An On-Road Examination of Driver Errors at Intersections

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Abstract
A significant proportion of road trauma occurs at intersections. Understanding driver behaviour at intersections therefore has the potential to lead to significant injury reductions. This paper presents the findings of an on-road study investigating the nature of errors made by drivers at intersections. To understand how the complexity of modern intersections shapes behaviour these are compared to the errors made mid-block, and the role of wider systems failures in intersection error causation is investigated. Twenty-five participants drove a pre-determined route, incorporating 25 intersections, in an instrumented vehicle. Two in-vehicle observers recorded the errors made while a range of other data was collected, including verbal protocols, video, eye glance behaviour and vehicle data (speed, braking, lane tracking). Participants also completed a post trial cognitive task analysis interview. Participants were found to make 39 different error types, with speeding violations being the most common. Drivers made significantly more errors at intersections compared to mid-block, with a failure to indicate on approach to the intersection, indicating too late and travelling too fast to turn being common errors observed. Drivers also made more errors at partially signalised crossings compared to fully signalised intersections. A range of system-wide prevention strategies to minimise intersection errors are proposed.

Introduction
Intersections are an integral part of the road system, but are also one of the most dangerous because they represent a point where road users converge and potentially conflict with each other. In Australia, the majority of urban crashes and a substantial proportion of rural crashes occur at intersections (McLean et al., 2010). In Victoria for example, between 2001 and 2005, 47% of car crashes, 47% of pedestrian crashes, 58% of cyclist crashes and 38% of motorcycle crashes occurred at intersections (VicRoads, 2011). The four main types of collisions that occur at intersections are: right-angle, right-turn-against, rear-end and crashes involving pedestrians (McLean et al., 2010). A range of factors contribute to crashes at intersections, including poor road design, environmental conditions, vehicle maintenance issues, and errors made by drivers and other road users (Devlin et al., 2011).

Driver error has been identified as a prominent causal factor in road traffic crashes. While estimates vary, studies typically suggest that anywhere from 75% (Hankey et al., 1999; cited in Medina et al., 2004) to 90% (Treat et al., 1979) of all road crashes involve some form of driver error. Reason (1990) defines error as: “a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency” (p. 9). Reason (1990) also classifies errors into four categories: slips, lapses, mistakes and violations. Slips are the most common error type and represent those errors where an incorrect action was performed even though the intention was correct (e.g., pressing the accelerator instead of the brake when intending to stop). Lapses occur when people unintentionally fail to perform an action and are associated with memory failures (e.g., forgetting to lock the car). Mistakes originate at the planning, rather than the execution level and involve a person intentionally performing an incorrect action (e.g., a driver accelerating toward an amber light when they should be braking). Violations include behaviours that intentionally or unintentionally deviate from the rules and procedures of a system (e.g., travelling above the speed limit).

Although human error research has a long tradition in other safety critical domains such as aviation and nuclear power (e.g., Jou, et al., 2011; Kontogiannis & Malakis, 2009; Shappell, et al., 2007), an in-depth understanding of driver error, including its nature, the role of different error types in road crashes, and the role of wider systems failures in error causation, is yet to be achieved (Stanton & Salmon, 2009). While driver errors occur at all points in the road network, errors may be particularly prominent at intersections, as these represent a complex part of the road system, where drivers are required to make decisions often at high speeds and within small timeframes. There is therefore a pressing need to examine the nature of errors made by drivers at intersections, including the factors that contribute to, or mitigate these errors from occurring.

In recent times, researchers have advocated the use of a holistic approach when examining driver error. This involves exploring not only the role of the driver in contributing to errors, but the role of other road users, the vehicle and the road environment as well. This approach augurs well with the Safe System Approach, which requires that all aspects of the transport system (i.e., roads, vehicle speeds, vehicles and the users of the system) work together to achieve the highest possible safety outcomes. A basic tenet of the safe systems approach is that even an alert and compliant driver will at some point make errors and the road system, therefore, needs to be designed in order for it to be tolerant of driver errors. Any investigation of driver errors at intersections must, therefore, consider the role of wider system factors, such as intersection design, in contributing to errors. Recent advances in research methods for investigating driver behaviour, such as the provision of instrumented on-road test vehicles, have made such a systems-based analysis possible. The use of instrumented vehicles, which are capable of recording a range of driver, vehicle and roadway measures, allow for the accurate and unobtrusive collection of objective, real-time data regarding driver errors and the system-wide factors that contribute to them.

The present study set out to investigate the nature of driving errors occurring at intersections through the conduct of an on-road study. In line with the systems approach, the study utilised a novel, multi-method approach, involving the use of an instrumented vehicle and a suite of ergonomics methods to investigate the number and type of errors made by drivers at intersections and to identify the wider system factors that contribute to these errors occurring.

Method

Participants

Twenty-five drivers (15 males, 10 females) aged 19-59 years (mean = 28.9, SD = 11.9) took part in the study. Sixteen participants held a valid Full driver's license while the remaining nine held a valid Probationary (P2) license. Participants were recruited through the weekly on-line Monash University newsletter and were compensated $50 for their time and travel expenses. The study was approved by the Monash University Human Ethics Committee.

Materials

On-Road Test Vehicle (ORTeV)

The MUARC ORTeV is an instrumented vehicle equipped to collect two main types of data: vehicle-related and eye tracking data. Vehicle data are acquired from the vehicle network and includes: vehicle speed, GPS location, accelerator and brake position, steering wheel angle, lane tracking and headway logging, primary controls (windscreen wipers, indicators), and secondary controls (sat-nav, entertainment system). Driver eye movements can be tracked and overlaid on a driver's-eye camera view using the FaceLab and SceneCam eye tracking systems. ORTeV is also equipped with seven unobtrusive cameras recording forward and peripheral views spanning 90° each respectively as well as three interior cameras and a rearward-looking camera. For the purposes of this study, vehicle-related data and eye tracking data were collected whilst drivers drove ORTeV around a pre-determined route.

Driver Verbal Protocols
Verbal Protocol Analysis (VPA), or 'think aloud' protocol analysis, was used to elicit data regarding the cognitive and physical processes undertaken by drivers while driving. Participants provided concurrent verbal protocols as they drove around the test route. Participants were asked to think aloud about what they were doing and seeing, but not explain or rationalise their behaviour, so as to minimise the effect of the verbal protocols on driving performance. The verbal protocols were recorded using a digital Dictaphone and transcribed verbatim post-trial.

Critical Decision Method interviews
Cognitive task analysis interviews were held post-drive with each participant using the Critical Decision Method (CDM; Klein, Calderwood & McGregor, 1989). CDM is a semi-structured interview approach that has previously been used to investigate cognition and decision making in a range of domains, including road transport (Stanton et al., 2007; Walker et al, 2009). Each interview focused on one of the errors made by participants during the drive using a set of probes adapted from the literature (Crandall et al., 2006; O'Hare et al., 1998). Participant responses were recorded on a CDM interview pro-forma.

Test Route
The test route comprised a 21 km urban route around the suburbs surrounding the Monash University Clayton Campus. The test route contained a total of 25 intersections, made up of the mixture of intersection types. These included 16 cross junction intersections (9 requiring a straight-on manoeuvre, 4 requiring a right-turn manoeuvre, 3 requiring a left-turn manoeuvre), 8 T-junction intersections (4 requiring a straight-on manoeuvre, 4 requiring a left-turn manoeuvre), and 1 Y-junction intersection (requiring a left turn manoeuvre). Fully signalised intersections were defined as those where right turn phases were controlled with arrows, while partially signalised were those where right turn phases were not controlled with arrows.

Procedure
A demographic (age, gender, license type, driving history) questionnaire was completed by participants prior to the study. Participants drove the test route using ORTeV. Participants first completed a short practice drive and familiarised themselves with ORTeV and the VPA method. At the end of the practice route, participants were informed that the test had begun and that data collection had commenced. Two in-vehicle observers used an error pro-forma to manually record the errors made during the drive. En-route, the observer located in the front passenger seat provided directions. Both observers recorded errors made by the driver, including the error type, where on the route it occurred, and the context in which it occurred. Upon completion of the drive, the two observers checked agreement on the errors recorded. They then selected an appropriate error for further analysis through the CDM interview.

Error classification
For the purpose of this paper, errors were identified as occurring at an intersection if they occurred within approximately 20 metres before and after an intersection, or they related directly

to the intersection (e.g., failure to indicate). Speeding errors were classified as any instance where the driver's speed exceeded the speed limit for a period of 5 seconds or more, while lane excursions were recorded if any part of the vehicle moved outside of the current lane of travel. The errors observed during the on-road study were classified post-hoc using the driver error taxonomy developed by Stanton and Salmon (2009), which contains 22 error types grouped into the following categories: action errors, cognitive and decision making errors, observation errors, information retrieval errors, and violations. Two trained researchers with significant experience in the use of error classification taxonomies independently classified the errors (as recorded by the in-vehicle observers) into error types using the taxonomy. Based on a comparison of both analysts' classifications, a very high level of agreement was found (Cohen's Kappa = .871), with any disagreements being resolved through further discussion and reclassification if necessary.

Results

Participants made a total of 296 errors. These errors were categorised into 39 specific error types. A breakdown of the 39 different error types made is presented in Table 1 which also includes the frequency with which each error was made. Of the 296 errors made, 169 (57.1%) occurred at intersections and 127 (42.9%) were made mid-block. A t-test revealed that the number of errors made at intersections was significantly higher than the number of errors made mid-block ($t(24)=2.25$, $p=.034$).

Table 1. Frequency of different error types made by participants

Error	Total No. of errors	No. errors - Intersections	No. errors - Mid-block
Speeding	93	3	90
Change lanes without indicating immediately after turn	49	49	0
Failing to indicate	25	15	10
Activating indicator too early	15	15	0
Travelling too fast for turn	14	14	0
Braking late and hard	13	12	1
Lane excursion/poor lane keeping	12	3	9
Accelerating too fast	12	10	2
Activating indicator too late	8	6	2
Ran red light	4	4	0
Gave way unnecessarily	4	3	1
Activated wipers instead of indicator	4	3	1
Tailgating	3	1	2
Didn't see vehicle in adjacent lane (but checked)	3	0	3
Delayed recognition of green traffic light	3	3	0
Attempted to make an incorrect turn	3	3	0
Failed to make turn	3	3	0
Mounted kerb	2	2	0
Changed lane within intersection	2	2	0
Selected unsafe gap when turning right at intersection	2	2	0
Stopped in a keep clear zone	2	2	0
Failed to notice indicator had turned off	2	2	0
Blocking intersection due to there not being enough room to complete turn	2	2	0
Other	16	10	6
TOTAL	**296**	**169**	**127**

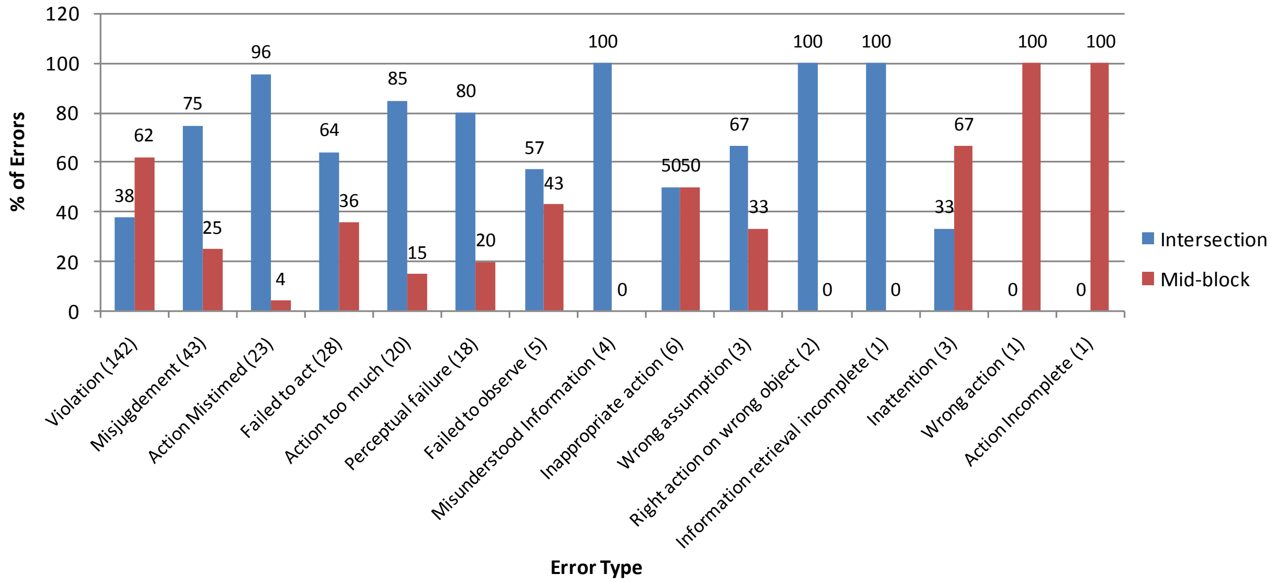

Figure 1 *Percentage of errors made at intersections vs. mid-block for various error types. Number of errors in parentheses*

The intersection errors were examined in further detail by breaking them down across intersection type. Figure 2 displays the number of errors made at each of the different intersection types encountered on the test route. As shown, it is obvious that errors were particularly pronounced at partially signalised intersections. Thus, the number and type of errors made at fully and partially signalised intersections were examined in further detail.

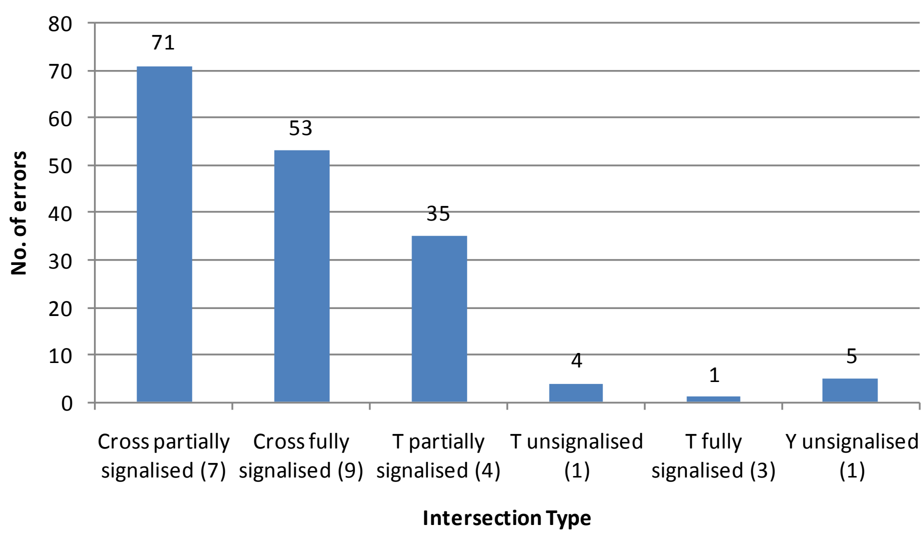

Figure 2 *Number of errors made at each intersection type. Number of intersections in parentheses*

Analysis showed that drivers made a significantly greater number of errors at partially signalised intersections (mean = 4.2, SD = 2.4) than at fully signalised (mean = 2.2, SD = 1.5) intersections ($t(24)=4.82$, $p<.001$). The types of errors made at fully and partially signalised intersections were also examined to identify if the nature of the errors made differed across the two control configurations. As Figure 3 shows, drivers, almost exclusively, made a greater proportion of each error type at partially signalised intersections. The only exceptions were the small number of 'inappropriate action' and 'right action on wrong object' errors, which occurred only at fully signalised intersections. Of particular note, is that the 'misjudgement', 'action mistimed' and 'failed to act' errors were particularly pronounced at partially signalised intersections compared to fully signalised intersections.

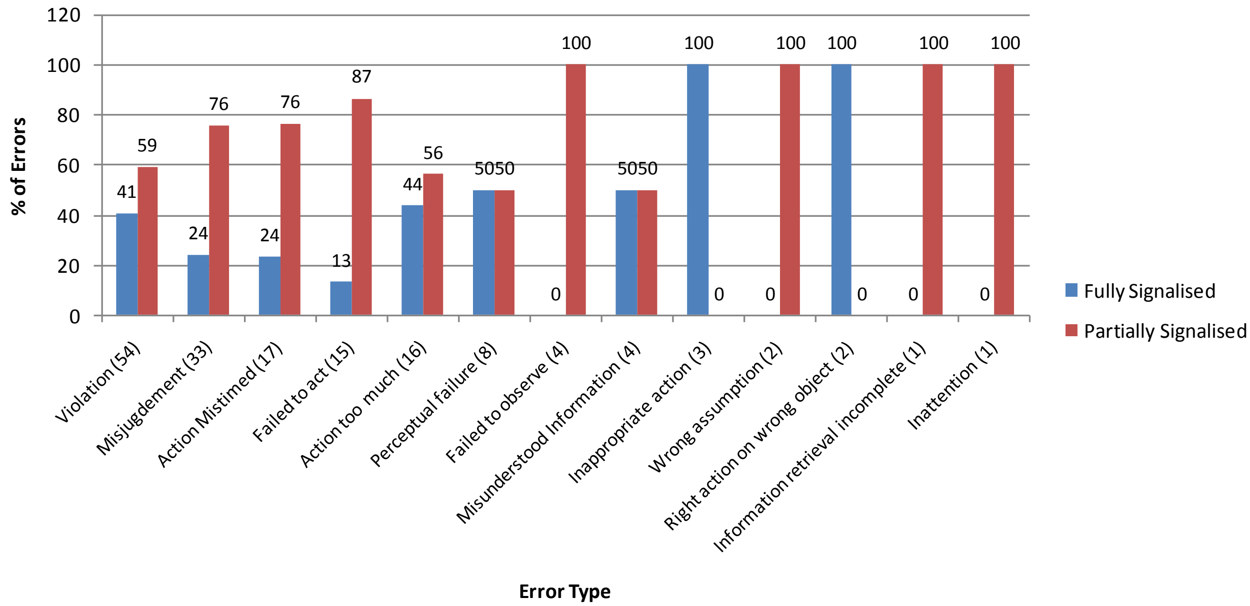

Figure 3 *Percentage of errors made at fully vs. partially signalised intersections for various error types. Number of errors in parentheses*

Case Studies

To illustrate the role of road signal design in contributing to a sample of the errors made at intersections during the on-road study, three still images from the on-board cameras are presented (Figure 4). All three errors shown occurred at the same partially signalised intersection. In the top image, the driver can be seen making a right hand turn in front of an on-coming vehicle (misjudgement error). The participant misjudged the distance and speed of the on-coming vehicle when they initiated their turn, narrowly avoiding a collision. In the middle image, the driver failed to observe that there were vehicles banked up on the road in which they were turning into, which prevented them from being able to complete their right turn (failure to observe error). The driver was forced to stop mid-way through the turn, blocking the intersection. In the bottom image, the driver failed to observe that there were pedestrians on the crossing to the right until part-way through a right turn (failure to observe error). As well as almost colliding with the pedestrians, the driver was forced to stop mid-way through the turn, blocking the intersection until the pedestrians cleared the crossing.

In all three errors, due to the nature of the intersection signal controls, the drivers were required to make right hand turn decisions while also negotiating a busy pedestrian crossing and observing traffic build-up on the road into which they were turning. The task of selecting a safe gap in traffic when tuning is, in itself, a complex one (Hancock et al., 1990). When this task is coupled with the requirement for drivers to attend to other information elements or make other complex decisions (e.g., negotiating a pedestrian crossing) the driver can easily become overloaded and commit the types of errors observed in these case studies.

Figure 4 *Driver errors occurring at partially signalised intersection*

Discussion

Utilising a novel, on-road multi-method approach, the current study aimed to explore the nature of errors made by drivers at intersections. Of particular interest was the number and type of errors made at intersections and how these differ from mid-block errors and across different intersection control types. Overall, the number and type of errors made at intersections differed to those made at mid-block. Drivers made a significantly greater number of errors at intersections. These comprised 32 specific error types, of which ‘changing lanes without indicating immediately after a turn' (49), 'failing to indicate' (15), activating indicator too early' (15) and travelling too fast for turn (14), were the more common errors occurring at intersections.

The specific error types were then classified into error categories according to the driver error taxonomy developed by Stanton and Salmon (2009). From analysis of this classification it was revealed that drivers made a greater number of action, misjudgement and information errors at intersections than at mid-block. This finding is not unexpected given that drivers are generally required to make a greater number of decisions, deal with higher amount of information and perform a greater number of actions at intersections compared to mid-block. The relatively lower number of decisions and actions required at mid-block may, however, make drivers 'zone out' or become less vigilant, as seen in the greater proportion (albeit still small) of inattention errors made at mid-block compared to intersections. A greater number of violations, the majority of which were excessive speeding violations, were also made at mid-block sections compared to intersections. Again, this finding is not unexpected given that drivers tend to have more opportunity to speed mid-block than they do at intersections.

The types of errors observed at intersections in the current study are in line with those observed in other intersection error studies (Gstalter & Fastenmeier, 2010; Sandin, 2009). Gstalter and Fastenmeier, for example, found that drivers committed a range of error types at intersections, including errors in velocity, signals and communications, tracking and lane use, traffic light errors, errors in the inner area of intersections, errors affecting pedestrians and cyclists, and checking and viewing errors, all of which were made by participants during the present study.

The intersection errors were examined in further detail by breaking them down across fully and partially signalised intersections. A greater number of errors were made at partially signalised intersections. The types of errors made also differed slightly across the two intersection control types, but, almost exclusively, each error type was made more often at partially signalised intersections. The occurrence of 'misjudgement', 'action mistimed' and 'failed to act' errors were particularly pronounced at partially signalised intersections.

One of the advantages of the method used in the current study is that it allowed for the retrospective examination of each driving error observed during the study. An examination of the on-board video and driving data revealed that many of the misjudgement and failure to observe errors made at partially signalised intersections were safety critical and involved drivers coming into conflict with on-coming traffic and pedestrians when turning. Moreover, the data demonstrated the role of intersection design and, in particular, traffic signal design, in contributing to some of the errors made during the study. Specifically, the use of partial signalling at busy intersections, where drivers are required to make right hand turn decisions without the assistance of turn arrows, can lead to a range of critical errors being committed. The intersection illustrated in the case studies is located at a busy suburban shopping strip, with high pedestrian and vehicle traffic. In all three cases examined, the drivers were unable to process the high amount of information required to safely negotiate the right hand turn, leading them to conflict with other vehicles and pedestrians and block the intersection. Installation of fully signalised traffic controls at this and similar, high traffic intersections is likely to reduce the types of errors observed in the case studies presented.

Conclusions

Intersections represent a complex part of the road network, where drivers are required to make multiple decisions, often under considerable time pressure and at high speed. This complexity is reflected in the number and type of errors made by drivers at intersections during the current on-road study. Further, the key role that the wider road transport 'system' plays in error contribution has been highlighted by this study. In particular, errors at intersections appear to be exacerbated by intersection design, namely the use of partially signalised intersection controls which require drivers to make complex turn decisions across on-coming traffic while also observing pedestrian crossings and light signals. This study suggests that a range of the error types made by drivers at intersections could be reduced simply by installing fully signalised traffic controls at high traffic intersections, or intersections where a right turning vehicle could come into conflict with pedestrians. Other roadway design changes that could also reduce some of the error types observed in the current study include restricting the placement of pedestrian crossings at high workload segments of the roadway such as slip lanes and making turn lanes clearly visible to drivers.

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