Understanding driver distraction associated with specific behavioural interactions with in-vehicle and portable technologies

Mitchell L. Cunningham[1], Michael A. Regan[1], Kelly Imberger[2]

[1]*The Australian Road Research Board (ARRB), Sydndey, Australia*

[2]*VicRoads, Melbourne Victoria, kelly.imberge@roads.vic.gov.au*

Corresponding Author: Mitchell Cunningham, 2-14 Mountain St, Ultimo, NSW 2007, Australia. Mitchell.cunningham@arrb.com.au, +61 2 9282 4411.

This peer-reviewed paper was first presented at the 2016 Australasian Road Safety Conference (ARSC2016) held in Canberra, ACT, Australia and first published in the ARSC2016 Proceedings as a 'Full Paper'. It underwent the full peer-review process by independent experts in the field. It is being reproduced here with the kind permission of the authors and is now only available in this edition of the JACRS.

Key Findings

- An initial taxonomy was developed that links distraction-related driving behaviours with performance degradation and changes in crash risk for various technologies.
- The link between behaviour, performance and safety outcomes could not be discerned for all technologies and their associated functions.
- The taxonomy developed in this project is, to the knowledge of the authors, the first to use this method to classify specific performance and safety impacts of different technology driver behavioural interactions.
- Development of the taxonomy highlighted gaps in knowledge and suggested avenues for future research to provide performance and safety impacts of distraction related behaviours for in-vehicle technologies.
- The taxonomy is a 'living document' that can be expanded and refined as more research data become available.

Abstract

In-vehicle distraction contributes significantly to road trauma. Consequently, there is a need to understand the level of crash risk and performance degradation associated with driver engagement with in-vehicle technologies. This will assist in better informing the design of legislation and other road safety countermeasures. This study, commissioned by VicRoads, had two aims: (a) to develop a taxonomy that links different technologies (including mobile phones, in-vehicle computer screens, video screens, head-mounted displays and head-up displays), their functions and the specific behavioural actions required of the driver when interacting with them, to changes in driving performance and crash risk; and (b) to identify any gaps in scientific knowledge about crash risks associated with specific driver behavioural interactions with in-vehicle technologies. This involved a literature review and a series of task analyses. The precise links between driver behaviour, performance and safety outcomes could not be discerned for all technologies and their associated functions. However, the taxonomy derived from this study is a 'living resource' that can be expanded and refined as more research data become available.

Keywords

Driver distraction, in-vehicle technologies, taxonomy, human factors, ergonomics

Introduction

Driver distraction has been defined as the "diversion of attention away from activities critical for safe driving toward a competing activity, resulting in insufficient or no attention to activities critical for safe driving" (Regan, Hallett & Gordon, 2011, p. 1776).

In the Australian National Crash In-depth Study (Beanland, Fitzharris, Young, & Lenne, 2013), which utilised this definition in classifying crash data, around 58% of serious injury crashes involved driver inattention as a contributing factor, and 16% involved distraction. In-vehicle distractions, such as driver interaction with passengers and mobile phones, accounted for around 20% of distraction-related crashes. With the evolution of both portable technology applications (e.g. driver interactions with social media on mobile phones) and also the implementation of newer in-vehicle technologies (e.g. head-up displays, touch screens), it is imperative that research is undertaken to assess the implications for driver safety of driver engagement with such technologies. Technologies of interest (as specified by VicRoads) include mobile phones, in-vehicle computer screens, video screens, head-mounted displays and head-up displays.

To this end, VicRoads, the road transport authority in the State of Victoria, Australia, commissioned the ARRB Group to undertake a research study with two aims:

1. Develop a taxonomy that links different technologies, their functions and the specific actions required of the driver when interacting with them, to changes in driving performance and crash risk.
2. Identify any gaps in knowledge about crash risks associated with distracting interactions with in-vehicle technologies that might be explored in the future.

This paper describes the methods used to derive the taxonomy, the findings derived from the research undertaken, and the implications of the study for driver distraction and injury countermeasure development.

Literature Review

A literature review was first conducted to identify known crash risk and/or performance degradation deriving from specific driver interactions with a number of in-vehicle technologies. The technologies of interest in this study were mobile phones (e.g. calls, texts and using social media), navigation, email and music systems, video screens, head mounted displays (e.g. texting with Google Glass) and head-up displays.

Where no information on crash risk was found, the performance degradation of the behavioural interaction alone was identified and documented. If information on crash risk was found, both this data and performance degradation data were documented. Where research indicated different crash risks for different driver groups, these were noted.

A number of reference sources were searched: PubMed, Science Direct, targeted journals (e.g. *Accident Analysis and Prevention*, *Human Factors*, *Traffic Injury Prevention*), conference proceedings and government websites. The abstracts of manuscripts uncovered were read in order to judge whether the study would be appropriate for the present research. Where multiple manuscripts were found investigating similar driver interactions (e.g. impact of mobile phone conversations on driving performance), the more highly-cited paper was selected for review. Meta-analyses and review papers were used, where possible, to reduce redundancy in papers and present aggregate data.

A full systematic literature review was not in the scope of the project and therefore not as many studies were initially uncovered. The only primary inclusion/exclusion criteria for the study was the relevance and appropriateness of the abstracts to the aims of the research.

Taxonomy Development

A distraction by crash risk/performance degradation taxonomy was developed for mobile phones (e.g. calls, texts and using social media), navigation, email and music systems, video screens, head mounted displays (e.g. texting with Google Glass) and head-up displays. This was informed by the outputs of the literature review, and involved the following activities:

1. A Hierarchical Task Analysis (Stanton 1997) was performed by the two lead authors, both with backgrounds in experimental psychology and one a Chief Scientist in Human Factors with expertise in driver inattention and distraction. The analysis involved defining the goal of the interaction with the technology (e.g. "write a text message"), and identifying the generic tasks (i.e., only primary behaviours as identifying all would be impossible) required to accomplish this goal. However these were not documented. For each task, we then derived and documented possible behavioural actions, drawn from the list in Regan, Young, Lee and Gordon (2009), required to support performance of each task (e.g., locating, holding, touching, looking, typing, thinking). If physical interactions with a specific technology were not possible (this occurred for head-mounted and head-up display technologies only) because it was not available, YouTube and other online resources were used to identify potential interactions drivers could undertake in while driving. We then pooled these for all the tasks supporting that goal. Interactions identified from this Task Analysis were also subsequently searched for in the literature to uncover other studies, however no additional studies were uncovered.
2. Using the information above, a series of taxonomy tables was constructed for each technology (Appendix A). Each table was labelled, at the top, according to the technology of interest (e.g., 'Mobile Phone') and contained five rows which contained, from top to bottom, the following information:

- Row 1 – actions associated with driver technology interaction (and function) that have been investigated in the literature (e.g., 'writing text message').
- Row 2 – possible behaviours associated with the actions listed in Row 1 (derived from the task analysis). This row indicates the particular behaviours which have not been specifically investigated in the literature (e.g. the action of dialling a mobile phone, in general, has been investigated, but the literature has not discerned between the behaviours of holding the phone and pressing the buttons to complete the dialling action). All behaviours from the Task Analysis were considered, but only those with evidence to performance degradation and/or links to crash risk are reported.
- Row 3 – types of distraction: visual distraction (visual), auditory distraction (auditory), cognitive distraction (cognitive) and manual interference (manual) that were hypothesised by the authors to occur from driver technology interaction. Thus, the types of distraction that are hypothesised to underlie some or all of the driving performance decrements, and levels of crash risk, are listed in Rows 4 and 5. The distraction types were defined as follows:
    - *visual distraction* was defined as driver distraction triggered by a competing visual activity (e.g., a mobile phone display message)
    - *auditory distraction* was defined as driver distraction triggered by a competing auditory activity (e.g., a mobile phone ringing)

- *cognitive distraction* was defined as driver distraction triggered by internal thought (e.g., thinking about how to compose a text message)
- *manual interference* was defined as observable interference with vehicle control (e.g., steering; accelerator pedal control) by a driver interacting physically with a technology (e.g. lateral deviation of a car brought about by a driver attempting to perform a U-turn with one hand because the other is holding a mobile phone or a driver who steers off the road to the left when reaching left to remove something from the glove box).

- For each of the distraction types arising from the actions in Row 1, an expert judgement was made as to which distraction types for an action were most likely to degrade driving performance (these are bolded in the table).
- Row 4 – driving performance decrements from the literature review, which were associated with driver actions (Row 1).
- Row 5 – driver risks of being involved in a safety-critical event (crash or near-crash) associated driver actions (Row 1). This risk is expressed as an odds ratio - The odds ratio measures the frequency of event occurring relative to the frequency of event non-occurrence. In the domain of crash risk, the odds ratio is defined as the odds of distraction resulting in a crash divided by the odds of a distraction not resulting in a crash event (baseline conditions). If an odds ratio of greater than one is produced then the factor increases risk (e.g. an odds ratio of 2 indicates a double in crash risk), if it is less than one then risk is reduced (e.g. an odds ratio of 0.5 indicates a halving of crash risk). A confidence interval (usually at the 95% confidence level) of how sure a person can be of the results, is calculated for the odds ratio to determine if it is statistically significant (Deeks 2007). The odds ratios were taken directly from the studies/literature reviewed. Bolded odds ratios signify those which were found to be statistically significant.

Information found in Rows 1-3 were derived from the task analysis, while information found in Rows 4 and 5 were derived from the literature review.

Results

The literature review initially identified 65 studies that provided information about (a) driving performance decrements and/or (b) the risk of a safety critical event associated with driver interaction for the technologies of interest. Most were US-based studies.

A final sample of 44 studies was distilled after reading the abstracts to ensure appropriateness and relevance (e.g. investigated the technology of interest). The number of studies per technology group was as follows:

- Mobile phones – 23
- In-vehicle touch/computer screens – 11
- Video screens and radio - 6
- Head-mounted displays – 2
- Head-up displays - 2

More than 60 percent of the 44 papers reviewed appear in reputable peer-reviewed journals (i.e. with impact factors in the higher end of the range for transport journals) or peer-reviewed conference proceedings. Many of the remaining reports were produced by reputable local and international specialist transport safety research centres that require at least internal peer-review of their publications. Most studies found in the literature review reported driving performance decrements. Relatively few studies were found that reported changes in crash risk.

Most studies reviewed did not identify specific behaviours associated with driver engagement for the selected technologies, or their impacts on driving performance and crash risk. The actions that were not specifically examined are identified within each of the tables in Appendix A in the row titled 'Associated actions not specifically investigated' (Row 2). For the specific technologies reviewed, the available literature focused primarily on driver engagement with mobile phones.

Using the research derived from this literature review, a taxonomy was developed that links distraction-related driving behaviours with performance degradation and changes in crash risk for mobile phones (e.g. calls, texts and using social media), navigation, email and music systems, video screens, head mounted displays (e.g. texting with Google Glass) and head-up displays. The task analysis helped identify a number (~15) of possible primary interactions drivers can have with the various technologies. Due to the increased functionality of new devices, such as head-mounted technologies, these were associated with the greatest number of potential driver interactions. Full results are taxonomically-tabulated and presented in Appendix A. Results are discussed below.

Discussion

Using information derived from the relevant tables in Appendix A, the following sections will, where possible, discern how specific technology functions and behavioural interactions have affected driving performance and crash risk (addressing Research Aims 1 and 2, respectively) in *General Observations*. In addition, instances where research has not explored the impact of specific technology functions and behavioural interactions will be highlighted in *Gaps in Knowledge*.

Mobile Phones

Texting - General Observations: Both reading and writing text messages are associated with decrements in driving performance (e.g. Owens et al. 2011) and increased risk of a safety-critical event (Dingus et al. 2016). However, the taxonomy reveals that writing a text message is more detrimental to driving performance than reading a text message (Reed & Robin, 2008). Odds ratios for manual texting ranged from 3.9 to 163.6 (Klauer et al. 2014; Hickman et al. 2010). Findings from the studies reviewed also suggest that texting via voice activation is less detrimental to driving performance than manual texting (e.g. Owens et al. 2011). However, no ORs were available for voice-activated texting. See Table 1.

Texting - Gaps in Knowledge: For both reading and writing text messages, further research is needed to differentiate ORs by driver group, driver experience and other relevant variables. No known ORs have been derived for voice-controlled texting. Analysis of ORs that are associated with internet browsing is also required.

Conversing - General Observations: Table 2 of the taxonomy reveals that the physical act of reaching for and dialling a hand-held mobile phone is associated with decrements in both driving performance (Caird et al. 2008) and an increased risk of a safety-critical event (ORs ranged from 3.3 to 7.1;Farmer et al. 2014; Klauer et al. 2014).

One study suggests driving experience may moderate this relationship and that younger/novice drivers may be at increased risk from reaching for their mobile phone (OR=7.1;Klauer et al. 2014).

Talking on a hand-held mobile phone was not associated with significantly increased crash risk, except for the latest naturalistic driving study which yielded an OR of 2.2 (Dingus et al. 2016). However, research reviewed found this activity produced driving performance decrements, particularly poorer detection of potentially hazardous events on the road.

Conversing on a hands-free phone appears to be associated with similar driving performance decrements to those associated with using a hand-held phone (Caird et al. 2008). However, as indicated above, the Dingus et al. (2016) study shows an increased crash risk of talking on a hand-held phone. One naturalistic driving study (Fitch et al. 2013) found that there was no increase in the risk of a safety-critical event when conversing on a hands-free mobile phone, for both portable hands-free (Bluetooth headset) and integrated (Bluetooth connectivity with in-vehicle speaker) hands-free interactions.

Findings regarding the relationship between conversing on a hands-free mobile phone and crash risk are mixed, with one study suggesting the behaviour is not any riskier than just driving (no mobile phone use; Fitch et al., 2013), and three other studies (Olsen et al., 2009; Hickman et al., 2010; Fitch et al., 2015) suggesting the behaviour may actually be less risky than driving without conversing on a mobile phone. There are number of explanations that may account for these discrepant findings (e.g. see Engström et al. 2005, for impact of cognitive load on driving behaviour).

Conversing - Gaps in knowledge: Table 2 presents findings on the impact of conversing on a mobile phone – for 'reaching', 'dialling' and 'talking/listening'. No literature was found that examined the impact on driving performance or safety of 'receiving' phone calls or 'hanging-up' the phone.

The taxonomy suggests that further research is needed on use of the mobile phone for 'talking/listening – to (a) understand performance decrements associated with different ways of conversing on a phone 'hands-free' and (b) to differentiate ORs by driver group, driver experience and by different ways of communicating hands-free. Different vehicle manufacturers provide alternative solutions for 'hands-free' mobile phone use. Some provide voice recognition. Others provide Bluetooth solutions, which eliminate the requirement to touch the phone. However, these can sometimes require complicated driver interactions with controls on the steering wheel and the requirement for the driver to look excessively at phone information displayed on in-car display screens (and increase interference with driving).

Social Media - General Observations: Only one study (Basacik et al. 2011) directly examined the link between use of social media (Facebook) while using a hand-held mobile phone and associated driving performance decrements. Both writing and reading messages through this social network platform were associated with poorer driving performance (Table 3).

Social Media - Gaps in Knowledge: Table 3 outlines the impact of using Facebook on a mobile phone – for 'writing message' and 'reading message'. No literature was found on the impact of 'receiving message'. No research was found on the impact of social media use on safety in real-life driving studies.

In-vehicle Touch/Computer Screens

Navigation Devices - General Observations: Table 4 suggests that manual destination entry is associated with a greater number of performance decrements compared with input via voice recognition (e.g. Tsimhoni et al. 2004). In addition, the findings reviewed suggest that voice activated systems result in faster destination entry and less deterioration of vehicle control.

Navigation systems that provide only visual directions are associated with greater driving performance decrements than those that provide auditory, or auditory plus visual route-guidance (Dingus et al. 1995). Route-guidance information that is not supplemented with voice-guidance is more visually demanding to process and is likely to interfere with activities critical for safe driving.

Navigation Devices - Gaps in Knowledge: No ORs were identified that are associated with specifically entering a destination or following directions on in-vehicle navigation systems.

Email Systems - General Observations: Findings suggest that opening, checking and replying to emails using in-vehicle email systems that are speech-based are associated with a range of driving performance decrements (Lee et al. 2001; Jamson et al. 2004;Table 4). Thus, although manual interaction is eliminated, there is still distraction. Dingus and colleagues (2016) found an OR of 2.7 for car drivers reading email or checking stocks.

Email System - Gaps in Knowledge: For the three studies reviewed (Lee et al. 2001; Jamson et al. 2004, Dingus et al. 2016), there was no differentiation between the impacts of 'opening', 'checking' and 'replying' to emails in regards to their link with driving performance.

Playing Music - General Observations: Manual interaction with the in-vehicle computer display to browse and select music is associated with greater variability in lateral control according to findings from one study (Kujala, 2013). Another study suggests that voice-activated music retrieval from in-vehicle computers is associated with less eyes off road time than manual interactions with portable MP3 players (Garay-Vega et al. 2010).

Playing Music - Gaps in Knowledge: No known ORs exist in relation to driver behaviours associated with playing music through in-vehicle display systems (not conventional radio;Table 4).

Video Screens, Tablets and Computers

In-vehicle DVD Players - General Observations: The few available studies suggest that watching, listening to and manipulating in-vehicle DVD players can impair activities critical for safe driving (e.g. Hatfield & Chamberlain 2005;Table 5). Watching DVDs and manipulating them appears to degrade performance (specifically vehicle speed, lateral position and driver critical event detection) more than listening to them.

In-vehicle DVD Players - Gaps in Knowledge: No ORs were reported in any of the studies in relation to driver interaction with DVD players (watching, listening, manipulating).

Interacting with Radio - General Observations: Two studies show that the visual-manual task of tuning a radio and simply listening to the radio can impair driving performance (Horberry et al. 2006;Table 5). The latest NDS yields an OR of 1.9 for distraction from in-vehicle radio (Dingus et al. 2016).

Interacting with Radio - Gaps in Knowledge: The taxonomy (Table 5) reveals a lack of research pertaining to the safety risk of interacting with a radio system (tuning and listening).

Head-mounted Displays

Google Glass - General Observations: The taxonomy reveals that text messaging using a head-mounted display (i.e., Google Glass) impairs driving performance compared with not texting at all (Table 6). However, the impairment caused by texting with a head-mounted display appears to be less severe than that associated with visual-manual texting using a smartphone due to the use of voice-activation (He et al., 2015; Sawyer et al., 2014).

Google Glass – Gaps in knowledge: ORs that related to driver interaction with head-mounted displays were not found. In addition, there appears to be no research about the impact on driving performance of using head-mounted displays to access functions other than texting.

Head-up Displays

Head-up Displays - General Observations: The studies reviewed suggest that HUDs in vehicles are less distracting than conventional or head-down displays (e.g. Liu & Wen 2004;Table 7). This is most likely due to the fact that the use of HUD reduces eyes-off-road-time as information is projected directly into the driver's forward line of sight.

Head-up Displays - Gaps in Knowledge: The taxonomy (Table 7) reflects the limited published research on potential distraction resulting from head-up displays (HUDs). The two known studies that have investigated the impact of HUDs on driving performance did not differentiate reported impacts according to the type of behaviours involved, and no ORs were reported. Research is also required on the extent to which information displayed on the HUD itself (e.g. the overlay of vehicle information from the HUD on the external visual scene) may distract drivers from activities critical for safe driving. Other displayed information may include texts, web pages, videos, music lists etc.

General Conclusions

The aim of this project was to attempt to determine, based on a literature review and task analyses, driving behaviours associated with the use of in-vehicle and portable technology, and their associated driving performance and safety outcomes. An initial taxonomy was developed that links distraction-related driving behaviours with performance degradation and changes in crash risk for various technologies. The link between behaviour, performance and safety outcomes could not be discerned for all technologies and their associated functions.

The taxonomy developed in this project is, to the knowledge of the authors, the first to use this method to classify specific performance and safety impacts of different technology driver behavioural interactions.

Development of the taxonomy highlighted gaps in knowledge and suggested avenues for future research to provide performance and safety impacts of distraction related behaviours for in-vehicle technologies. The taxonomy is a 'living document' that can be expanded and refined as more research data become available. This is an important area of study as new technologies continue to come to market and become integrated into vehicles.

There are several practical implications of this research for technology manufacturing (i.e., designing technology to be as ergonomic as possible to avoid distraction), legislation, and public education. Although hand-held mobile phone use, and texting and use of social media for all phones, is banned under the Australian road rules, the research on mobile phone use can be used to inform the public of the risks of specific behavioural interactions when using various phone functions, and for setting penalty levels. The same applies for the use of visual display units (VDUs) and other technologies such as HUDs, which are now available in new vehicles. Public messages may include only using VDUs when the vehicle is stationary, particularly when lists are involved such as during navigation or scrolling for music.

References

Basacik, D., Reed, N., & Robbins, R (2011) *Smartphone use while driving: A simulator study*, report no. PPR592, TRL, Wokingham.

Beanland, V., Fitzharris, M., Young, K. & Lenne, M. (2013) Driver inattention and driver distraction in serious casualty crashes: Data from the Australian National Crash In-depth Study, *Accident Analysis and Prevention*, *54*(1), 99–107.

Brookhuis, K.A., de Vries, G. & de Waard, D. (1991) The effects of mobile telephoning on driving performance, *Accident Analysis & Prevention*, *23*(4), 309–16.

Caird, J.K., Willness, C.R., Steel, P. & Scialfa, C. (2008) A meta-analysis of cell phone use on driver performance, *Accident Analysis & Prevention*, *40*, 1282–93.

Caird, J.K., Johnston, K.A., Willness, C.R., Asbridge, M. & Steel, P. (2014) A meta-analysis of the effects of texting on driving, *Accident Analysis & Prevention*, *71*, 311–18.

Chiang, D., Brooks, A. & Weir, D. (2001) An experimental study of destination entry with an example automobile navigation system', *Proceedings of the Workshop on Exploring the Occlusion Technique: Progress in Recent Research and Applications*, Torino, Italy.

Cooper, J., Yager, C., & Crysler, S. (2011) *An investigation of the effects of reading and writing text-based messages while driving*, Southwest Region University Transportation Center (Texas Transportation Institute), Texas.

Deeks, J. (2007) *Swots corner: What is an odds ratio*, Bandolier – Evidence Based Thinking about Health Care, Centre for Statistics in Medicine, Oxford, viewed 29 June 2015, <http://www.medicine.ox.ac.uk/bandolier/band25/b25-6.html>.

Dingus, T., McGehee, D., Hulse, M., Jahns, S., Manakkal, N., Mollenhauer, M. & Fleischman, R . (1995) *TravTek evaluation task C3 camera car study*, pub. no. FHWARD-94-076, U.S. Department of Transportation, Federal Highway Administration Washington, D.C.

Dingus, T.A., Guo, F., Lee, S., Antin, J.F., Perez, M., Buchanan-Kinga, M. & Hankey, J. (2016) Driver crash risk factors and prevalence evaluation using naturalistic driving data', *Proceedings of the National Academy of Sciences*, *113* (10), 2636–2641.

Drews, F.A., Yazdani, H., Godfrey, C.N., Cooper, J.M. & Strayer, D.L. (2009) Text messaging during simulated driving, *Human Factors*, *51*, 762–70.

Engström, J., Johansson E. & Östlund, J. (2005) Effects of visual and cognitive load in real and simulated motorway driving, *Transportation Research Part F*, *8,* 97–120.

Farmer, C.M., Klauer, S.G., McClafferty, J.A. & Guo, F. (2014) *Relationship of near-crash/crash risk to time spent on a cell phone while driving*, Insurance Institute for Highway Safety, Arlington, Virginia.

Fitch, G.M., Soccolich, S.A., Guo, F., McClafferty, J., Fang, Y., Olson, R., Perez, M., Hanowski, R., Hankey, J. & Dingus, T. (2013) *The impact of hand-held and hands-free cell phone use on driving performance and safety-critical event risk*, report no. DOT HS 811 757, National Highway Traffic Safety Administration, Washington, DC.

Fitch, G., Hanowski, R. & Guo, F. (2015) The risk of a safety-critical event associated with mobile device use in specific driving contexts', *Traffic Injury Prevention*, *16*, 124-132.

Funkhouser, D & Chrysler, ST 2007, *Assessing driver distraction due to in-vehicle video systems through field testing at the Pecos research and testing center*, Texas Southwest Region University Transportation Center, College Station, Texas, USA.

Garay-Vega, L., Pradhan, A.K., Weinberg, G., Schmidt-Nielsen, B., Harsham, B., Shen, Y., Divekar, G., Romoser, M., Knodler, M. & Fisher, D.L. (2010) Evaluation of different

speech and touch interfaces to in-vehicle music retrieval systems, *Accident Analysis and Prevention*, *42*, 913–20.

Gärtner, U., König, W., & Wittig, T. (2001) Evaluation of manual vs. speech input when using a driver information system in real traffic', *Proceedings of the International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, Aspen, Colorado.

Gibbs, S. (2014) *Apple's iPhone 'lock-out' patent could end texting while driving*, The Guardian, viewed 23 June 2015, <http://www.theguardian.com/technology/2014/apr/24/apples-iphonelock-out-patent-could-end-texting-while-driving>.

Haque, M. & Washington, S. (2013) Effects of mobile phone distraction on drivers' reaction times', *Journal of the Australasian College of Road Safety*, *24*(3), 20–29.

Haque, M., & Washington, S. (2015) The impact of mobile phone distraction on the braking behaviour of young drivers: a hazard-based duration model, *Transportation Research Part C: Emerging Technologies*, *50*, 13–27.

Hatfield, J., & Chamberlain, T. (2005) *The effects of in-vehicle audiovisual display units on simulated driving*, University of New South Wales, NSW Injury Risk Management Research Center Sydney, Australia.

He, J., Chapparo, A., Nguyen, B., Burge, R., Crandall, J., Chaparro, B., Ni, R. & Cao, S. (2013) Texting while driving: Is speech-based texting less risky than hand-held texting?, *Proceedings of Automotive User Interfaces and Interactive Vehicular Applications*, Eindhoven, Netherlands.

He, J., Choi, W., McCarley, J.S., Chaparro, B. & Wang, C. (2015) Texting while driving using Google Glass: promising but not distraction-free', *Accident Analysis & Prevention*, *81*, 218–229.

Hickman, J.S., Hanowski, R.J. & Bocanegra, J. (2010), *Distraction in commercial trucks and buses: assessing prevalence and risk in conjunction with crashes and near-crashes*, Federal Motor Carrier Safety Administration, Washington D.C.

Horberry, R., Anderson, J., Regan, M., Triggs, Y. & Brown, J. (2006) Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance', *Accident Analysis & Prevention, 38*, 185–191.

Horrey, W. & Wickens, C. (2006) The impact of cell phone conversations on driving using meta-analytic techniques, *Human Factors*, *48*(1)*,* 196–205.

Jamson, A.H., Westerman, S.J., Hockey, G.R., & Carsten, M.J. (2004) Speech based e-mail and driver behaviour: effects of an in-vehicle message system interface, *Human Factors*, *46*(4), 625–639

Jäncke, L., Musial, F., Vogt, J., & Kalveram, K.T. (1994) Monitoring radio programs and time of day affect simulated car driving performance, *Perceptual Motor Skills*, *79*, 484–486.

Kircher, A., Vogel, K., Törnros, J., Bolling, A., Nilsson, L., Patten, C., Malmström, T. & Ceco, C. (2004) *Mobile telephone simulator study*, report no. 969A, Swedish National Road and Transport Research Institute, Linköping, Sweden.

Klauer, S.G., Dingus, D.R., Neale, T.A., Sudweeks, J. & Ramsey, D.J. (2006) *The impact of driver inattention on near-crash/crash risk: an analysis using the 100-car naturalistic study data*, report no. DOT HS 810 594, National Highway Traffic Safety Administration, Washington, D.C.

Klauer, S.G., Guo, F., Simons-Morton, B.G., Ouimet, M.C., Lee, S.E., & Dingus, T.A. (2014) Distracted driving and risk of road crashes among novice and experienced drivers, *New England Journal of Medicine*, *370*, 54–59.

Kujala, T. (2013) Browsing the information highway while driving: Three in-vehicle touch screen scrolling methods and distraction, *Personal and Ubiquitous Computing*, *17*, 815–823.

Lee, J.D., Caven, B., Haake, S. & Brown, T.L. (2001) Speech-based interaction with in-vehicle computers: The effects of speech-based E-mail on drivers' attention to the roadway, *Human Factors*, *45*, 631–639.

Liu, Y.C. (2003) Effects of using head-up display in automobile context on attention demand and driving performance, *Displays*, *24*(4), 157–165.

Liu, Y.C., & Wen, M.H. (2004) Comparison of head-up display (HUD) vs. head-down display (HDD): driving performance of commercial vehicle operators in Taiwan, *International Journal of Human-Computer Studies*, 61(5), 679–697.

McEvoy, S., Stevenson, M., McCartt, A., Woodward, M., Haworth, C., Palamara, P., & Cercarelli, R. (2005) Role of mobile phones in motor vehicle crashes resulting in hospital attendance: a case-crossover study, *British Medical Journal*, *331*, 428–430.

NHTSA (2015) *Traffic Safety Facts Research Note, April 2015*, U.S. Department of Transportation National Highway Traffic Safety Administration, Washington, DC.

Olson, R., Hanowski, R., Hickman, J. & Bocanegra, J. (2009) *Driver Distraction in Commercial Vehicle Operations*, report no. FMCSA-RRR-09-042, Federal Motor Carrier Safety Administration, Washington, DC.

Owens, J.M., McLaughlin, S.B. & Sudweeks, J. (2011) Driver performance while text messaging using hand-held and in-vehicle systems, *Accident Analysis & Prevention*, *43*, 939–947.

Patten, C.J., Kircher A., Ostlund J. & Nilsson L. (2004) Using mobile telephones: cognitive workload and attention research allocation, *Accident Analysis & Prevention*, *36*(3), 341–350.

Reed, N., & Robbins, R. (2008) *The effect of text messaging on driver behaviour*, report no. PPR 387, Transport Research Laboratory, England.

Regan, M.A., Hallett, C. & Gordon, C.P. (2011) Driver distraction and driver inattention: Definition, relationship and taxonomy, *Accident Analysis & Prevention*, *43*, 1771–1781.

Regan, M.A., Lee, J.D. & Young, K.L. (eds.) (2009) *Driver distraction: theory, effects, and mitigation*, Boca Raton: CRC Press, Florida.

Regan, M.A. Williamson, A., Grzebieta, R., Charlton, J., Lenne, M., Watson, B., Haworth, N., Rakotonirainy, A., Woolley, J., Anderson, R., Senserrick, T. & Young, K. (2013) The

Australian 400-car naturalistic 1 driving study: innovation in road safety research and policy, *Road Safety Research, Policing and Enforcement Conference*, *Brisbane, Australia, 29-30 August*, Australasian Council of Road Safety, Melbourne.

Rudin-Brown, C., Young, K., Patten, C., Lenne, M. & Ceci, R. (2013) Driver distraction in an unusual environment: effects of text-messaging in tunnels, *Accident Analysis & Prevention*, *50*(1), 122–129.

Sawyer, B.D., Finomore, V.S., Calvo, A.A. & Hancock, P.A. (2014) Google Glass: driver distraction cause or cure?, *Human Factors*, *56*(7), 1307–1321.

Stanton, N. (eds.) (1997) *Human factors in Consumer products*, Boca Raton: CRC Press, Florida.

Strayer, D.L., Drews, F.A. & Johnston, W.A. (2003) Cell phone induced failures of visual attention during simulated driving, *Journal of Experimental Psychology: Applied*, *9*(1), 23–32.

Tijerina, L., Parmer, E. & Goodman, M. (1998) Driver workload assessment of route guidance system destination entry while driving: A test track study, *Proceedings of the 5th ITS World Congress*, Seoul, Korea.

Törnros, J.E.B. & Bolling, A.K. (2005) Mobile phone use – effects of hand-held and hands-free phones on driving performance, *Accident Analysis & Prevention*, *37*, 902–909.

Tsimhoni, O. & Green, P. (2001) Visual demands of driving and the execution of display-intensive in-vehicle tasks, *Human Factors and Ergonomics Society 45th Annual Meeting*, 1586–1590.

Tsimhoni, O., Smith, D. & Green, P. (2004) Address entry while driving: speech recognition versus a touch-screen keyboard, *Human Factors*, *46*(4), 600–610.

Victor, T, Bärgman, J, Boda, C, Dozza, M, Engström, J, Flannagan, C, Lee J & Markkula, G 2014, 'Analysis of naturalistic driving study data: safer glances, driver inattention, and crash risk', *Safety Project S08A Prepublication Draft*, Gothenburg, Sweden: Safer vehicle and traffic safety centre at Chalmers.

White, C., Fern, L., Caird, J., Kline, D., Chisholm, S. & Scialfa, C. (2006) The effects of DVD modality on drivers' performance, *37th Annual Conference of the Association of Canadian Ergonomics*, Banff, Canada.

Yager, C. (2013) *An evaluation of the effectiveness of voice-to-text programs at reducing incidences of distracted driving*, Texas A&M Transportation Institute, Texas A&M University System, College Station, Texas.

Young, K.L., Regan, M.A., Lee, J.D. (2008) Factors moderating the impact of distraction on driving performance and safety', in M Regan, J Lee & K Young (eds), *Driver Distraction: Theory, Effects, and Mitigation*, CRC Press Taylor & Francis Group, Boca Raton, FL, USA, pp. 335–52.

Appendix A – High-level findings from literature review

Table 1 Performance decrements and safety risk associated with text messaging on mobile phone

Actions investigated	Reading text	Writing: Hand-held (i.e. manual texting)	Writing: Hands-free (i.e. texting using voice only)
Actions not investigated	Locating, holding, looking, thinking	Locating, holding, touching, looking, typing, thinking	Locating, holding, pressing, speaking, looking, thinking, listening (to feedback)
Type of distraction	**Visual**, cognitive, manual interference (hereafter 'manual')	**Visual**, **cognitive**, manual	Visual, **cognitive**, manual
Performance decrements	***Increased reaction time (RT) to hazardous events**** (Reed & Robin 2008) ***Increased lateral variability**** [a] (Reed & Robin 2008) ***Increased longitudinal variability**** (Reed & Robin 2008) ***No effect on driving performance***** (Owens et al. 2011) *Compared with just driving **When message is read to driver by in-vehicle system using text-to-speech software [a]More pronounced in female drivers compared with male drivers	***Increased RT to hazardous events**** (Brookhuis et al. 1991; Törnros & Bolling 2005; Reed & Robin 2008; Drews et al. 2009; Caird et al. 2014) ***Increased lateral variability**** (Cooper et al. 2011; Reed & Robin 2008; Rudin-Brown et al. 2013[a]; Caird et al. 2014) ***More missed traffic signals and driver conflicts*** (Brookhuis et al. 1991; Törnros & Bolling 2005; Cooper et al. 2011; Caird et al. 2014) ***Increased headways**** (Cooper et al. 2011; Caird et al. 2014) ***Longer glances from roadway**** (Owens et al. 2011; Caird et al. 2014) ***Increased lateral and longitudinal variability***** (Reed & Robin 2008) *Compared with just driving **Compared with reading text message [a] Especially prominent in unfamiliar driving contexts (e.g. tunnel)	***Less glances from roadway**** (Owens et al. 2011) ***Increased steering control**** (Owens et al. 2011) ***Increased time spent looking off forward roadway***** (Owens et al. 2011) ***Reduced standard deviation of lateral position****** (He et al. 2013) ***Increased standard deviation of lateral position******* (He et al. 2013) ***Increased RT to hazardous events******* (Yager 2013) ***No difference in RT to hazardous events****** (Yager 2013) *Using integrated vehicle system compared with manual texting, not no texting ** Using integrated vehicle system compared with no texting ***Using speech-to-text software on mobile compared with manual texting, not no texting ****Using speech-to-text software on mobile compared with no texting
Risk	None available	**23.24*** for truck (commercial) drivers (Olson et al. 2009) 1.73***** for car drivers (Fitch et al. 2013) **163.6*** for truck and bus drivers (Hickman et al. 2010) **3.87** for novice drivers (Klauer et al. 2014) **7 (near crash), 5.6 (crash & near crash combined)** for experienced drivers (Victor et al. 2104) **6.1** for hand-held phone (Dingus et al. 2016) *Represents texting in general (reading and writing) and internet browsing via the mobile phone. The studies do not discern the particular risks associated with these different behaviours/functions	None available

Table 2. Performance decrements and safety risk associated with conversing on mobile phone

Actions investigated	Reaching (hand-held mobile)	Dialling (hand-held mobile)	Talking/listening (Handheld)	Talking/listening (Handsfree)
Actions not investigated	Locating, thinking, holding, looking	Holding, pressing, looking, thinking	Holding, thinking	Thinking
Type of distraction	**Visual**, cognitive, **manual**	**Visual**, **cognitive**, **manual**	**Cognitive**, **manual**, auditory	**Cognitive**, auditory
Performance decrements		***Increased reaction time**** (Caird et al. 2008) ***Increased lateral variability**** (Törnros & Bolling 2005) *Compared with just driving	***Increased reaction time to hazards**** (Horrey & Wickens 2006; Caird et al. 2008[a]; Haque & Washington 2013) ***No effect on lateral control**** (Horrey & Wickens 2006; Caird et al. 2008) ***Speed reduction**** (Horrey & Wickens 2006) ***No effect on headway**** (Caird et al. 2008) ***Increased number of missed objects and driving errors**** (Horrey & Wickens 2006) *Compared with just driving [a]This study notes that this decrement is more pronounced in older drivers	***Increased RT to road safety events**** (Strayer et al. 2003[a]; Patten et al. 2004; Caird et al. 2008; Haque & Washington 2013[b]) ***No difference in RT to road safety events***** (Patten et al. 2004; Horrey & Wickens 2006; Caird et al. 2008; Haque & Washington 2013) ***More abrupt and excessive braking**** (Haque & Washington 2015) *Compared with just driving **Compared with talking/listening on a hand-held mobile [a]This study found that this decrement is more pronounced in heavier traffic environments [b]This study found the decrement to be more pronounced in provisional-licence drivers compared with open-licence drivers
Risk	**7.05** for novice car drivers, 1.37 for experienced car drivers (Klauer et al. 2014) **3.31** for experienced car drivers (locating/reaching) (Farmer et al. 2014) **3.38** for truck and bus drivers (Hickman et al. 2010) **3.65** for car drivers (Fitch et al. 2013) 1.7 for car drivers (Victor et al. 2014)	**2.8** for experienced car drivers (Klauer et al. 2006) **5.93** for truck (commercial) drivers (Olson et al. 2009) **3.5** (Hickman et al. 2010) **8.32** for novice car drivers, **2.49** for experienced car drivers (Klauer et al. 2014) **2.77** for car drivers (Farmer et al. 2014) 0.63 (pressing to begin/end all only) for car drivers (Fitch et al. 2013) **12.2** for car drivers (Dingus et al. 2016)	1.3 for experienced car drivers (Klauer et al. 2006) 1.0 for truck (commercial) drivers (Olson et al. 2009) 0.79 for truck and bus drivers (Hickman et al. 2010) 0.79 for car drivers (Fitch et al. 2013) 4.1 for car drivers (McEvoy et al. 2005) 0.61 for novice car drivers and 0.76 for experienced car drivers (included hands-free) (Klauer et al. 2014) 0.90 for experienced drivers (talking/listening/using voice commands) (Farmer et al. 2014) **1.2** for commercial drivers when not at a junction (Fitch et al. 2015) 1.1 for light vehicle drivers when not at a junction (Fitch et al. 2015) **2.2** for car drivers (Dingus et al. 2016)	2.37 for experienced car drivers (Farmer et al. 2014) **0.44** for portable hands-free for truck (commercial) drivers (Olson et al. 2009) **0.65** for truck and bus drivers (Hickman et al. 2010) 0.73 for portable hands-free for car drivers (Fitch et al. 2013) 0.71 for integrated hands-free for car drivers (Fitch et al. 2013) **0.44** for portable hands-free for commercial drivers when not at a junction (Fitch et al., 2015)

Table 3. Performance decrements and safety risk associated with using social media on mobile phone

Actions investigated	Manually writing message (handheld)	Reading message (Handheld)
Actions not investigated	Locating, holding, touching, looking, scrolling, typing, thinking	Locating, looking, holding, pressing, touching, scrolling, thinking
Type of distraction	**Visual, cognitive, manual**	**Visual, cognitive**, manual
Performance decrements	*Slower mean speed** *Greater standard deviation of speed** *Increased lateral variability** *Increased variability in headway** *Longer glances off forward roadway** *30% increase in reaction time** Basacik et al. (2011) *Compared with just driving	*Slower mean speed** *Increased variability in headway** *Longer glances off forward roadway** Basacik et al. (2011) *Compared with just driving
Risk	None available	None available

Table 4. Performance decrements and safety risk associated with in-vehicle navigation, in-vehicle email and music systems

Actions investigated	Navigation - Entering destination (manual)	Navigation - Entering destination (voice)	Navigation - Following directions (w/ voice guidance)	Navigation - Following directions (visual only)	Email - Opening, checking, replying (speech-based)	Play music - Browsing/select music
Actions not investigated	Looking, touching, pressing, typing, scrolling, thinking	Pressing (turn on voice-control), looking, thinking, speaking, listening	Listening, thinking, looking	Looking, thinking	Looking, speaking, listening, thinking	Looking, touching, pressing, scrolling, thinking
Type of distraction	**Visual**, **cognitive**, **manual**	**Visual**, **cognitive**	**Visual**, **cognitive**, auditory	**Visual**, **cognitive**	**Visual**, **cognitive**, auditory	**Visual, cognitive, manual**
Performance decrements	***Increased lateral deviation**** (Tsimhoni et al. 2004; Tsimhoni & Green 2001) ***Increased number of braking errors**** (Dingus et al. 1995; Tsimhoni & Green 2001) ***Increased number of glances off roadway****	***Reduced lateral variability**** (Gärtner et al. 2001; Tsimhoni & Green 2001; Tijerina et al. 1998; Tsimhoni et al. 2004) ***Less frequent glances off forward roadway**** (Gärtner et	***Reduced lateral deviations**** (Dingus et al. 1995) ***Less braking errors**** (Dingus et al. 1995) ***Less number of glances away from roadway**** (Dingus et al. 1995) *Compare-d with	***Similar glance activity away from road and lateral variability**** (Dingus et al. 1995) *Compared with using a conventional map	***Increased RT to hazardous events**** (Lee et al. 2001) ***Fewer corrective steering movements **** (Jamson et al. 2004) ***Longer headways**** (Jamson et al. 2004)	***Greater variability in lateral control**[a]*** (Kujala 2013) ***Greater number of glances off forward roadway***** (Garay-Vega et al. 2010). *Compared with just driving **Compared with voice-activated system [a]This decrement more pronounced

Actions investigated	Navigation - Entering destination (manual)	Navigation - Entering destination (voice)	Navigation - Following directions (w/ voice guidance)	Navigation - Following directions (visual only)	Email - Opening, checking, replying (speech-based)	Play music - Browsing/select music
	(Chiang et al. 2001) ***Reductions in speed**** (Chiang et al. 2001) *Compared with just driving	al. 2001; Tsimhoni & Green 2001; Tijerina et al. 1998) *Compared with manual input	methods without voice-guidance		***Increased braking time**** (Jamson et al. 2004) *Compared with just driving	for swiping methods instead of point-touching
Risk	None available	None available	**4.6** for car drivers (Dingus et al. 2016) – not this is for "interacting with a <u>non</u>-radio/no-heating, ventilation and air conditioning (HVAC) in-vehicle device (e.g. touch screen menus) – thus presumed to include navigation		**2.7** for car drivers reading email or checking stocks (Dingus et al. 2016)	None available

Table 5. Performance decrements and safety risk associated with in-vehicle video screens and radio

Actions investigated	DVD - Watching	DVD -Listening only	DVD - Manually manipulating	Radio - Manual tuning	Radio - Listening only
Actions not investigated	Looking, thinking, listening	Thinking	Looking, touching, pressing, thinking, holding, inserting	Looking, touching, thinking	Thinking
Type of distraction	**Visual**, **cognitive**, auditory	**Cognitive**, auditory	**Visual**, **cognitive**, **manual**	**Visual,** cognitive, **manual**	**Cognitive,** auditory
Performance decrements	***Increased speed variability**** (Hatfield & Chamberlain 2005) ***Increased RT to hazardous events**** (Kircher et al. 2004; White et al. 2006) ***Increased braking times**** (Hatfield & Chamberlain 2005) ***Longer glances off forward roadway**** (Funkhouser & Chrysler 2007[a]) ***Increased lateral variability on curves**** (Hatfield & Chamberlain 2005) *Compared with just driving [a]This study used a	***No effect on lateral variability**** (Hatfield and Chamberlain 2005) ***No effect on speed variance**** (Hatfield & Chamberlain 2005) ***Increased braking times**** (Hatfield & Chamberlain 2005) ***No effect on RT to hazardous events**** (White et al. 2006) *Compared with just driving	***Greater average scaled lateral accelerations**** (Funkhouser & Chrysler 2007) [a] ***Slower mean speed**** (Funkhouser & Chrysler 2007) [a] ***Increased RT for hazardous events**** (Funkhouser & Chrysler 2007) [a] ***Less accurate peripheral detections**** (Funkhouser & Chrysler 2007) [a] ***Increase in braking time**** (Funkhouser & Chrysler 2007) [a] *Compared with just driving	***Degraded speed control*** (Horberry et al. 2006) ***Delayed responses to unexpected hazards*** (Horberry et al. 2006) *Compared with just driving	***Degrade lane keeping performance**** (Jäncke et al. 1994) *Compared with just driving

Actions investigated	DVD - Watching	DVD -Listening only	DVD - Manually manipulating	Radio - Manual tuning	Radio - Listening only
	portable DVD player strapped to passenger seat (facing driver)		[a]This study used a portable DVD player strapped to passenger seat (facing driver)		
Risk	None available	None available	None available	**1.9** for in-vehicle radio [task not specified] (Dingus et al. 2016)	**1.9** for in-vehicle radio [task not specified] (Dingus et al. 2016)

Table 6. Performance decrements and safety risk associated with using head-mounted displays

Actions investigated	Writing text message (using voice input into Google Glass)
Actions not investigated	Listening (for incoming message), tilting head, looking, reading, speaking, thinking, swiping (frame to turn off display)
Type of distraction	**Visual**, **cognitive**, **manual** (head tilting)
Performance decrements	***Reduced standard deviation of lateral position**** (He et al. 2015) ***Reduced number of lane excursions**** (He et al. 2015) ***Greater standard deviation of steering wheel position***** (He et al. 2015) ***Reduced standard deviation of steering wheel position****** (He et al. 2015) ***Greater braking response time**** (He et al. 2015) ***No difference in braking response time****** (He et al. 2015) ***Lower headway distances****** (He et al. 2015) ***No difference in headway distances***** (He et al. 2015) ***Better lane keeping performance**[a]* (Sawyer et al. 2014) ***Adopted closer headways**[a]* (Sawyer et al. 2014) *Compared with texting using Smartphone (both manually and using voice activation). No difference in this decrement when compared with just driving **Compared with just driving ***Compared with texting using Smartphone (both manually and using voice activation) [a]Compared with manual texting
Risk	None available

Table 7. Performance decrements and safety risk associated with using head-up displays

Actions investigated	Navigation and speed maintenance
Actions not investigated	Depends on functions implemented on head-up display Predominantly looking, thinking
Type of distraction	Visual cognitive
Actions investigated	Navigation and speed maintenance
Performance decrements	***Increased speed control**** (Liu & Wen 2004) ***Increased steering control**** (Liu 2003; Liu & Wen 2004) ***Reduced RT for hazardous events**** (Liu 2003; Liu & Wen 2004) *Compared with conventional or head-down display
Risk	None available

Road Safety Policy & Practice

Vulnerable road users in a Safe System

Trevor Bailey[1] and Jeremy Woolley[2]

1 Centre for Automotive Safety Research (CASR), University of Adelaide, South Australia, trevor@casr.adelaide.edu,au

2 CASR (as above), jeremy@casr.adelaide.edu.au

Corresponding Author: Trevor Bailey, Centre for Automotive Safety Research, University of Adelaide, South Australia 5005, trevor@casr.adelaide.edu.au, +61 8 8313 0916.

Key Findings

- Vulnerable road users tend to be poorly accounted for in Safe System models.
- Safe Systems involve more than just susceptibility to crash forces and forgiving systems.
- Studies of traffic conflicts of vulnerable road users can extend Safe System thinking.

Abstract

Road users such as pedestrians, cyclists and motorcyclists are highly susceptible to crash forces. Yet, while Safe System thinking accords susceptibility to crash forces and a forgiving system as focal principles, the greater vulnerability of these road users is barely recognised in many models of a Safe System. This is a concern of growing importance, given current efforts to increase usage of active travel modes and substantially rising injury rates among cyclists and motorcyclists. This paper explores a selection of research studies aiming to identify relevant factors behind traffic conflicts involving vulnerable road users, as a means to determine appropriate countermeasures particularly those involving infrastructure and vehicle technology. A better understanding of the contextual nature and causes of traffic conflict has much potential to contribute to Safe System thinking and conceptualisations, allowing them to extend beyond their traditional focus on susceptibility to crash forces and systems that are forgiving.

Keywords

Active travel, Cyclists, Pedestrians, Safe System, Vulnerable road users

Introduction

Vulnerable road users, namely pedestrians, cyclists and motorcyclists, constitute the road user groups most susceptible to death and injury from crash forces. The ability of the human body to withstand crash forces, or human physical frailty, is a focal principle in many conceptualisations of Safe System thinking found in documents such as the *National Road Safety Strategy 2011-2020* (NRSS) (Australian Transport Council (ATC), 2011). The NRSS emphasises two other principles inherent in Safe System thinking: that humans make mistakes, and the need for a 'forgiving' transport system.