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Lateral damage and point of impact in intersection crashes: Implications for injury

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Article abstract

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ABSTRACT

Crashes in intersections may result in damage to vehicles and injury to occupants in many different ways. One vehicle hitting the side of another (T-type) is the classic side impact; however, we have argued in the past that other crash configurations (e.g., L-type) may subject occupants to similar risks because both vehicles may sustain lateral damage. To test this assumption, we examined crash data from police reports of 4032 intersection right-angle crashes (IRC), collected by the Insurance Corporation of British Columbia for 2002. We compared the risk and types of injury in target and bullet vehicles for T-type crashes, L-type crashes by front and rear fender involvement and for all other IRC crashes. There were 787 T-type crashes (impact into either side of target vehicle), compared to 798 L-type crashes (impact into front fender) and 350 L-type (impact into rear fender). Overall, injury risk was 23.5%. Proportions injured were very similar for occupants of target and bullet vehicles in T-type crashes (OR = 0.996; 95% ci 0.80 to 1.24.); for L-type crashes, the proportions were 23.2% for front and/or front fender involvement and 15.0% for

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crashes involving the rear fender of one vehicle and the front or front fender of the other (OR = 1.71; 95% ci 1.40 - 2.10). Apart from rear fender crashes, proportions injured were very similar (P > 0.05). Other factors, notably weather, lighting, land use and vehicle damage differed significantly by crash type, and were strongly associated with injury risk. Since rear-fender crashes are a small proportion of IRC crashes, this suggests that it is not necessary to subdivide crashes by configuration in IRC crashes.

Keywords: Lateral impact, vehicle damage, injury.

RÉSUMÉ

Cet article traite des accidents d'automobile au niveau des intersections routières et susceptible de causer diverses blessures aux occupants ou divers dommages aux véhicules. L'impact classique est le fait d'un véhicule de frapper le côté d'un autre véhicule (Type T). Cependant, les auteurs ont démontré par le passé qu'il existe d'autres formes d'accident, tel, Type L) susceptibles de causer aux occupants des risques similaires car les deux véhicules peuvent subir des dommages latéraux. Pour tester cette hypothèse, ils ont examiné les données d'accident de constats établis par la police, soit 4 032 accidents aux angles droits des intersections (IRC), compilées en 2002 par Insurance Corporation of British Columbia (ICBC). Ils ont aussi comparé le risque et les types de blessures lorsque les véhicules sont à la fois la cible et le projectile dans les accidents dits Type T, les accidents frontaux ou de pare-chocs arrière dits Type L et dans les autres accidents aux angles droits des intersections (IRC). Nous avons dénombré 787 accidents dits Type T (impact latéraux de véhicules), comparativement à 798 accidents dits Type L au niveau des pare-choc avant et 350 accidents dits Type L au niveau des pare-choc arrière. Globalement le risque de blessure corporelle se situait à 23,5 %. Les proportions de blessure étaient similaires en ce qui concerne les occupants de véhicules cibles ou de véhicules projectiles dans les accidents dits Type T (OR = 0,996; 95 % ci 0,80 à 1,24) ; pour les accidents dits Type L, les proportions de blessure s'établissaient à 23,2 % pour les accidents frontaux ou impliquant les pare-chocs avant et à 15 % pour les accidents impliquant les pare-chocs arrière d'un véhicule et autres accidents frontaux ou impliquant les pare-chocs avant (OR = 1,71; 95 % ci 1,40 à 2,10). Sauf en ce qui concerne les accidents impliquant les pare-chocs arrières, on en arrive aux mêmes proportions de blessures (P > 0,05). D'autres facteurs, principalement les conditions du temps, les éclairs, le terrain et les dommages matériels diffèrent de façon significative selon le type d'accident et sont fortement reliés au risque de blessures corporelles. Vu que les accidents impliquant les pare-chocs arrière ne sont qu'une faible proportion des accidents aux angles droits des intersections (IRC), ceci semble indiquer qu'il n'est pas nécessaire de subdiviser la forme des accidents lorsqu'ils se produisent aux angles droits des intersections (IRC).

Mots clés : Dommages latéraux, dommages au véhicule, blessures corporelles.

1. INTRODUCTION

Crashes that occur at intersections frequently involve two or more vehicles, with lateral damage (i.e., side impact) for at least one and sometimes both vehicles. Although the classic form of side impact crash involves one vehicle moving into the side of a second vehicle, other configurations are quite possible, even likely.

Investigators in Vancouver, Toronto and Montreal have been studying the factors affecting the occurrence and severity of side impact crashes. In some circumstances, where a detailed crash investigation provided data, it has been possible to identify crashes that were classic T-type crashes: it was clear which vehicle was the 'target' and which was the 'bullet' in each crash, and the angle of impact was within 45° of a right angle (Chipman, Persaud, Bou-Younes et al., 2004b). In other circumstances, crashes were described as 'intersection right-angle' (IRC) on the police crash report, but it was not possible to differentiate between struck and striking vehicles in many cases (Chipman, Desapriya, Brussoni et al., 2004a).

Therefore we had the following questions:

1. How many 'intersection right angle' crashes have lateral damage reported to one or both vehicles?
2. How does the risk and pattern of injury vary in different configurations of IRC crashes?

A review of the literature (Chipman, 2004) identified studies that had used a variety of definitions of the type of crash we were interested in. Studies of older drivers often looked at crashes simply by whether they occurred at intersections, rather than a more specific crash configuration. Zhang, Lindsay, Clarke et al. (2000) looked at crashes in Ontario by the configuration of intersections (with and without traffic controls, compared to non-intersections). They also looked at crash configuration, described as 'side-swipe' compared to head-on, rear-end or single vehicle crashes. Studies in Finland (Hakamies-Blomqvist, 1993) and in Alabama in the United States (MacGwin and Brown, 1999), that examined the crash risks of older drivers, looked at intersection crashes as well as crash configuration, but did not consider these variables together. The assumption seems to be that intersection crashes have a limited number of similar crash configurations.

Data from health care providers include different information about injury and may take a different approach to these definitions. In examining differences in the pattern and severity of injury to patients admitted to a Canadian trauma centre, McLellan, Rizoli, Brenneman et al. (1996) compared patients in 'lateral' crashes to 'non-lateral' crashes. These authors documented higher Injury Severity

Scores (ISS) with lateral impact, and a higher incidence of injuries to the chest and abdomen. Head injury was common, but equally so in lateral and non-lateral crashes.

Other studies have clearly articulated the different roles of target and bullet vehicles. Many were particularly concerned with the relative sizes and compatibility between the struck and the striking vehicle. Broyles, Narine, Clarke et al. (2003) distinguished between vehicles hit laterally and from the rear relative to frontal impact and found that the odds of injury was 2.47 in passenger cars relative to the odds in four wheel drive vehicles. Austin and Faigin (2004) similarly distinguished, in side impact crashes, between occupants of the struck and the striking vehicle in examining the risks of death or incapacitating injuries. The source of data in these studies varies, from crashes involving one type of vehicle in a single state in one year to five years of data from the Fatality Analysis Record System (FARS) and the National Automotive Sampling System (NASS).

The crashes coded as 'intersection right-angle' by the police in British Columbia may be of several types. Some will be T-bone crashes with impact of the front of one vehicle directly into the side of another. Some, however, are better described as L-type crashes: the impact of the front or front fender of one vehicle with either the front or rear fender of the other vehicle. In these circumstances, the force and direction of impact may spin the vehicles so that they come together like blades of scissors, with the potential of some lateral damage to both vehicles.

In previous work with these data, no distinction was made between these types of crash; instead, all IRC were considered as a group (Chipman, Desapriya, Brussoni et al., 2004; Chipman, Desapriya, Brussoni et al., 2005). In this report, we have attempted to classify crashes more precisely and examine differences in the risk of injury by crash type in each group of IRC crashes.

2. METHODS

All crashes reported by police in British Columbia in 2002 were the source of data for this study. From these data, all two-vehicle crashes coded by police as IRC were selected if they met the following criteria:

- Both vehicles were licensed in British Columbia.
- The age of both drivers was recorded in the report.

- Both vehicles were designed to carry passengers; i.e., they were cars, minivans, sports utility vehicles or pickup trucks. Crashes involving buses, transport trucks, recreational vehicles etc. were excluded.

Under these conditions, there were 4032 crashes available for study.

The police record location of damage to each vehicle, and indicate the location on a diagram (Fig. 1). This information is numerically coded in the crash records maintained by ICBC. These codes – not the diagram – were what was available for use in these analyses.

From the many codes available, the following classifications were used to define different types of IRC:

T-bone: damage to the front of one vehicle and to the left or right side of the other vehicle.

L-type (front): damage to the front of one vehicle and to the left or right front fender of the other OR damage to the left or right front fenders of both vehicles.

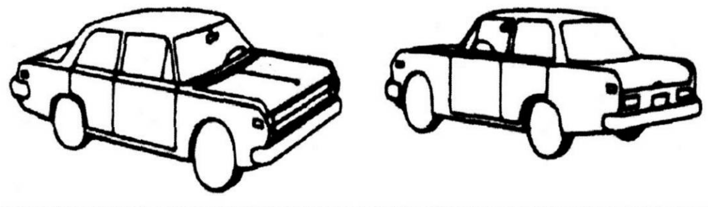
L-type (rear): damage to the front or left or right front fender of one vehicle and damage to the left or right rear fender of the other.

Other: damage that did not meet any of these classifications, including damage to the windshield, both front and rear of the vehicle etc.

In T-bone crashes, lateral damage has been coded as present (= 1) for one vehicle and absent (= 0) for the other. For vehicles in L-type crashes this distinction between struck and striking vehicle could not be made.

The police report includes some information on the injury status of each occupant. For the injury that is judged 'most serious', police code the location (e.g., head, neck, etc.) and type (e.g., abrasions,

FIGURE 1
DIAGRAM IN THE BC POLICE REPORT USED TO INDICATE LOCATION OF DAMAGE TO ONE VEHICLE



bruises, etc.) of injury. Injury rates (percentage of all occupants with injury by type and location) were computed for occupants in each type of crash, and for the occupants of target and bullet vehicles in T-type crashes.

For T-type crashes, the rates of injury to occupants of target and bullet vehicles could be compared using matched analyses (McNemar's test, conditional logistic regression), so that the occupants of one vehicle are directly compared to the occupants of the second vehicle in the same crash (Fleiss, Levin and Paik, 2003). Clearly this within-crash comparison controls for a variety of factors specific to each crash which may affect the risk of injury. For other types of crash, it was not possible to label the vehicles as 'target' or 'bullet'; for these analyses ordinary logistic regression was used, with environmental factors and seat position included as covariables.

Initial analyses looked at all injuries; in addition, the distribution of injuries by type and location of the most serious was compared by type of crash.

3. RESULTS

Of the 4032 IRC crashes identified, 787 were T-type crashes and 1148 were L-type, 798 involving the front and front fenders of both vehicles and 350 involving the rear fender of one vehicle. (Table 1).

With this definition, the classic T-bone crash accounted for only 20% of eligible crashes; crashes that could not be classified as either T- or L-type crashes using this algorithm were slightly more than half (52%) of all IRC.

TABLE 1
CRASH TYPES IN ELIGIBLE IRC CRASHES, BRITISH COLUMBIA, 2002

Crash type	N	%
T-type	787	19.5%
L-type (front)	798	19.8%
L-type (rear)	350	8.7%
Other	2,097	52.0%
TOTAL	4,032	100.0%

Table 2 contains information on road jurisdictions, road characteristics, light conditions and weather for each crash type. Many road characteristics varied little for different crash configurations: posted speed limits, number of lanes, proportion of one-way streets. Other variables, notably land use, ambient light and weather, varied significantly by type of crash; these variables were included as covariables for the analyses of injury rates.

TABLE 2
CRASH CHARACTERISTICS (%) BY CRASH TYPE

Characteristic	T-type N = 787	L-type (front) N = 798	L-type (rear) N = 350	Other N = 2097
Jurisdiction:	%	%	%	%
Municipal	88.7	87.2	85.4	86.8
Provincial	9.0	11.0	12.0	11.1
Other	2.3	1.8	2.6	2.2
Median # of lanes	2 lanes	2 lanes	2 lanes	2 lanes
Median posted speed limit	50 kph	50 kph	50 kph	50 kph
% with two-way traffic	95.2	97.5	93.1	95.5
Land use:	%	%	%	%
Urban residential	51.9	47.0	48.6	48.5
Business-commercial	35.0	38.6	34.8	37.1
Industrial	5.4	5.2	5.6	3.9
Rural	6.8	6.7	7.2	7.4
School/recreation	1.9	2.3	3.8	3.1
Significance test	$\chi^2 = 29.42$ (12 df); $p = 0.0034$			
Lighting:	%	%	%	%
Daylight	74.1	75.6	75.7	72.2
Dawn/dusk	3.3	4.6	2.9	3.4
Lit dark	9.9	7.2	7.0	9.4
Unlit dark	0.6	1.5	1.2	1.3
Partial lit dark	12.1	11.2	8.8	13.8
Significance test	$\chi^2 = 33.93$ (12 df); $p = 0.0007$			
Weather:	%	%	%	%
Clear	50.4	53.1	55.0	52.8
Cloudy	29.2	30.1	29.2	28.4
Rain	16.8	13.7	13.2	14.6
Snow/sleet	3.1	2.2	2.3	3.3
Fog/smog/smoke	0.4	1.0	0.3	0.8
Significance test	$\chi^2 = 22.37$ (12 df); $p = 0.0336$			

Table 3 contains similar information for the vehicles and drivers by crash type. For T-type crashes, struck and striking vehicles have been presented and analysed separately. Over 90% of vehicles in all crash configurations were for personal use and the average age, of both the vehicles and the drivers, was similar for all crash types. The proportion of drivers over 65 years was lowest (11.9%) for 'other' configurations and highest for L-type (front) crashes (14.8%); this variation was not significant ($p > 0.05$). Occupant position also did not vary greatly. Vehicle damage, however, was markedly different by crash type. Vehicles damaged beyond repair (write-off) were much more common among target than among bullet vehicles in T-type crashes ($p = 0.02$); differences were more complex for L-type and other configurations. The latter group had a higher proportion of write-off and lightly damaged vehicles, and vehicles in front end L-type crashes sustained heavier damage that those in rear fender crashes ($p < 0.0001$). Vehicle damage was considered as a covariable in the analysis of injury rates.

Unadjusted injury rates by crash type are presented in Table 4. The overall injury rate is 2724 of 11608 occupants injured, or 23.5%. The proportion of injuries is lowest for occupants of L-type rear crashes (OR = 0.58 compared to L-type frontal crashes, with 95% ci 0.48 – 0.71; $P < 0.001$).

For T-type crashes, comparing injuries in target vehicles with the bullet vehicles in the same crash, the estimated odds ratio of injury was 0.98, with a 95% confidence interval of 0.80 to 1.19; thus there is no evidence of difference in injury risk. Only total injuries were considered in this comparison, as comparing subjects in different vehicles in the same crash on type or location of injury seemed uninformative; e.g., considering only head injuries when occupants of either vehicle might have sustained other potentially serious injuries.

The distribution of injuries by type or location, however, is not very different for target and bullet vehicles in T-type crashes, or among front and rear L-type crashes and other IRC. Of all injuries, whiplash is the most common, reported in 37-44% of cases, closely followed by bruises. More severe injuries, such as fractures or concussion, are reported for less than 5% of injuries in all crash configurations. Occupants in IRC that we were unable to classify as either T- or L-types of crash had injury rates overall and injuries by type and location of most serious injury that are very comparable to all but L-type rear crashes.

With a logistic model it was possible to examine the influence of crash type on injury risk controlling for environmental variables and vehicle damage. The results are shown in Table 5. L-type frontal crashes were chosen as the reference group, so that the odds of injury for all T-type, L-type (rear) and Other were compared to this category.

TABLE 3
VEHICLE AND DRIVER CHARACTERISTICS BY CRASH TYPE

	T-type		L-type		
	Bullet N = 787	**Target** N = 787	**Front** N = 1596	**Rear** N = 700	**Other** N = 4194
Vehicle use:	%	%	%	%	%
Personal use	91.1	92.3	92.2	92.7	90.6
Vehicle damage:*	%	%	%	%	%
Write-off	4.2	8.0	5.7	2.9	8.0
Severe (frame)	30.1	29.2	30.1	20.9	28.3
Moderate (dents)	34.3	43.3	43.1	43.1	35.9
Light/none	31.4	18.5	21.1	33.1	27.9
Significance tests	χ^2 =20.6 on 6 df; $p = 0.02$		χ^2 = 94.6 on 6 df ; $p < 0.0001$		
Median model year	1993	1993	1993	1992	1993
Driver age: Mean ± SD	41.5 ± 18.2	41.6 ± 18.3	42.5 ± 18.8	41.4 ± 18.9	40.5 ± 18.1
% aged 65+	13.3	13.9	14.8	13.9	11.9
Occupants by position:	%	%	%	%	%
Driver	69.3	68.7	69.9	69.1	69.5
Other front seat	19.1	20.6	18.9	19.7	19.7
Left rear	4.3	3.8	4.3	3.6	3.9
Centre rear	2.0	1.6	1.7	1.4	1.9
Right Rear	4.7	4.2	4.3	5.2	4.4
Other	0.3	0.7	0.6	0.7	0.4

* Vehicle damage not specified in 6% of crashes

TABLE 4
OCCUPANT INJURY RATES BY TYPE, LOCATION AND CRASH TYPE

	T-type		L-type		
	Bullet	Target	Front	Rear	Other
# of occupants	1126	1155	2281	1013	6033
# with injuries	281	283	530	152	1478
Injury rate (%)	25.0	24.5	23.2	15.0	24.5
Injuries by type:	%	%	%	%	%
Bruise	33.1	32.5	39.6	35.5	36.3
Abrasion	10.3	9.5	8.5	12.5	7.9
Fracture	4.3	3.9	2.8	2.6	3.3
Concussion	3.9	1.4	2.1	1.3	2.8
Whiplash	37.4	44.2	37.4	40.8	37.6
Other	11.0	8.5	9.6	7.3	12.1
Injuries by location:	%	%	%	%	%
Head	24.2	23.0	21.7	23.0	24.8
Neck	29.5	31.4	32.6	31.6	30.4
Chest	13.9	7.8	15.7	7.2	11.2
Abdomen	2.1	3.9	1.5	2.6	2.5
Arm/hand.	17.8	15.2	13.6	16.4	15.4
Leg/foot	9.6	13.1	9.4	9.9	12.9
Other	2.9	5.6	5.5	9.3	2.8

TABLE 5
LOGISTIC REGRESSION RESULTS: INJURY AS A FUNCTION OF CRASH TYPE, ENVIRONMENT AND DAMAGE SEVERITY

Variable	OR	95% confidence interval
L-type front	1.00	NA
T-type	1.09	0.94 to 1.27
L-type rear	0.73	0.59 to 0.90
Other	1.10	0.97 to 1.25
Land use	$\chi^2 = 30.0$ on 4 df; $p < 0.0001$	
Light	$\chi^2 = 16.53$ on 4 df; $p = 0.0024$	
Weather	$\chi^2 = 28.23$; $p < 0.0001$	
Damage severity	$\chi^2 = 859.80$; $p < 0.0001$	

The confounding variables, damage severity and the environmental variables of land use, light and weather were all highly significant in their association with risk of injury. The odds ratios for different crash configurations were all close to 1, an indication that injury risk was similar to that for L-type (front) crashes, with one exception. L-type rear crashes had a significantly lower odds of injury, even after controlling for confounding factors.

4. DISCUSSION

The Insurance Corporation of British Columbia (ICBC) is a crown corporation operating in the province of British Columbia, Canada. Since 1973, it has provided basic automobile insurance for all registered motor vehicles in the province. It has also been given responsibility for driver licensing and vehicle registration. In these circumstances, ICBC possesses data from all police-reported traffic crashes in the province, independently of any claims filed by either involved driver. Additional data from claims files might have augmented these analyses, but was not available for several reasons, the most important being concerns about confidentiality. The files used in these analyses had been stripped of all identifying information regarding the vehicle and any occupants before being used in these analyses.

For many crashes, these files would contain more detailed information about the nature and severity of injuries, particularly severe injuries, thanks to information provided by physicians and hospitals involved in the diagnosis and treatment of people making claims. From the police report, the location and type of only the injury that appeared to be 'most severe' were available. The accuracy of this information is uncertain. However, apart from reporting the distributions of these characteristics by type of crash (Table 4), only the overall proportion of injuries reported has been used in analyses.

These files might also have provided more detailed information about the crash itself which could have been used to refine the algorithm used to classify crashes as T-type, L-type or Other. The fact that a large proportion of IRC were Other; i.e., could not be classified by the algorithm used here, is a cause for concern. The algorithm itself may define categories too narrowly, excluding crashes that, with more information, would have been classified as T- or L-type. Alternatively, the translation from a diagram in the crash report to a coded value may be more difficult than we have assumed: the diagrams may be hard to interpret, resulting in coding errors, for example. We are interested in the initial impact damage; the police report the total damage. In crashes where one of the two vehicles rolled over, or hit a tree after the initial impact, it may be very difficult to classify crashes as we have tried to do. Some jurisdictions include a text description of the crash, with diagrams; this was not available for these data. It may be useful to compare the documentation of crashes in this and other jurisdictions to assess the effectiveness of different methods used to classify crashes.

An alternative explanation is simply that the designation "intersection, right angle" includes many different types of crash, a much richer variety than has been assumed here: rear-end, head-on, etc. The proportions reporting injuries is about the same as for classic T-type and L-type (front) crashes, but, if the varieties of crashes is greater, the remedies to reduce crash risk and the risk of injury will also need to be more varied.

The comparison of target and bullet vehicles in T-type crashes, with and without adjusting for environmental factors, indicates comparable risks of injury for occupants of both vehicles in these crashes. This is despite significant differences in vehicle damage between target and bullet vehicles in the same crash. This is surprising: the occupants of target vehicles are assumed to be less well protected by the side of their vehicle than occupants of a bullet vehicle are by mass and vehicle design in the front. This might be explained by seat belt use and by vehicle damage absorbing some of the energy of the crash that would otherwise be transferred to occupants. Other studies of instrumented crashes or computer simulations would be valuable to examine this further.

Because occupants of target and bullet vehicles had similar risks of injury, all vehicles in T-type crashes were considered together in comparisons with other crash types, where discrimination between target and bullet vehicles was impossible from these data. The crude injury rate for all T-type crashes is 24.7%, very similar to rates for other types of crash, with the exception of L-type rear crashes. This pattern held even after adjustment for some highly significant environmental variables: weather, light, and land use.

Crashes involving the rear corner of one vehicle have both lower proportions injured and lower levels of vehicle damage. If a large proportion of IRC are of this type, then the risk of injury may appear lower than applies to most intersection crashes. With less than 10% of the eligible crashes fitting this configuration, however, these crashes have little influence on the overall risk. This suggests that our characterization of intersection right-angle crashes and their risks as a single group may not be far off the truth. The hazards of injury in most intersection right angle crashes do not vary very much, including those crashes we could not classify reliably.

The variety of crash configurations is often influenced by the design of the intersection, lines of sight, traffic control etc. Some designs, like traffic circles, reduce the chance of T-type crashes simply by altering the speed and relative directions of travel of vehicles. Although these designs have been used primarily in residential neighbourhoods in Canada, they are also found on motorways in the UK, so they have potential for a wide variety of traffic situations.

The risk of injury is also influenced by vehicle size; there is no indication of vehicle weight in these data; vehicle type has been used, in related studies, to examine the differences in crashes involving passenger cars and larger passenger vehicles: pick-up trucks, minivans etc. (Desapriya, Chipman, Joshi et al., 2005). While the effects of vehicle mismatch on injury appear strong, they are unlikely to influence the comparisons here, unless vehicle mismatch is more or less common in different crash configurations. This seems unlikely.

The injury rates used here are not true estimates of injury risk; i.e., the probability that, if an occupant is involved in a crash, he or she will be injured. This is because, in this jurisdiction, there is substantial under-reporting of property damage only crashes, where no one involved in the crash is injured. For this reason, we have used the odds ratio to compare the proportions injured. The odds ratio is not affected by such under-reporting (Selvin, 1995) provided that it is equally likely in T-type, L-type and other crashes. This assumption seems likely, but cannot be evaluated from these data. It would require comparisons of types of IRC from a data base that used the same data collection system but was more complete, to see if selection factors exist.

Despite limitations, these analyses have provided useful information about the variety and consistency of intersection right-angle crashes. This should help to inform our interpretation of data from such crashes in the future.

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