trip distances?

	Never (1)	Rarely (2)	Sometimes (3)	Often (4)	All of the Time (5)
Up to 5 km (1)	❑	❑	❑	❑	❑
Between 5 km and 10 km (2)	❑	❑	❑	❑	❑
Between 11 and 20 km (3)	❑	❑	❑	❑	❑
Between 21 and 30 km (4)	❑	❑	❑	❑	❑
Over 30 km (5)	❑	❑	❑	❑	❑

Q21 How many children, up to 16 years of age, usually travel with you in your car? (FORCED RESPONSE)
❍ 1 (1)
❍ 2 (2)
❍ 3 (3)
❍ More than 3 (4)

Q22 How old is CHILD 1 (your eldest child)? Please indicate years and months (eg. 5 years and 7 months as 5 and 7).

Years (1)	❍ 1 (1)	❍ 2 (2)	❍ 3 (3)	❍ 4 (4)	❍ 5 (5)	❍ 6 (6)	❍ 7 (7)	❍ 8 (8)	❍ 9 (9)	❍ 10 (10)	❍ 11 (11)	❍ 12 (12)
Months (2)	❍ 1 (1)	❍ 2 (2)	❍ 3 (3)	❍ 4 (4)	❍ 5 (5)	❍ 6 (6)	❍ 7 (7)	❍ 8 (8)	❍ 9 (9)	❍ 10 (10)	❍ 11 (11)	

Q23 What gender is CHILD 1 (your eldest child)?
❍ Male (1) ____________________
❍ Female (2) ____________________

Q24 What is the current height of CHILD 1 (your eldest child)? Please indicate in centimetres (eg 105).

Q25 What is the weight of CHILD 1 (your eldest child)? Please indicate in kilograms (eg 7.0, 25.5)

Q26 CHILD 1 (your eldest child) Please indicate the type of restraint/combination of restraints that Child 1 currently uses.
❑ Rearward facing child restraint (1)
❑ Rearward facing child restraint that converts to a forward facing restraint but is still rearward facing (2)
❑ Forward facing that has been converted from rearward facing (3)
❑ Forward facing that was not convertible from rearward facing (4)
❑ Booster seat (with a high back) (5)
❑ Booster cushion (without a back support) (6)
❑ Seat belt - Lap and Shoulder Sash (7)
❑ Seat belt - Lap only (8)
❑ Child Safety Harness (added H-harness) (9)

Answer If How many children, up to 16 years of age, usually travel ... 2 Is Selected Or How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q27 How old is CHILD 2 (your second eldest child)? Please indicate years and months (eg. 5 years and 7 months as 5 and 7).

Years (1)	❍ 1 (1)	❍ 2 (2)	❍ 3 (3)	❍ 4 (4)	❍ 5 (5)	❍ 6 (6)	❍ 7 (7)	❍ 8 (8)	❍ 9 (9)	❍ 10 (10)	❍ 11 (11)	❍ 12 (12)
Months (2)	❍ 1 (1)	❍ 2 (2)	❍ 3 (3)	❍ 4 (4)	❍ 5 (5)	❍ 6 (6)	❍ 7 (7)	❍ 8 (8)	❍ 9 (9)	❍ 10 (10)	❍ 11 (11)	

Answer If How many children, up to 16 years of age, usually travel ... 2 Is Selected Or How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q28 What gender is CHILD 2 (your second eldest child)?

❍ Male (1) ____________________

❍ Female (2) ____________________

Answer If How many children, up to 16 years of age, usually travel ... 2 Is Selected Or How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q29 What is the current height of CHILD 2 (your second eldest child)? Please indicate in centimetres (eg 105).

Answer If How many children, up to 16 years of age, usually travel ... 2 Is Selected Or How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q30 What is the weight of CHILD 2 (your second eldest child)? Please indicate in kilograms (eg 7.0 or 25.5)

Answer If How many children, up to 16 years of age, usually travel ... 2 Is Selected Or How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q31 CHILD 2 (your second eldest child) Please indicate the type of restraint/combination of restraints that Child 2 currently uses.

❑ Rearward facing child restraint (1)

❑ Rearward facing child restraint that converts to a forward facing restraint but is still rearward facing (2)

❑ Forward facing that has been converted from rearward facing (3)

❑ Forward facing that was not convertible from rearward facing (4)

❑ Booster seat (with a high back) (5)

❑ Booster cushion (without a back support) (6)

❑ Seat belt - Lap and Shoulder Sash (7)

❑ Seat belt - Lap only (8)

❑ Child Safety Harness (added H-harness) (9)

Answer If How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q32 How old is CHILD 3 (with Child 1 being the eldest)? Please indicate years and months (eg. 5 years and 7 months as 5 and 7).

Years (1)	❍ 1 (1)	❍ 2 (2)	❍ 3 (3)	❍ 4 (4)	❍ 5 (5)	❍ 6 (6)	❍ 7 (7)	❍ 8 (8)	❍ 9 (9)	❍ 10 (10)	❍ 11 (11)	❍ 12 (12)
Months (2)	❍ 1 (1)	❍ 2 (2)	❍ 3 (3)	❍ 4 (4)	❍ 5 (5)	❍ 6 (6)	❍ 7 (7)	❍ 8 (8)	❍ 9 (9)	❍ 10 (10)	❍ 11 (11)	

Answer If How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q33 What gender is CHILD 3 (with Child 1 being the eldest)?

- ❍ Male (1) ____________________
- ❍ Female (2) ____________________

Answer If How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q34 What is the current height of CHILD 3 (with Child 1 being the eldest)? Please indicate in centimetres (eg 105).

Answer If How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q35 What is the weight of CHILD 3 (with Child 1 being the eldest)? Please indicate in kilograms (eg 7.0 or 25.5)

Answer If How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q36 CHILD 3 (with Child 1 being the eldest)Please indicate the type of restraint/combination of restraints that Child 3 currently uses.

- ❑ Rearward facing child restraint (1)
- ❑ Rearward facing child restraint that converts to a forward facing restraint but is still rearward facing (2)
- ❑ Forward facing that has been converted from rearward facing (3)
- ❑ Forward facing that was not convertible from rearward facing (4)
- ❑ Booster seat (with a high back) (5)
- ❑ Booster cushion (without a back support) (6)
- ❑ Seat belt - Lap and Shoulder Sash (7)
- ❑ Seat belt - Lap only (8)
- ❑ Child Safety Harness (added H-harness) (9)

Answer If How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q37 How old is CHILD 4 (with Child 1 being the eldest)? Please indicate years and months (eg. 5 years and 7 months as 5 and 7).

Years (1)	❍ 1 (1)	❍ 2 (2)	❍ 3 (3)	❍ 4 (4)	❍ 5 (5)	❍ 6 (6)	❍ 7 (7)	❍ 8 (8)	❍ 9 (9)	❍ 10 (10)	❍ 11 (11)	❍ 12 (12)
Months (2)	❍ 1 (1)	❍ 2 (2)	❍ 3 (3)	❍ 4 (4)	❍ 5 (5)	❍ 6 (6)	❍ 7 (7)	❍ 8 (8)	❍ 9 (9)	❍ 10 (10)	❍ 11 (11)	

Answer If How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q38 What gender is CHILD 4 (with Child 1 being the eldest)?

- ❍ Male (1) ____________________
- ❍ Female (2) ____________________

Answer If How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q39 What is the current height of CHILD 4 (with Child 1 being the eldest)? Please indicate in centimetres (eg 105).

Answer If How many children, up to 16 years of age, usually travel ... More than 3 Is Selected
Q40 What is the weight of CHILD 4 (with Child 1 being the eldest)? Please indicate in kilograms (eg 7.0 or 25.5)

Answer If How many children, up to 16 years of age, usually travel ... More than 3 Is Selected
Q41 CHILD 4 (with Child 1 being the eldest)Please indicate the type of restraint/combination of restraints that Child 4 currently uses.
- ❑ Rearward facing child restraint (1)
- ❑ Rearward facing child restraint that converts to a forward facing restraint but is still rearward facing (2)
- ❑ Forward facing that has been converted from rearward facing (3)
- ❑ Forward facing that was not convertible from rearward facing (4)
- ❑ Booster seat (with a high back) (5)
- ❑ Booster cushion (without a back support) (6)
- ❑ Seat belt - Lap and Shoulder Sash (7)
- ❑ Seat belt - Lap only (8)
- ❑ Child Safety Harness (added H-harness) (9)

Answer If Please select what type of car this is 2 door sedan Is Selected Or Please select what type of car this is 2 door hatchback Is Selected Or Please select what type of car this is 4 door sedan Is Selected Or Please select what type of car this is 4 door hatchback Is Selected
Q42 Please allocate each CHILD to their usual or most common seating position. Please state A for passenger front seat, or B, C or D for rear seat positions) as indicated in the picture of the car below. (Your eldest child is Child 1, the second eldest is Child 2 etc).

Child 1 (1)
Child 2 (if applicable) (2)
Child 3 (if applicable (3)
Child 4 (if applicable) (4)

Answer If Please select what type of car this is. Station wagon Is Selected Or Please select what type of car this is 4WD/AWD with 2 rows of seats Is Selected
Q43 Please allocate each CHILD to their usual or most common seating position. Please state A for passenger front seat, or B, C or D for rear seat positions) as indicated in the picture of the station wagon/ 2 row 4WD below. (Your eldest child is Child 1, the second eldest is Child 2 etc).

Child 1 (1)
Child 2 (if applicable) (2)
Child 3 (if applicable (3)
Child 4 (if applicable) (4)

Answer If Please select what type of car this is . 4WD/AWD with 3 rows of seats Is Selected Or Please select what type of car this is . People mover/van Is Selected Or Please select what type of car this is . Other (Please specify) Is Selected
Q44 Please allocate each CHILD to their usual or most common seating position. Please state A for passenger front seat, or B, C or D for rear seat positions) as indicated in the picture of a Van/People Mover/4WD with 3 seating rows below. (Your eldest child is Child 1, the second eldest is Child 2 etc).

Child 1 (1)
Child 2 (if applicable) (2)
Child 3 (if applicable) (3)
Child 4 (if applicable) (4)
Child 5 (if applicable) (5)
Child 6 (if applicable) (6)

Q45 If you feel that the seating options indicated do not match your seating positions accurately, please describe your seating arrangements below.

Q46 Do you ever change any aspects of child restraint use (eg. different type or seat children differently etc.) due to the circumstances of the particular trip?

- ❍ Yes (1)
- ❍ No (2)

Answer If Do you ever change any aspects of child restraint use (eg... Yes Is Selected

Q47 Please let us know of any trip circumstances that you would change your child restraint use to your family's routine day-to-day travel.

	Do you change anything about your usual child restraint use under the following circumstances?		Please state which child/ren? (Child 1, Child 2, All etc)						If Yes, what do you change for this type of trip?	If Yes, why?
	Yes (1)	No (2)	Child 1 (1)	Child 2 (2)	Child 3 (3)	Child 4 (4)	SOME (5)	ALL (6)	Answer 1 (1)	Answer 1 (1)
Absence vs presence of a front seat adult passenger (1)	❍	❍	❍	❍	❍	❍	❍	❍		
Long trips vs short trips (2)	❍	❍	❍	❍	❍	❍	❍	❍		
Night trips vs day trips (3)	❍	❍	❍	❍	❍	❍	❍	❍		
Trips with additional children (4)	❍	❍	❍	❍	❍	❍	❍	❍		
Trips with additional items eg. luggage (5)	❍	❍	❍	❍	❍	❍	❍	❍		
Trips for a particular purpose (Please specify purpose). (6)	❍	❍	❍	❍	❍	❍	❍	❍		
Trips with your partner/other person driving the family vehicle (7)	❍	❍	❍	❍	❍	❍	❍	❍		
Trips in another family vehicle (8)	❍	❍	❍	❍	❍	❍	❍	❍		
Other. (Please specify) (9)	❍	❍	❍	❍	❍	❍	❍	❍		

Answer If How many children, up to 16 years of age, usually travel ... 1 Is Selected Or How many children, up to 16 years of age, usually travel ... 2 Is Selected Or How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q48 Does Child 1 (the eldest) use the following items or engage in the following activities during your REGULAR DAY-TO-DAY travel routine? Please indicate how often and any related seating behaviours that you have noticed.

	HOW OFTEN?						HOW DOES THIS AFFECT THE CHILD'S SEATING BEHAVIOUR?			
	Not applicable (1)	Never (2)	Rarely (3)	Sometimes (4)	Mostly (5)	Always (6)	Worsens (1)	No affect observed (2)	Improves (3)	Not applicable (4)
Food (1)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Drink (2)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Books (3)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Toys (4)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Electronic handheld devices (5)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Comforters (eg blankets, dummies etc) (6)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Inbuilt or after-market DVD viewing (7)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Window shades (8)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Driver interacting with this child (eg. talking, singing, passing food etc.) (9)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Adult passengers interacting with this child (10)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Other younger children interacting with this child (11)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Answer If How many children, up to 16 years of age, usually travel ... 1 Is Selected Or How many children, up to 16 years of age, usually travel ... 2 Is Selected Or How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q49 Does Child 1 (the eldest) use the following items or engage in the following activities when circumstances are SPECIAL/DIFFERENT to your regular day-to-day travel routine? Please indicate how often, when and why you do you do it and any related seating behaviours that you have noticed.

	HOW OFTEN?						PLEASE EXPLAIN	HOW DOES THIS AFFECT SEATING BEHAVIOUR?			
	Not applicable (1)	Never (2)	Rarely (3)	Sometimes (4)	Mostly (5)	Always (6)	WHEN and WHY? (1)	Worsens (1)	No affect observed (2)	Improves (3)	Not applicable (4)
Food (1)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Drink (2)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Books (3)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Toys (4)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Electronic handheld devices (5)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Comforters (eg blankets, dummies etc) (6)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Inbuilt or after-market DVD viewing (7)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Window shades (8)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Driver interacting with this child (eg. talking, singing, passing food etc.) (9)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Adult passengers interacting with this child (10)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Other younger children interacting with this child (11)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍

Answer If How many children, up to 16 years of age, usually travel ... 2 Is Selected Or How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q50 Does Child 2 (the second eldest) use the following items or engage in the following activities during your REGULAR DAY-TO-DAY travel routine? Please indicate how often and any related seating behaviours that you have noticed.

	HOW OFTEN?						HOW DOES THIS AFFECT THE CHILD'S SEATING BEHAVIOUR?			
	Not applicable (1)	Never (2)	Rarely (3)	Sometimes (4)	Mostly (5)	Always (6)	Worsens (1)	No affect observed (2)	Improves (3)	Not applicable (4)
Food (1)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Drink (2)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Books (3)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Toys (4)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Electronic handheld devices (5)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Comforters (eg blankets, dummies etc) (6)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Inbuilt or after-market DVD viewing (7)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Window shades (8)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Driver interacting with this child (eg. talking, singing, passing food etc.) (9)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Adult passengers interacting with this child (10)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Other younger children interacting with this child (11)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Answer If How many children, up to 16 years of age, usually travel ... 2 Is Selected Or How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q51 Does Child 2 (the second eldest) use the following items or engage in the following activities when circumstances are SPECIAL/DIFFERENT to your regular day-to-day travel routine? Please indicate how often, when and why do you do it and any related seating behaviours that you have noticed.

	HOW OFTEN?						PLEASE EXPLAIN	HOW DOES THIS AFFECT SEATING BEHAVIOUR?			
	Not applicable (1)	Never (2)	Rarely (3)	Sometimes (4)	Mostly (5)	Always (6)	WHEN and WHY? (1)	Worsens (1)	No affect observed (2)	Improves (3)	Not applicable (4)
Food (1)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Drink (2)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Books (3)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Toys (4)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Electronic handheld devices (5)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Comforters (eg blankets, dummies etc) (6)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Inbuilt or after-market DVD viewing (7)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Window shades (8)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Driver interacting with this child (eg. talking, singing, passing food etc.) (9)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Adult passengers interacting with this child (10)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Other younger children interacting with this child (11)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍

Answer If How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q52 Does Child 3 (the third eldest) use the following items or engage in the following activities during your REGULAR DAY-TO-DAY travel routine? Please indicate how often and any related seating behaviours that you have noticed.

	HOW OFTEN?						HOW DOES THIS AFFECT THE CHILD'S SEATING BEHAVIOUR?			
	Not applicable (1)	Never (2)	Rarely (3)	Sometimes (4)	Mostly (5)	Always (6)	Worsens (1)	No affect observed (2)	Improves (3)	Not applicable (4)
Food (1)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Drink (2)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Books (3)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Toys (4)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Electronic handheld devices (5)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Comforters (eg blankets, dummies etc) (6)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Inbuilt or after-market DVD viewing (7)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Window shades (8)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Driver interacting with this child (eg. talking, singing, passing food etc.) (9)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Adult passengers interacting with this child (10)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Other younger children interacting with this child (11)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Answer If How many children, up to 16 years of age, usually travel ... 3 Is Selected Or How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q53 Does Child 3 (the third eldest) use the following items or engage in the following activities when circumstances are SPECIAL/DIFFERENT to your regular day-to-day travel routine? Please indicate how often, when and why do you do it and any related seating behaviours that you have noticed.

	HOW OFTEN?						PLEASE EXPLAIN	HOW DOES THIS AFFECT SEATING BEHAVIOUR?			
	Not applicable (1)	Never (2)	Rarely (3)	Sometimes (4)	Mostly (5)	Always (6)	WHEN and WHY? (1)	Worsens (1)	No affect observed (2)	Improves (3)	Not applicable (4)
Food (1)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Drink (2)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Books (3)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Toys (4)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Electronic handheld devices (5)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Comforters (eg blankets, dummies etc) (6)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Inbuilt or after-market DVD viewing (7)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Window shades (8)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Driver interacting with this child (eg. talking, singing, passing food etc.) (9)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Adult passengers interacting with this child (10)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Other younger children interacting with this child (11)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍

Answer If How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q54 Does Child 4 (numbered from eldest to youngest) use the following items or engage in the following activities during your REGULAR DAY-TO-DAY travel routine? Please indicate how often and any related seating behaviours that you have noticed.

	HOW OFTEN?						HOW DOES THIS AFFECT THE CHILD'S SEATING BEHAVIOUR?			
	Not applicable (1)	Never (2)	Rarely (3)	Sometimes (4)	Mostly (5)	Always (6)	Worsens (1)	No affect observed (2)	Improves (3)	Not applicable (4)
Food (1)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Drink (2)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Books (3)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Toys (4)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Electronic handheld devices (5)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Comforters (eg blankets, dummies etc) (6)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Inbuilt or after-market DVD viewing (7)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Window shades (8)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Driver interacting with this child (eg. talking, singing, passing food etc.) (9)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Adult passengers interacting with this child (10)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Other younger children interacting with this child (11)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Answer If How many children, up to 16 years of age, usually travel ... More than 3 Is Selected

Q55 Does Child 4 (numbered from eldest to youngest) use the following items or engage in the following activities when circumstances are SPECIAL/DIFFERENT to your regular day-to-day travel routine? Please indicate how often, when and why do you do it and any related seating behaviours that you have noticed.

	HOW OFTEN?						PLEASE EXPLAIN	HOW DOES THIS AFFECT SEATING BEHAVIOUR?			
	Not applicable (1)	Never (2)	Rarely (3)	Sometimes (4)	Mostly (5)	Always (6)	WHEN and WHY? (1)	Worsens (1)	No affect observed (2)	Improves (3)	Not applicable (4)
Food (1)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Drink (2)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Books (3)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Toys (4)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Electronic handheld devices (5)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Comforters (eg blankets, dummies etc) (6)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Inbuilt or after-market DVD viewing (7)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Window shades (8)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Driver interacting with this child (eg. talking, singing, passing food etc.) (9)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Adult passengers interacting with this child (10)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍
Other younger children interacting with this child (11)	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍

Q56 Have you obtained child restraint safety information online in the past?

❍ Yes (1)

❍ No (2)

Answer If Have you obtained child restraint safety information onli... Yes Is Selected

Q57 Can you recall where you obtained this online information from?

- ❍ Yes. Please name organisation/site. (1) ____________________
- ❍ No. I can't recall.. (2)

Q58 To assist in understanding general child restraint knowledge in Australia, the following statements are a mixture of either TRUE or FALSE statements. Please answer according to your own personal knowledge.

	True or False	
	True (1)	False (2)
Children under six months of age must travel in a rearward facing child restraint. (1)	❍	❍
Children older than twelve months should only be moved to a forward facing child restraint when they have outgrown their rearward facing restraint. (2)	❍	❍
The Child Restraint Evaluation Program (CREP) provides restraint buyers independent and consistent information on the levels of protection from injury in a crash provided by child restraints available on the market. (3)	❍	❍
All children aged four to seven years of age should be moved into a booster seat that uses the lap/sash belt or a h-harness. (4)	❍	❍
Forward facing child restraints that comply with the most recent child restraint safety standards do not have a weight limit but instead use an approximate age and shoulder height markers to guide selection. (6)	❍	❍
A child aged four to seven years of age must travel in either a forward facing child restraint with an inbuilt harness and a top tether attachment to the vehicle or a booster seat with the use of the lap/sash seat belt. The type of restraint will depend on the child's size. (7)	❍	❍
An adult lap/sash seatbelt is designed for people with a minimum height of 145 cm. (9)	❍	❍
Although children over seven years of age can travel in the front passenger seat research shows that children under sixteen years of age are at 40% greater injury risk when travelling in the front seat. (10)	❍	❍
Once a child is over the age of six months a child can safely be turned around. (11)	❍	❍
An 'h-harness' add-on accessory provides additional protection to all booster seat use. (13)	❍	❍
Most children will have reached the minimum height requirement to safely use an adult lap-sash belt by the age of seven. (14)	❍	❍
A child can travel in the front passenger seat if s/he has an appropriate child restraint regardless of vehicle type and occupant numbers. (15)	❍	❍
The main purpose of seatbelt guides on the sides of booster seats is for added travel comfort. (19)	❍	❍

Harnesses need to be adjusted for each individual trip for best protection against injury. (20)	❍	❍

Q59 How concerned are you about the possibility of being in a car crash?
- ❍ Not at all concerned (1)
- ❍ Somewhat concerned (2)
- ❍ Quite concerned (3)
- ❍ Extremely concerned (4)

Q60 Do you think that children are more susceptible to injury in the event of a car crash than the average adult?
- ❍ Yes (1)
- ❍ No (2)

Q61 In the event of a crash, the level of safety provided to the driver and passengers is the responsibility of;

	Strongly Disagree (1)	Disagree (2)	Neither Agree nor Disagree (3)	Agree (4)	Strongly Agree (5)	Don't know (6)
Driver/Parent's driving abilities (1)	❍	❍	❍	❍	❍	❍
Driver/Parent's safety compliance (2)	❍	❍	❍	❍	❍	❍
Driver/Parent's choice in child restraint (3)	❍	❍	❍	❍	❍	❍
Driver/Parent's choice in car (4)	❍	❍	❍	❍	❍	❍
Other driver's behaviours (5)	❍	❍	❍	❍	❍	❍
Road maintenance (6)	❍	❍	❍	❍	❍	❍
Legislation and policy makers (7)	❍	❍	❍	❍	❍	❍
Fate (8)	❍	❍	❍	❍	❍	❍

Q62 Please rank the following options, from the most difference (1) to the least difference (6) that you think they make to your children's travel safety. Please select and move each option by clicking your mouse on each option and dragging it upwards or downwards into your own chosen order.

______ The vehicle used (1)
______ The type/brand of restraint used (2)
______ Restraint fitment into the car (3)
______ Children's rear seating location within the car (Please explain) (4)
______ Child/ren's movement around during travel (5)
______ Provide best driving performance (6)

Q63 Thinking about how your children travel in their current child restraint, booster seat or seat belt, have you observed them deliberately or otherwise removing their belts or harnesses while they have been travelling in their current restraint?
- ❍ Yes (1)
- ❍ No (2)

Answer If Thinking about how your children travel in their current ... Yes Is Selected

Q64 Which child/children removed their belt or harnesses?
- ❑ Child 1 (1)
- ❑ Child 2 (if applicable) (2)

- ❑ Child 3 (if applicable) (3)
- ❑ Child 4 (if applicable) (4)
- ❑ Additional Children of yours (Please specify age) (5) ____________________

Answer If Thinking about how your children travel in their current ... Yes Is Selected And Which child/children removed their belt or harnesses? Child 1 Is Selected

Q65 What response do you usually give Child 1 when s/he removes their belt or harness?

	Order of Response		Click to write Column 1	Click to write Column 4	Click to write Column 3
	I don't respond this way (1)	As a first or only type of response (2)	As a second response (1)	As a last response (1)	Don't remember (1)
Verbally instruct them to adjust the belt/harness. (1)	❍	❍	❍	❍	❑
Stop the car over and adjust the belt/harness myself. (2)	❍	❍	❍	❍	❑
Nothing. I concentrate on driving . (3)	❍	❍	❍	❍	❑
Other (Please specify) (4)	❍	❍	❍	❍	❑

Answer If Thinking about how your children travel in their current ... Yes Is Selected And Which child/children removed their belt or harnesses? Child 2 (if applicable) Is Selected

Q66 What response do you usually give Child 2 when s/he removes their belt or harness?

	Order of Response		Click to write Column 1	Click to write Column 4	Click to write Column 4
	I don't respond this way (1)	As a first or only type of response (2)	As a second response (1)	As a last response (1)	Don't remember (1)
Verbally instruct them to adjust the belt/harness. (1)	❍	❍	❍	❍	❍
Stop the car over and adjust the belt/harness myself. (2)	❍	❍	❍	❍	❍
Nothing. I concentrate on driving . (3)	❍	❍	❍	❍	❍
Other (Please specify) (4)	❍	❍	❍	❍	❍

Answer If Thinking about how your children travel in their current ... Yes Is Selected And Which child/children removed their belt or harnesses? Child 3 (if applicable) Is Selected

Q67 What response do you usually give Child 3 when s/he removes their belt or harness?

	Order of Response		Click to write Column 1	Click to write Column 4	Click to write Column 4
	I don't respond this way (1)	As a first or only type of response (2)	As a second response (1)	As a last response (1)	Don't remember (1)
Verbally instruct them to adjust the belt/harness. (1)	❍	❍	❍	❍	❍
Stop the car over and adjust the belt/harness myself. (2)	❍	❍	❍	❍	❍
Nothing. I concentrate on driving. (3)	❍	❍	❍	❍	❍
Other (Please specify) (4)	❍	❍	❍	❍	❍

Answer If Thinking about how your children travel in their current ... Yes Is Selected And Which child/children removed their belt or harnesses? Child 4 (if applicable) Is Selected

Q68 What response do you usually give Child 4 when s/he removes their belt or harness?

	Order of Response		Click to write Column 1	Click to write Column 4	Click to write Column 4
	I don't respond this way (1)	As a first or only type of response (2)	As a second response (1)	As a last response (1)	Don't remember (1)
Verbally instruct them to adjust the belt/harness. (1)	❍	❍	❍	❍	❍
Stop the car over and adjust the belt/harness myself. (2)	❍	❍	❍	❍	❍
Nothing. I concentrate on driving . (3)	❍	❍	❍	❍	❍
Other (Please specify) (4)	❍	❍	❍	❍	❍

Answer If Thinking about how your children travel in their current ... Yes Is Selected And Which child/children removed their belt or harnesses? Additional Children of yours (Please specify age) Is Selected

Q69 What response do you usually give your additional children (other than Child 1 - Child 4) when they remove their belt or harness?

	Order of Response		Click to write Column 1	Click to write Column 4	Click to write Column 4
	I don't respond this way (1)	As a first or only type of response (2)	As a second response (1)	As a last response (1)	Don't remember (1)
Verbally instruct them to adjust the belt/harness. (1)	❍	❍	❍	❍	❍
Stop the car over and adjust the belt/harness myself. (2)	❍	❍	❍	❍	❍
Nothing. I concentrate on driving . (3)	❍	❍	❍	❍	❍
Other (Please specify) (4)	❍	❍	❍	❍	❍

Q70 Please rank the following statements from most important (1) to least important ((6) in their level of influence on your choice of current child restraints or booster seats. Please select and move each option by clicking your mouse on each option and dragging it upwards or downwards into your own chosen order.

______ Fines/legal deterrances (1)
______ Cultural norms (2)
______ Community/family views (3)
______ To minimize injury risk (4)
______ Other features not related to safety (eg price, colour, size) (6)
______ Child/ren's choice/preference (5)

To help us understand common trends in travel safety behaviour, the next set of questions will ask you about your general life perspectives.

Q71 Please indicate your agreement/disagreement with the following statements

	Strongly Disagree (1)	Disagree (2)	Neither Agree nor Disagree (3)	Agree (4)	Strongly Agree (5)
Being at the right place, at the right time is essential for getting what you want in life. (1)	❍	❍	❍	❍	❍
You cannot fool your destiny. (2)	❍	❍	❍	❍	❍
People are lonely because they are not given the chance to meet new people. (3)	❍	❍	❍	❍	❍
If you set realistic goals, you can succeed no matter what. (4)	❍	❍	❍	❍	❍
Chance has a lot to do with someone being successful. (5)	❍	❍	❍	❍	❍

Whatever plans you make, there is something that always crosses them. (6)	❍	❍	❍	❍	❍
Heredity determines most of a person's personality. (7)	❍	❍	❍	❍	❍
Intelligence is a given and cannot be trained or become stunted. (8)	❍	❍	❍	❍	❍
If I successfully accomplish my task, it's because it was an easy one. (9)	❍	❍	❍	❍	❍
School success is mostly a result of one's socio-economic background. (10)	❍	❍	❍	❍	❍

Q72 Please indicate your agreement/disagreement with the following statements relating to health.

	Strongly Disagree (1)	Disagree (2)	Neither Agree nor Disagree (3)	Agree (4)	Strongly Agree (5)
If I get injured, it is my own behaviour which determines how severe the injury is. (1)	❍	❍	❍	❍	❍
No matter what I do, if I am going on to get injured, I will get injured. (2)	❍	❍	❍	❍	❍
Having regular contact with my physician is the best way to avoid illness. (3)	❍	❍	❍	❍	❍
Most things that affect my health happen to me by accident. (4)	❍	❍	❍	❍	❍
Whenever I don't feel well, I should consult a medically trained professional. (5)	❍	❍	❍	❍	❍
I am in control of my health. (6)	❍	❍	❍	❍	❍
Other people play a big part in whether I stay healthy or get injured. (7)	❍	❍	❍	❍	❍
If I get injured I am to blame. (8)	❍	❍	❍	❍	❍
Luck plays a big part in determining how badly I get injured if I do get injured. (9)	❍	❍	❍	❍	❍
The policies developed from safety professionals control my safety. (10)	❍	❍	❍	❍	❍
My good health is largely a matter of good fortune. (11)	❍	❍	❍	❍	❍
The main thing which affects my health is what I myself do. (12)	❍	❍	❍	❍	❍
If I take care of myself, I can avoid injury. (13)	❍	❍	❍	❍	❍
When I recover from an illness, it's usually because other people (for example doctors, nurses, family, friends) have been taking good care of me. (14)	❍	❍	❍	❍	❍

No matter what I do, I'm likely to get sick. (15)	❍	❍	❍	❍	❍
If I get injured, it's a matter of fate. (16)	❍	❍	❍	❍	❍
If I take the right actions, I can stay healthy. (17)	❍	❍	❍	❍	❍
Regarding my safety, I can only do what policies advise me to do. (18)	❍	❍	❍	❍	❍

Q73 Lastly, please indicate your agreement/disagreement with the following driving related statements.

	Strongly Disagree (1)	Disagree (2)	Neither Agree nor Disagree (3)	Agree (4)	Strongly Agree (5)
Driving with no car crashes is mainly a matter of luck. (1)	❍	❍	❍	❍	❍
The careful driver can prevent any car crash. (2)	❍	❍	❍	❍	❍
Car crashes happen mainly because of different unpredictable events. (3)	❍	❍	❍	❍	❍
If you are going to be involved in a car crash, it is going to happen anyhow, no matter what you do. (4)	❍	❍	❍	❍	❍
Car crashes happen because the driver does not make enough effort to detect all sources of danger while driving. (5)	❍	❍	❍	❍	❍
It is possible to prevent car crashes even in the most difficult conditions such as narrow roads, darkness, rain and so on. (6)	❍	❍	❍	❍	❍
It depends on me if I have a car crash. (7)	❍	❍	❍	❍	❍
My own behavior in traffic does not much influence my likelihood of having a car crash. (8)	❍	❍	❍	❍	❍

Q74 Would you like the opportunity to be involved in this child safety research further? This information will not be shared with any third parties outside of MUARC, all participation will be voluntary and contact details can be removed at your request at any time. Thank you.

- ❍ Yes please (1)
- ❍ No thank you (2)

Answer If Would you like the opportunity to be involved in this chi... Yes please Is Selected

Q75 Please provide your contact details so the Monash University Accident Research Centre (MUARC) can invite you to participate.

First Name (1)
Surname (2)
Street Address (3)
Suburb (4)
Postcode (5)
Home telephone contact (6)
Work telephone contact (7)
Mobile (8)
Email (9)

Answer If Would you like the opportunity to be involved in this chi... Yes please Is Selected

Q76 How would you prefer to be contacted?

- ❑ Home telephone (1)
- ❑ Mobile (2)
- ❑ Email (3)
- ❑ Mail/Post (4)

Monash Accident Research Centre would like to thank you for your valuable participation!

Appendix G - NDS Recruitment Posters

MONASH University
Accident Research Centre

A centre within the Monash University Injury Research Institute

Children safety in cars

The Monash University Accident Research Centre is leading an international research project to explore children's behaviour while travelling in child restraints or booster seats and the way this affects their safety.

Background and purpose of the research

Child restraints, or child car seats, are designed to provide specialised protection for child passengers in the event of a crash. However, their effectiveness depends on correct fitting of the child restraint in the vehicle, correct harnessing of the child in the child restraint, and use of an appropriate restraint for the child's size. Research indicates that inappropriate use and misuse of child restraints is widespread.

In a world-first research project, Monash University will conduct a national online survey with parents and a large-scale observational study using instrumented vehicles to study the behaviour of children in cars and how this might affect the protection offered by their child restraint. Secondly, the study will examine children's interactions with parents/drivers during car trips, and how this may influence drivers' attention to the roadway and driving performance.

How can you participate?

1. **Online survey study.** We invite all Australian parents who have at least one child between 1 and 8 years of age, who usually travel in a forward-facing child restraint or booster seat to become involved in this exciting research by completing the online survey.

   What does participation in the survey involve?

   The online survey collects information on general demographics (such as age, gender, number of children), driving behaviour and parental beliefs, child restraint use, safety knowledge/awareness and child restraint travel practices. The survey takes approximately 25 minutes to complete.

   Please access the online survey at http://goo.gl/sBq1g.

2. **Observational Study**. Eligible participants who complete the online survey, will be invited to participate in an observational driving study. This will involve the use of a Monash University study vehicle to undertake everyday trips with children for approximately two weeks. Vehicles are fitted with concealed cameras and recording equipment to monitor children's behaviour in their child restraints, driver behaviour and traffic conditions.

   Compensation
   Full tank of petrol and an $80 petrol voucher for driving the study vehicle.
   Free session with a professional child restraint fitter for your personal vehicle

   Are you eligible to drive a project vehicle?
   To be a participant in the observational driving study you must be over 25 years of age, have at least one child in a forward-facing child restraint or booster seat, hold a full and valid driver's licence and live within approximately 50km from Monash, Clayton in Victoria.

This study has approval from the Monash University Human Research Ethics Committee – Project Number CF12/4032 – 201200195.

Please take our details from below to participate or to contact the researchers at Monash University, Monash Accident Research Centre.

Children in Cars Study
Survey link: http://goo.gl/sBq1g
Ph: 9902 0452 or 9905 1808

Children in Cars Study
Survey link: http://goo.gl/sBq1g
Ph: 9902 0452 or 9905 1808

Children in Cars Study
Survey link: http://goo.gl/sBq1g
Ph: 9902 0452 or 9905 1808

Children in Cars Study
Survey link: http://goo.gl/sBq1g
Ph: 9902 0452 or 9905 1808

Children in Cars Study
Survey link: http://goo.gl/sBq1g
Ph: 9902 0452 or 9905 1808

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Survey link: http://goo.gl/sBq1g
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Survey link: http://goo.gl/sBq1g
Ph: 9902 0452 or 9905 1808

Children in Cars Study
Survey link: http://goo.gl/sBq1g
Ph: 9902 0452 or 9905 1808

Children in Cars Study
Survey link: http://goo.gl/sBq1g
Ph: 9902 0452 or 9905 1808

Children in Cars Study
Survey link: http://goo.gl/sBq1g
Ph: 9902 0452 or 9905 1808

Appendix H - Royal Automobile Club of Victoria (RACV) invitation

Children safety in cars

The Monash University Accident Research Centre is leading an international research project to explore children's behaviour while travelling in child restraints or booster seats and the way this affects their safety.

Background and purpose of the research

Child restraints, also commonly referred to as child car seats, are systems that are designed and proven to provide specialised protection for child passengers in the event of a crash. However, their effectiveness is dependent on the correct installation of the child restraint in the vehicle, the correct harnessing of the child in the child seat, and the use of an appropriate restraint for the child's size. Research indicates that inappropriate use and misuse of child restraints is widespread.

In a world-first research project, Monash University will conduct a national online survey with parents and a large-scale observational study using instrumented vehicles to study the behaviour of children in cars and how this might affect the protection offered by their child restraint system. Secondly, the study will examine children's interactions with parents/drivers during car trips, and how this may influence drivers' attention to the roadway and driving performance.

How can you participate?

1. **Online survey study.** We encourage all Australian parents that have at least one child between 1 and 8 years of age, who usually travel in a forward-facing child restraint or booster seat to become involved in this exciting research by completing the survey.

   What does participation in the survey involve?

   The *Driver Demographic and Child Restraint Online Survey* collects information on general demographics (such as age, gender, number of children), driving behaviour and parental beliefs, as well as valuable information on the influences on child restraint use, safety knowledge/awareness and child restraint travel practices. The survey takes approximately 25 minutes to complete.

   Please access the survey at http://goo.gl/sBq1g.

2. **Observational Study**. Eligible participants who complete the online survey, will be invited to participate in a driving study. This will involve the use of a Monash University study vehicle to undertake everyday trips with children for approximately two weeks. Vehicles are fitted with concealed cameras and recording equipment to monitor children's behaviour in their child restraints, driver behaviour and traffic conditions. Participants will be provided with a full tank of petrol and a petrol voucher. *Are you eligible to drive a project vehicle?*

   To be a participant in the driving study you must be over 25 years of age, have at least one child in a forward facing child restraint or booster seat, hold a full and valid driver's licence and live approximately 50km from Monash, Clayton in Victoria.

   If you would like any further information in relation to either of these two studies, please contact the researchers at Monash University, Monash Accident Research Centre on 9902 0452 or 9905 1808.

Appendix I - Ethics Approval - Monash University Research Ethics Committee (MUHREC)

MONASH University

Monash University Human Research Ethics Committee (MUHREC)
Research Office

Human Ethics Certificate of Approval

Date:	**25 March 2013**
Project Number:	**CF12/4032 - 2012001945**
Project Title:	**Children in cars: a field study of child passengers and drivers in vehicles**
Chief Investigator:	**Assoc Prof Judith Charlton**
Approved:	**From 25 March 2013 to 25 March 2018**

Terms of approval

1. The Chief investigator is responsible for ensuring that permission letters are obtained, if relevant, and a copy forwarded to MUHREC before any data collection can occur at the specified organisation. **Failure to provide permission letters to MUHREC before data collection commences is in breach of the National Statement on Ethical Conduct in Human Research and the Australian Code for the Responsible Conduct of Research.**
2. Approval is only valid whilst you hold a position at Monash University.
3. It is the responsibility of the Chief Investigator to ensure that all investigators are aware of the terms of approval and to ensure the project is conducted as approved by MUHREC.
4. You should notify MUHREC immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.
5. The Explanatory Statement must be on Monash University letterhead and the Monash University complaints clause must contain your project number.
6. **Amendments to the approved project (including changes in personnel):** Requires the submission of a Request for Amendment form to MUHREC and must not begin without written approval from MUHREC. Substantial variations may require a new application.
7. **Future correspondence:** Please quote the project number and project title above in any further correspondence.
8. **Annual reports:** Continued approval of this project is dependent on the submission of an Annual Report. This is determined by the date of your letter of approval.
9. **Final report:** A Final Report should be provided at the conclusion of the project. MUHREC should be notified if the project is discontinued before the expected date of completion.
10. **Monitoring:** Projects may be subject to an audit or any other form of monitoring by MUHREC at any time.
11. **Retention and storage of data:** The Chief Investigator is responsible for the storage and retention of original data pertaining to a project for a minimum period of five years.

Ben Canny

Professor Ben Canny
Chair, MUHREC

cc: Dr Sjaan Koppel; Dr Christina Rudin-Brown; Ms Suzanne Cross; Dr Kristy Arbogast; Dr David Eby; Ms Katarina Bohman; Prof Mats Svensson; Prof Lotta Jakobsson

Postal – Monash University, Vic 3800, Australia
Building 3E, Room 111, Clayton Campus, Wellington Road, Clayton
Telephone +61 3 9905 5490 Facsimile +61 3 9905 3831
Email muhrec@monash.edu www.monash.edu/research/ethics/human/index/html
ABN 12 377 614 012 CRICOS Provider #00008C

Appendix J – T-test analyses on CRS-related knowledge groups

To provide further understanding outside of the scope of this PhD research program parents' CRS-related knowledge score groups (high/low) were also explored for relationships with; i) parents' attribution of responsibility to child occupant safety factors, and; ii) LOC scores from scales not specific to child occupant safety. These analyses were conducted to see whether parents' attribution of responsibility to internal child occupant safety factors or the internality dimensions on the LOC scales can help predict high CRS-related knowledge. Independent sample t-tests were conducted (see Tables 1 and 2).

Table 1. Mean differences between parents' CRS-related knowledge group (higher/lower) and LOC scales

LOC Scale	**CRS-related knowledge scores**				**Significance***
	Low Group		High Group		
	M	SD	M	SD	
G LOC	23.68	4.95	23.47	4.56	t (336) = 0.40, p = 0.69
MHLOC					
Internal	20.47	3.50	20.31	3.19	t (334) = 0.45, p = 0.65
Powerful others	13.44	3.44	13.78	3.06	t (335) = -0.94, p = 0.69
Chance	13.45	3.45	13.85	3.22	t (334) = -1.08, p = 0.28
Driver Internality Externality					
Internality	41.35	8.95	38.634	8.62	t (335) = 0.52, p = 0.60
Externality	37.68	7.52	0.84	7.06	t (335) = -1.19, p = 0.24

*Statistically significant at *p*<0.05, no significant findings revealed.

Table 2. Test for mean differences between parents' CRS-related knowledge score group (low/high) and attribution of responsibility to child occupant safety

Attribution of responsibility	**CRS-related knowledge scores**				**Significance**
	Low group		High group		
	M	SD	M	SD	
INTERNAL					
1 Driver/parent's driving abilities‡	82.21	20.33	83.38	17.35	t (343) = -0.57, p = 0.57
2 Driver/parent's safety compliance‡	83.63	17.27	84.18	18.71	t (343) = -0.28, p = 0.78
3 Driver/parent's choice in CRS‡‡	80.11	19.34	82.86	19.72	t (342) = -1.27, p = 0.20
4 Driver/parent's choice of motor vehicle‡	69.15	22.87	68.12	23.61	t (343) = 0.40, p = 0.69
EXTERNAL					
5 Other driver's behaviours‡‡‡	78.90	19.36	75.22	21.80	t (341) = 1.60, p = 0.11
6 Road Maintenance±	59.34	22.49	60.47	25.65	t (344) = -0.42, p = 0.68
7 Legislation and policy makers±	54.85	25.37	54.06	27.63	t (344) = 0.27, p = 0.78
8 Fate±	28.76	30.30	26.52	26.85	t (344) = 0.72, p = 0.47

*Statistically significant at *p*<0.05, no significant findings revealed

‡Driver/parents's driving abilities, Driver/Parent's safety compliance and Driver/parent's choice in motor vehicle, n=345

‡‡Driver/parent's choice in CRS n = 344

‡‡‡Other driver's behaviours, n = 343

±Road maintenance, Legislation and policy makers and fate, n= 346

Appendix K –- Participants' Explanatory Statement and Consent Form

MONASH University

Participant ID: _ _ _ _ **Researcher:** _._ **Date:** __/__/__

Explanatory Statement - Children in cars: a field study of children's behaviour in child restraints

(Drivers/Parents)

The Monash University Accident Research Centre (MUARC) is undertaking the above named research project in collaboration with Holden to explore children's behaviour while travelling in child restraints or booster seats. The Chief Investigator is Associate Professor Judith Charlton, Associate Director at MUARC.

Your consent

This Explanatory Statement and Consent Form is 7 pages long. Please make sure you have all the pages. Please read this Explanatory Statement carefully. Feel free to ask questions about any information in the document.

Once you understand what the project is about and if you agree to take part in it, you will be asked to sign the Consent Form. By signing the Consent Form, you indicate that you understand the information and that you give your consent to participate in the research project. You will be given a copy of the Explanatory Statement and Consent Form to keep as a record.

Background and purpose of the research

Child restraint systems (CRS) for vehicles are designed to provide specialised protection for child occupants of vehicles in the event of a crash. Existing evidence suggests that CRS offer a good level of crash protection during an impact. However, the effectiveness of CRS is dependent on correct installation in the vehicle, correct harnessing of the child in the CRS, and use of the appropriate restraint for the child's size. Research indicates that inappropriate use and misuse of CRS is widespread. Further, there is limited research into the behaviour of children while travelling in CRS, and how this behaviour may distract the driver or influence driver behaviour.

The aims of this project are to examine how children are restrained and seated in CRS, to gain an understanding of children's behaviour while travelling in cars, and to identify if their behaviour influences driver behaviour.

The project will incorporate two additional Doctorate of Philosophy (PhD) degrees that will explore behaviours that contribute to children becoming out-of-position when travelling in cars and contributors to driver distraction.

Benefits of the project

The results of this project will provide valuable insight into child behaviour while travelling in a vehicle and how to further improve CRS and vehicle safety. It will provide you with the opportunity to drive a Holden Commodore vehicle for approximately two weeks. You will also be provided with a petrol cheque up to the value of $80.

What does participation involve?

To take part in this project you must:

- hold a valid and full Victorian car driver's licence;
- be aged over 25 years;
- have at least one child aged between 1 and 8 years, who usually travels in a CRS or booster seat in the rear seat of your vehicle;
- have not more than three regular child passengers who travel in the rear seat of your vehicle;
- have normal hearing and vision (glasses and contact lenses may be worn);
- not have any known medical conditions that may affect your driving (e.g. epilepsy, dementia, or other serious neurological disorders); and
- not have any known problems with substance abuse (alcohol, drugs etc).

If you agree to take part in the project, you will be asked to drive a Monash University study vehicle for two weeks. You will be asked to drive this vehicle in the same manner as you would drive your own vehicle. While you drive the vehicle, video cameras that are installed in the vehicle will record you and your passengers. However, only consenting participants and passengers will be videoed and interviewed. Passengers and children over the age of 15 years are free to refuse their consent. In the event that a passenger or child over the age of 15 refuses consent and travels in the vehicle, the system MUST be switched OFF by the participant.

The cameras are very small and will be concealed in the vehicle so they are not obvious to the vehicle occupants. Video cameras will also record the road and traffic environment while driving. All cameras will start recording automatically and will be initiated when the driver activates the vehicle's central locking system. The video recordings (including sound recording) will be analysed to provide information on the:

- child/children's seating arrangements in the vehicle;
- child/children's body position when seated in a CRS or booster seat during car trips;
- child/children's use of seat belts and CRS or booster seats during car trips;
- child/children's activity and communication patterns during car trips;
- interactions between driver/parent and child occupants during car trips, and
- the road and traffic conditions while driving (using cameras positioned to record the road ahead and behind your vehicle).
- Driver's willingness to engage in potentially distracting activities

A vehicle data acquisition unit will also collect information directly from the vehicle and include recording speed, acceleration, braking, steering, lane deviation and GPS information.

Prior to driving the vehicle, you will be involved in a Participant Briefing and Training session at the time of vehicle handover and invited to complete a Driver Demographic and Child Restraint Online Survey. This will be held at a time and location that is convenient to both you and the MUARC researcher. This session will last for 30 minutes to 1 hour. At this session you will be further briefed on the purpose of the study and on what your participation will involve. You will be asked to complete a brief questionnaire so that we can gather some background information on you (e.g. age, number of children, driving experience). Prior to the commencement of the project, we will show you the video recording system and data acquisition unit, and explain how the video recording system can be switched off.

To participate in this project, you, your partner, all your immediate family members and any other passengers who regularly travel in your vehicle MUST agree to participate. Any passenger who is over the age of 15 years must sign a separate consent form. Any regular child passenger under the age of 15 years must have the consent of their parents to participate in the research. You also MUST agree to switch off the video camera system when a passenger enters the project vehicle who has not agreed to participate in the research.

If you elect to participate in the study, it will be on the understanding that no one but you or your partner drives the vehicle provided.

It is also important to note that, under some circumstances, your participation in this project may be terminated. However, this will only happen if:

- your video data show that you have been repeatedly driving the project vehicle in a sustained dangerous manner;
- you do not take reasonable steps to properly maintain and secure the project vehicle;
- you are involved in a crash;
- you wilfully damage the project vehicle; or
- you purposely do not adhere to the study requirements (e.g. you allow someone else to drive the project vehicle, you do not switch off the video cameras when a non-participant is a passenger in your vehicle).

In the event of wilful damage occurring to the vehicle the petrol reimbursement cheque of $80 will be withheld and MUARC reserves the right to pursue legal proceedings.

To help the study to run as smoothly as possible, we would like to contact you one week after you are provided with the project vehicle so that we can monitor how the video recording system is performing, download data, and address any queries that you may have. In addition, there are two numbers which are available for you to use should you need assistance or require information:

- For mechanical problems or breakdown of the vehicle please contact Custom Fleet on 1300 139 555.

To provide informal feedback or to discuss any issues regarding the study procedures, please contact the MUARC Researchers; Suzanne Cross on 9902 0452 or Jonny Kuo on 9905 1808.

- On completion of the observation period, you will be invited to complete the Driver Reported In-Vehicle Occupant Behaviour and Knowledge Online Survey so that we can gather information on your driving behaviour and your child/ren's behaviour when travelling in a forward-facing CRS, booster seat and/or seat belt. The survey also includes questions on what influences CRS use, general parental awareness of correct CRS use and recent road rule changes that are specific to CRS and booster seats.

On completion of the observation period you will also be asked if you consent to any of your children aged between 5-12 years participating in the Child Car Passenger Interview. This is a short 5 minute interview on their likes and dislikes in relation to their CRS and/or seatbelt. If consent is granted, you will be required to be present for the duration of the interview.

Confidentiality

Subject to the exclusions stated below, we will treat with the utmost confidentiality any information we collect directly from you, and the video recordings we will collect. No findings that could identify any individual participant will be published. No names will be put into any written records of the study, with all names replaced by codes. No visual images will be used unless they are completely de-identified by obscuring or blurring all participants' faces and other potentially unique identifiers. All other data from this study will be kept at MUARC. Only members of the MUARC project team and co-investigators of this project will have access to the surveillance data. Electronic copies of the videos will be stored in locked cabinets and, under university regulations, will be stored for a minimum of five years. Online data from surveys will be collected by an external information processing company, Qualtrics Inc. but will in no instance be shared externally. It is possible that in this time we may choose to use the data collected from you for future research purposes. Should this data be considered appropriate for inclusion in future research, a member of the MUARC research team will contact you to explain the purpose of the new study and request your approval to access and use project information and identifiable video recordings.

This will be research conducted by MUARC, and only members of the MUARC project team and this project's co-investigators will have access to this data if this were to occur. International co-investigators have been informed that strict Victorian Privacy Principles are in place with respect to adhering to the privacy of all individual's that participate in this project. In the event of a crash, any video data collected from your vehicle may be subpoenaed and if so must be released by MUARC. It is recognised that, from time to time, you may inadvertently exceed the speed limit, follow cars in front too closely or forget to fasten your seatbelt. However, if it is found that you have driven in a sustained and repeatedly dangerous manner, or if we record any other illegal activity we reserve the right to bring the matter to the attention of our legal advisors or the Victoria Police.

Voluntary nature of participation

Participation in this study is entirely voluntary, and you are under no obligation to consent to participate. In addition, if you or a member of your family would like to switch the video recording system off at any stage during the course of the project you are free to do so. Alternatively, if at a later date you wish to delete footage of a particular journey, you will be able to view the data and ask us to delete the footage. Further, should you agree to participate, you are free to withdraw at any time, and for any reason. You will not be penalised in any manner should you chose to withdraw. In the event of withdrawal from the study, data collected prior to this withdrawal will continue to be used and form part of the project, unless you ask us not to do so. Should you wish to withdraw your consent, you can do so by contacting the MUARC Researchers; Suzanne Cross on 9902 0452 or Jonny Kuo on 9905 1808.

Study Results

The study results will be published in a final report that will be available on the Monash University Accident Research Centre's website (http://www.monash.edu.au/muarc/).

Ethical Guidelines

This project will be carried out according to the *National Statement on Ethical Conduct in Research Involving Humans* (June 1999) produced by the National Health and Medical Research Council of Australia. This statement has been developed to protect the interests of people who agree to participate in human research studies.

The ethical aspects of this research project have been approved by the Monash University Human Research Ethics Committee.

> If you have a complaint concerning the manner in which this Children in Cars research CF12/4032 - 201200195 is being conducted, please contact:
>
> Human Ethics Officer
> Monash University Human Research Ethics Committee (MUHREC)
> Building 3e Room 111
> Research Office
> Monash University VIC 3800
> Tel: +61 3 9905 2052 Fax: +61 3 9905 1420
> Email: muhrec@monash.edu

If you would like any further information or have any questions about any aspect of this study, please contact Associate Professor Judith Charlton on 9905 1903.

Yours Sincerely,

J. L. Charlton

Associate Professor Judith Charlton
Associate Director,
Monash University Accident Research Centre

Participant ID: _ _ _._ Researcher: _._ Date: __/__/__

Consent Form: Children in cars: a field study of children's behaviour in child restraints

(Drivers/Parents)

I agree to take part in the above named Monash University research project. I have had the project explained to me, and I have read the Explanatory Statement, which I will keep for my records. I understand that agreeing to participate means that I am willing to (please tick all the boxes):

- ❑ drive a study vehicle that is equipped with a video recording system and data acquisition unit that will record myself, my child/children, my passengers and the road and traffic environment and the vehicle while driving for approximately two weeks;
- ❑ understand that video recording can only take place where consent has been provided by the passengers and that the passengers (including children over 15 years of age) have the right to refuse consent. If consent of all passengers is not provided, the system must be switched off;
- ❑ attend a study vehicle handover session;
- ❑ complete a Driver Demographic and Child Restraint Online Survey with the external information processing provider Qualtrics Inc, where my information will remain confidential;
- ❑ complete a Driver Reported In-Vehicle Occupant Behaviour and Knowledge Online Survey with the external information processing provider Qualtrics Inc. where my information will remain confidential;
- ❑ have a researcher request my further consent for a brief Child Car Passenger Interview with my own child/ren (between 5 to 12 years of age only) to explore their child restraint and/or seatbelt likes and dislikes. This will be conducted at the time of study vehicle collection with myself or my participating partner present. Verbal consent from my child will also be required;
- ❑ have the video recording data and vehicle data downloaded onto a computer located at Monash University;
- ❑ understand and accept that, where necessary, for the purpose of the research project, personal information (such as video recordings) may be shared securely and exclusively with international and other Australian co-investigators that are signatories of this funded project;
- ❑ understand that, in the unlikely event that I am involved in an accident when I am driving responsibly, that the vehicle is fully covered under MUARC's comprehensive vehicle insurance policy, with no excess fee required from myself.
- ❑ accept that, in the unlikely event that I crash the study vehicle, the video recordings from the vehicle may be subpoenaed for use as evidence in a court of law;
- ❑ accept that, in the event that I drive in a sustained dangerous manner, or participate in any other illegal activity which is demonstrated from my video data, Monash University reserves the right to bring the matter to the attention of its legal advisors or Victoria Police;
- ❑ accept that my participation in the study will be terminated if: I am found to drive in a sustained dangerous manner; I fail to properly maintain and secure the study vehicle; I am

involved in a crash while driving the study vehicle; I willfully damage the study vehicle; I do not follow the study requirements, or for any other reason that Monash University reasonably considers that I should no longer participate in the study;

- ❑ ensure that I return the study vehicle in the same condition at it was given to me, and that, in the event of willful damage to the vehicle, the reimbursement cheque of $80 will be withheld by MUARC and, in severe circumstances, legal proceedings for damages may be pursued;
- ❑ pay any traffic infringement notice that is issued while I am driving the study vehicle;
- ❑ ensure no one other than myself or my partner is to drive the study vehicle;
- ❑ ensure that if any passengers, or children over 15 years of age who have not consented to participate in the project enter the study vehicle the video system MUST be switched off;
- ❑ be contacted in the future to ascertain my interest in participating in any future road safety research with the full right to provide or refuse consent.

I understand that, subject to the above mentioned conditions, any information I provide is confidential, and that no information that could lead to identification of any individual will be disclosed in any reports on the project, or to any other party.

I also understand that my participation is voluntary, that I can choose not to participate in part or all of the project without being penalised or disadvantaged in any way. I understand that I can switch the video recording system off at any stage and for any length of time during the course of the project.

I understand that both my partner and I must agree to participate in the project (if applicable). I also understand that my agreement to participate in the project is contingent upon myself and my partner agreeing that our child/children will take part in the project, as well as any regular passengers.

I agree that my child/children, listed below, for whom I am parent/guardian, may take part in the above named Monash University research project. I understand that if any of my children are aged over 15 years they must also agree to participate and sign a separate consent form. I understand that agreeing to take part in the project means that I am willing to allow all of my children (listed below) to be videorecorded while travelling in the project car.

Full name of child 1: ____
Age of child 1: _________

Full name of child 2 ____
Age of child 2: _________

Full name of child 3 ____
Age of child 3: _________

Full name of child 4 ____
Age of child 4: _________

Participant's Name: _______________________________________

Participant's Licence Number: _______________________________

Participant's Signature: ____________________________________

Date: _________________

Appendix L - Participants' Explanatory Statement and Consent Form (passengers over 15 years of age)

MONASH University

Parent's Participant ID: _ _ _._ **Researcher: _._** **Date: __/__/__**

Explanatory Statement - Children in cars: a field study of children's behaviour in child restraints

(Passengers – any child over the age of 15 years)

The Monash University Accident Research Centre (MUARC) is undertaking the above named research project in collaboration with Holden to explore children's behaviour while travelling in child restraints. The Chief Investigator is Associate Professor Judith Charlton, Associate Director at Monash University Accident Research Centre.

Your consent

This Explanatory Statement and Consent Form is 4 pages long. Please make sure you have all the pages. Please read this Explanatory Statement carefully. Feel free to ask questions about any information in the document.

Once you understand what the project is about and if you agree to take part in it, you will be asked to sign the Consent Form. By signing the Consent Form, you indicate that you understand the information and that you give your consent to participate in the research project. You will be given a copy of the Explanatory Statement and Consent Form to keep as a record.

Background and purpose of the research

Child restraint systems (CRS) for cars are designed to provide additional protection for child occupants of cars in the event of a crash. Existing evidence suggests that child restraints offer a good level of crash protection during an impact. However, the effectiveness of CRS is dependent on correct installation, correct use of the belts in the restraint, and use of the right restraint for the child's size and weight. Research indicates that inappropriate use and misuse of CRS is common. Further, there is limited research into the behaviour of children while travelling in CRS, and how this behaviour may distract the driver or change driver behaviour.

The aims of this project are to examine how children use their CRS, to gain an understanding of children's behaviour while travelling in cars, and to identify if their behaviour changes driver behaviour.

The project will incorporate two additional Doctorate of Philosophy (PhD) degrees that will explore behaviours that contribute to children becoming out-of-position when travelling in cars and contributors to driver distraction.

Benefits of the project

The results of this project will provide valuable insight into child behaviour and how to further improve CRS and car safety. It will provide your parent(s) with the opportunity to drive a new Holden Commodore vehicle for approximately two weeks. Your parent(s) will also be provided with a petrol cheque up to the value of $80.

What does participation involve?

If you agree to participate, you are agreeing to be video recorded while travelling with your parent(s) in the study car for approximately two weeks. There are no other tasks that you will be required do.

While your parent(s) drive the study car, video cameras that are installed in the car will record the driver and passengers. The cameras are very small and will be hidden in the car and not obvious to the driver or passengers. Video cameras will also record the road and traffic. All cameras will start recording automatically when the driver starts the car. The video recordings (including sound recording) will be watched to provide information on:

- child/children's seating positions in the study car;
- child/children's body position and safety belt use when seated in a seat belt, child restraint or booster seat during car trips;
- child/children's activity and communication patterns during car trips;
- interactions between driver/parent and child occupants;
- the road and traffic conditions outside of the study car while driving.

A data recording unit will also collect information directly from the study car and include speed, acceleration, braking, steering, position on the road and GPS (satellite positioning) information.

Confidentiality

Subject to the exclusions stated below, we will treat with the utmost confidentiality any information we collect directly from you, and the video recordings we will collect. No findings that could identify any individual participant will be published. No names will be put into any written records of the study, with all names replaced by codes. No visual images will be used unless they are completely de-identified by obscuring or blurring all participants' faces and other potentially unique identifiers. All other data from this study will be kept at MUARC. Only members of the MUARC project team and co-investigators of this project will have access to the data. The videos will be stored in locked cabinets and, under university regulations, will be stored for a minimum of five years. It is possible that in this time, we may choose to use the data collected from you and your family for future research purposes. This will be research conducted by MUARC, and only members of the MUARC project team will have access to this data if this were to occur.

In the event of a crash, any video data collected from the study car may be subpoenaed and if so, must be released by MUARC. Further, if it is found that your parent/s have driven in a sustained and repeatedly dangerous manner, or if we record any other illegal activity we reserve the right to bring the matter to the attention of our legal advisors or the Victoria Police.

Voluntary nature of participation

Participation in this study is entirely voluntary, and you are under no obligation to consent to participate. You have every right and choice to refuse participation. In addition, if you or a member of your family would like to switch the video system off at any stage during the course of the project, for privacy or any other reason, you are free to do so. Alternatively, if at a later date you wish to delete a particular journey, you will be able to view the data and ask us to delete the footage. Should you agree to participate, you are free to withdraw at any time, and for any reason. You will not be penalised in any manner should you chose to withdraw. In the event of withdrawal from the study data collected prior to this withdrawal will continue to be used and form part of the project, unless you ask us not to do so. Should you wish to withdraw your consent, you can do so by contacting the MUARC Researchers; Suzanne Cross on 9902 0452 or Jonny Kuo on 9905 1808.

Study Results

The study results will be published in a final report that will be available on the Monash University Accident Research Centre's website (http://www.monash.edu.au/muarc/).

Ethical Guidelines

This project will be carried out according to the National Statement on Ethical Conduct in Research Involving Humans (June 1999) produced by the National Health and Medical Research Council of Australia. This statement has been developed to protect the interests of people who agree to participate in human research studies.
The ethical aspects of this research project have been approved by the Monash University Human Research Ethics Committee.

If you have a complaint concerning the manner in which this research CF12/4032 - 201200195 is being conducted, please contact:

Human Ethics Officer
Monash University Human Research Ethics Committee (MUHREC)
Building 3e Room 111
Research Office
Monash University VIC 3800
Tel: +61 3 9905 2052 Fax: +61 3 9905 1420
Email: muhrec@monash.edu

If you would like any further information or have any questions about any aspect of this study, please contact Associate Professor Judith Charlton on 9905 1903.

Yours Sincerely,

J. L. Charlton

Associate Professor Judith Charlton
Associate Director,
Monash University Accident Research Centre

Parent's Participant ID: _ _ _._ **Researcher: _._** **Date: __/__/__**

Consent Form: Children in cars: a field study of children's behaviour in child restraints

(Passengers 15 years and older)

I agree to take part in the above named Monash University research project. I have had the project explained to me, I understand the collection of information and I have read the Explanatory Statement, which I will keep for my records. I understand that agreeing to participate means that I am willing to:

- be video recorded while travelling with my parent(s) in the study car provided by MUARC (unless I choose to refuse participation).

I understand that in the unlikely event that the study car is involved in a crash, the video recordings may be used for legal purposes.

I also understand that in the event that the study car is driven in a dangerous manner, or other illegal activity is recorded, Monash University may need to bring the matter to the attention of appropriate legal authorities.;

I understand that, apart from the above conditions, any information I provide is confidential, and that no information that could lead to identification of any individual will be included in any reports on the project, or to any other person/party.

I also understand that my participation is voluntary, that I can choose not to participate in part or all of the project without being penalised or disadvantaged in any way. I am aware that I can ask my parents to switch the system off for a particular trip by pushing the RED stop button that stops the cameras from recording, or withdraw my consent completely by contacting the MUARC Researchers; Suzanne Cross on 9902 0452 or Jonny Kuo on 9905 1808.

Name: ____

Signature: ____

Date: ________________

Appendix M – Pearson's correlations for GEE Model

Pearson's correlations were conducted to investigate the relationships between the factors of interest for consideration in analysis to predict child occupant suboptimal head position. These factors were considered to be measuring different factors and were included in the GEE model included in Publication 3. Whilst significant correlations were revealed they were not considered to be measuring the same thing. Interaction and activity revealed the strongest correlation. Child occupant activities can intuitively have a tendency for interactions with other vehicle occupants so this correlation was expected. The factors were investigated for their individual contributions to child occupant suboptimal head positions in a GEE model.

Table 1. Pearson's test for multicollinearity *of factors of interest for inclusion in GEE analysis (n=2,158)*

Factor of interest	**Restraint type‡**	**Child gender‡‡**	**Child age‡‡‡**	**Birth order±**	**Restraint use±±**	**Activity ±±±**	**Interaction ±±±±**
Restraint type‡	1	-	-	-	-	-	-
Child gender‡‡	0.06*	1	-	-	-	-	--
Child age‡‡‡	-0.02	0.03	1	-	-	-	-
Birth order±	-0.44*	0.01	-0.08*	1	-	-	-
Restraint use ±±	0.03	0.03	-0.07*	-0.02	1	-	-
Activity±±±	-0.04	0.03	-0.1*	0.06*	0.07*	1	-
Interaction±±±±	0.03	-0.03	0.09*	-0.02	-0.09*	-0.79*	1

*Statistically significant at $p<0.05$, no significant findings revealed.
‡FFCRS or BS
‡‡Male or Female
‡‡‡Younger/older for each CRS type (FFCRS or BS)
±First born or other
±±Correct or incorrect (shoulder belt/harness only)
±±±Conversation, lap-based activity or other
±±±±Yes or no