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Characteristics of Multiple Impact Crashes in ANCIS

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ABSTRACT

ANCIS (The Australian National Crash In Depth Study) has been collecting in-depth real-world crash cases for four years, with more than 350 cases collected to date in Victoria and NSW. In this retrospective study, participants have been hospitalised as a result of injuries sustained in a motor vehicle crash, where the vehicle in which they were travelling was manufactured since 1989. Where possible, participants are administered a structured interview, their medical records examined, the vehicle inspected and photographed and the site of the crash inspected in detail. A best evidence synthesis approach is utilised to determine the crash circumstances (without apportioning blame) and occupant injury causation.

Multiple impact crashes made up 32% of the dataset, showing a trend toward higher severity outcomes. In one-third of the multiple impacts a rollover was present, with the first impact being the most severe in the majority of cases, whether or not it happened to be the rollover event. While not yet a significant trend, there appeared to be a tendency toward higher injury severity (as measured by ISS) if the most severe impact occurred later in the crash sequence. Finally, head and spinal injuries of AIS3+ were significantly more likely to occur in multiple impacts compared with single impact crashes.

ANCIS is unique in that study sponsors from a wide variety of backgrounds are successfully collaborating to fund this valuable resource of in-depth data that will increasingly assist with a systems approach to solving the problem of road crashes, with in-depth information available on the occupant, vehicle and road environment aspects of a crash.

BACKGROUND

While much attention has been paid by researchers to real-world and laboratory crashes involving a single frontal, side, rear or rollover crash, real-world studies show that multiple impacts constitute a significant proportion of crashes and have their own particular characteristics. Using the ANCIS database of retrospectively collected crash data, consisting of around 240 in-depth cases collected over a four-year period where at least one occupant was hospitalised, this work aimed to identify some of the features of multiple impact crashes, contrasting them with those involving a single impact alone. More than 1300 variables focusing on the human (occupant interview and injuries), vehicle and road environment are acquired for each of the cases, allowing detailed analyses to be conducted into crash characteristics and injury causation not possible using mass databases.

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STATISTICAL METHOD

Cases in the database were divided into two groups according to whether the case participant was an occupant of a car involved in a multiple impact crash or a single impact crash. A multiple impact was defined as a crash in which the case vehicle experienced two or more separate, consecutive impacts with other vehicles or objects; or where there was a rollover event either before or after a single impact. Therefore, single impact crashes included cases in which the case vehicle was involved in a rollover but did not impact with another object; or was involved in a single impact without a rollover occurring. Methods used to analyse the effect of multiple impact crashes on injury outcomes include Fischer's Exact Test (in which observed cell counts were compared to expected cell counts and the difference between the two tested for significance) and Analysis of Variance (ANOVA) tests. Fisher's Exact Test was preferred over Pearson's Chi Square test for assessing the relatedness of categorical data because in many analyses there were several individual cells with low expected counts. ANOVAs were used to compare means for the continuous, scaled Injury Severity Score.

RESULTS

Distribution of single and multiple impact crashes

Of the 350 cases recruited at the time of writing, a number were in still progress and there were 245 cases in the ANCIS database for analysis. A case is represented by a single injured vehicle occupant. There were 218 vehicles involved in the 245 cases analysed. Two were discarded due to insufficient injury data. Of the remainder, 77 involved multiple impacts. While rollover events only made up one-third of the sample (26 of 77 crashes), their three-dimensional nature means that they are more likely to put occupants out of position or lead to ejection so they were treated as a key variable in this analysis. Crashes involving only a rollover were classified as single impacts and there were just six of these in the database. Table 1 shows that of the 77 multiple impacts in the database, 26 (34%) involved a rollover plus one or more impact. The rollover was the final event in 14 of these and the first event in a further eight. Similar patterns were observed when only occupants sustaining injuries of MAIS3 or greater were examined.

Table 1: Impact type by all injury severities and MAIS3+ injuries.

Impact Type	Single Impact		Multiple Impact		Total	
	All	AIS3+	All	AIS3+	All	AIS3+
Rollover before impact	-	-	8	6	8	6
Rollover after impact	-	-	14	10	14	10
Rollover occurred, sequence unknown	-	-	4	3	4	3
Rollover without impact	6	3	-	-	6	3
No Rollover	160	100	51	31	211	131
Total	166	103	77	50	243	153

Figure 1 shows the distribution of the maximum AIS for cases by whether they were involved in single and multiple impact crash. A Chi Square analysis showed that there was no statistically significant relationship between maximum AIS and whether the occupant was involved in a single vehicle or multiple impact crash ($\chi^2(6) = 7.183$, p = 0.296), although the chart suggests a trend towards a higher proportion of injuries of AIS4 and higher for multiple impacts compared with single impacts.

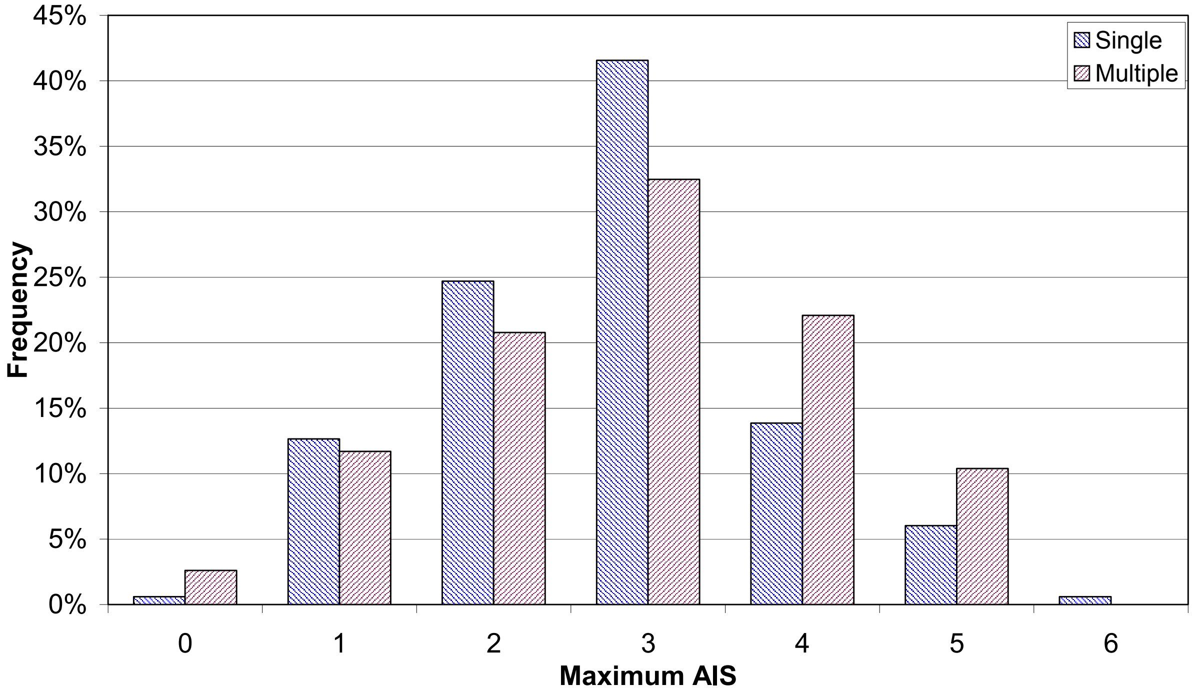

Figure 1. Distribution of Maximum AIS by single or multiple impact type.

The Injury Severity Score (ISS) is commonly used to indicate overall injury severity, as it takes into account the effect of injuries to more than one body region[2]. The mean ISS for the hospitalised sample contained within the ANCIS database was 14.5 (n = 166) for single impact crashes and 16.6 (n = 77) for multiple impact crashes, although this difference was not significant (t = -1.186, df = 241, p = 0.237).

Individual impact sequence and severity in multiple impact crashes

In this section the sequence of impacts in multiple impact crashes is considered in more detail. Table 2 shows the number of non-rollover impacts for the 77 multiple impact cases analysed, by the sequence in which the rollover event occurred. There was no rollover event in 51 of the 77 cases (66%). Of these non-rollover cases, the majority (41) involved two impacts, but up to five impacts were recorded in one crash. The most common multiple impact crash in which a rollover occurred was rollover plus another impact, comprising 15 cases. The ANCIS data collection team also makes a judgement as to the order of impacts in the crash event, including whether rollover happened before, in between or after any other impacts. In eight of the 15 ‘rollover plus one

[2] ISS is calculated by summing the squares of the highest AIS scores in the three most severely injured body regions [AAAM, 2001]

impact' crashes, the rollover happened after the impact. There were a total of 11 cases in which a case occupant was travelling in a vehicle that was involved in two or more separate impacts in conjunction with a rollover.

Table 2: Distribution of the number of non-rollover impacts in multiple impact crashes by the location of the rollover event in the crash sequence.

Rollover Occurred		Number of non-rollover impacts					Total
		1	2	3	4	5	
None	N	N/A	41	8	1	1	51
	%	N/A	80.4	15.7	2.0	2.0	100.0
Before impact	N	4	2	2	0	0	8
	%	50.0	25.0	25.0	0.0	0.0	100.00
After impact	N	8	4	2	0	0	14
	%	57.1	28.6	14.3	0.0	0.0	100.00
Unknown	N	3	0	1	0	0	4
	%	75.0	0.0	25.0	0.0	0.0	100.00
Total	N	15	47	13	1	1	77
	%	19.5	61.0	16.9	1.3	1.3	100.0

Note: There were no crashes recorded in which the rollover event occurred in between two or more non-rollover impacts.

The ANCIS database records the Collision Deformation Characteristic (CDC) code for the first three impacts, along with a CDC for any rollover damage. Table 3 shows the distribution of multiple impacts by the impact number in the crash sequence that represented the most severe impact, noting whether or not a rollover occurred. Note that the table does not include two cases that appeared in Table 2, as CDC codes are only recorded for the first three impacts. Severity in this table refers to crash severity, measured by extent of damage as indicated by the final digit of the CDC code, given that the usual indicators of crash severity, namely delta-V or EBS (Equivalent Barrier Speed), are not applicable to multiple impact or rollover crashes.

Table 3: Order in which the most severe impact occurred in the multiple impact crash sequence, including the presence and order of a rollover event.

Rollover Occurred		Most severe impact (chronological order)						Total
		Rollover before impact	1	2	3	Rollover, sequence unknown	Rollover after impact	
None	N	N/A	40	6	3	N/A	N/A	49
	%	N/A	81.6	12.2	6.1	N/A	N/A	100
Before impact	N	5	3	0	0	0	0	8
	%	62.5	37.5	0	0	0	0	100
After impact	N	0	10	0	0	0	4	14
	%	0	71.4	0	0	0	28.6	100
Unknown	N	0	1	0	0	3	0	4
	%	0	25	0	0	75	0	100
Total	N	5	54	6	3	3	4	75
	%	6.7	72	8	4	4	5.3	100

Table 3 clearly shows that regardless of the presence or order of rollover in the multiple impact crash sequence, the first impact was most likely to be the most severe, with this being the case in 55 of the 71 cases (77%) with a known crash sequence.

It is probably not unexpected that the first event in the crash sequence is most likely to be the more severe, since vehicle kinetic energy is at a maximum immediately prior to the beginning of the crash. However, injury severity may not follow the same pattern, for two main reasons. First, the majority of occupant protection systems are designed for a single crash event, with airbags (curtain side airbags excepted), deploying and deflating within a few hundred milliseconds. This leaves the occupant unprotected in the subsequent impacts. Second, the violent decelerations involved in many impacts are likely to throw the occupant into physical configurations both unsuited to the absorption of further energy and outside the scope considered by vehicle safety designers.

Despite the small number of cases available for analysis, an attempt was made to investigate this issue by computing the mean ISS for some of the cells in Table 3. In the case of non-rollover multiple impact crashes, the mean ISS varied from 14.1 (SD = 12.9) when the first impact was the most severe, to 17.8 (SD = 17.3) when the second impact was the severest, to 28.0 (SD = 16.1) when the third impact was the worst. Although the standard deviations are quite high, there is a trend toward the mean ISS being highest the later the most severe impact occurs in the crash sequence. For crashes where rollover occurred, the mean ISS was 16.0 (SD = 12.5) when the rollover was the most severe impact and occurred prior to other impacts, compared with 26.5 (SD = 13.6) when rollover occurred last and was the most severe impact. Once again, this suggests a trend toward higher injury severity when the more severe impact occurred at the end of the sequence. Note that it was not possible to reliably associate specific injuries with individual crash events, so it is not known whether the most severe impact in a sequence was the biggest contributor to the injuries sustained.

Injury outcomes by body region

In order to further investigate the apparent trend towards multiple impacts producing more severe injuries, the analysis was broken down into separate body regions. In each of the eight AIS regions (head, face, neck, thorax, abdomen/pelvis, spine, upper extremities and lower extremities) the observed number of AIS3+ injuries was compared with the number expected and a Chi Square test conducted for significance. The reader should be aware that because a Chi Square test is being conducted for each of the eight body regions, the probability of obtaining a significant p-value by chance in one of the tests is actually greater than 0.05.

Head Injuries

Table 4 shows that there were significantly more AIS3+ head injuries than expected for cases involved in multiple impacts (18 cases observed compared with 12 expected). There was one head injury with a coded severity of 9, meaning that insufficient information was available to accurately determine the AIS level. This injury was not included in the analysis.

Table 4: Distribution of cases receiving an AIS3+ head injury by whether the vehicle was involved in a single or multiple impact collision.

AIS3+ Head Injury		Single Impact	Multiple Impacts	Total
No	Observed	145	59	204
	Expected	139	65	204
Yes	Observed	21	18	39
	Expected	27	12	39
			$\chi^2(1) = 4.491$, p = 0.040	

Note: Expected values rounded to nearest whole number.

Of the 18 participants sustaining AIS3+ head injuries in a multiple impact crash, six had a single injury of this type, five with two head injuries and small numbers experiencing between three and six injuries. Further analysis was undertaken into the specific AIS anatomic structure in which these injuries occurred and to compare their occurrence in multiple versus single impact crashes. There were no cases involving the cranial nerves and one each coded as 'whole area' or 'intracranial vessels'. There was a non-significant trend toward a greater number of AIS3+ skull fractures in multiple impacts (($\chi^2(1) = 2.695$, p = 0.139), while the number of cases with internal head injuries of AIS3+ was significantly greater in multiple impacts, with 16 observed compared with 10 expected ($\chi^2(1) = 5.709$, p = 0.024). The various contact sources ascribed to the brain injuries included the windscreen, steering wheel, door and surround, roof and the exterior of the other vehicle. The only contact source whose incidence in multiple vehicle crashes was significantly greater than in single impacts was 'Ground or other vehicle/object' ($\chi^2(1) = 4.571$, p = 0.083). This may indicate that the head is more likely to protrude from the vehicle in multiple impacts (including rollovers), the other vehicle or external object may be intruding into the case vehicle (in side impacts, for example) or it could simply be a reflection of the greater difficulty in determining contacts in complex situations where occupant kinematics are less able to be confidently inferred. Although beyond the scope of this paper, a larger dataset would allow the different injury outcomes arising from the range of rollover initiation methods to be further investigated.

Facial Injuries

Table 5 shows the distribution of cases that received a facial injury of AIS3+ by whether the case was involved in a multiple or single impact collision. Note that while the most severe codable injury to the face is AIS4, there were no cases in the database that had a facial injury of this level. There were only three cases with facial injuries of AIS3+ in the database, so no trends can be observed at this stage. Even amongst facial injuries of all severity levels, there were no significant trends.

Table 5: Distribution of cases receiving an AIS3+ facial injury by whether the vehicle was involved in a single or multiple impact.

AIS3+ Face Injury		Single Impact	Multiple Impacts	Total
No	Observed	163	77	240
	Expected	164	76	240
Yes	Observed	3	0	3
	Expected	2	1	3
				$\chi^2(1) = 1.409$, $p = 0.554$

Note: Expected values rounded to nearest whole number.

Neck Injuries

For those not familiar with the AIS, neck injuries do not include those affecting the spinal cord or cervical vertebra, which are categorised under the spine (see later section). Only 33 of the 243 cases analysed had any neck injury, with just four of AIS3 or above. There was no relationship observed between multiple impact crashes and the number of cases with neck injuries (See Table 6 below).

Table 6: Distribution of cases receiving an AIS3+ neck injury by whether the vehicle was involved in a single or multiple impact.

AIS3+ Neck Injury		Single Impact	Multiple Impacts	Total
No	Observed	163	76	239
	Expected	163	76	239
Yes	Observed	3	1	4
	Expected	3	1	4
				$\chi^2(1) = 0.084$, $p = 1.0$

Note: Expected values rounded to nearest whole number.

Thorax Injuries

Of the multiple impact cases, 27 (35%) suffered a chest injury of AIS3+, as did 50 (30%) of the 166 single impact cases. However there was no significant relationship between the number of cases with injuries to the thorax and whether the case involved a single or multiple impacts (see Table 7).

Table 7: Distribution of cases receiving an AIS3+ thorax injury by whether the vehicle was involved in a single or multiple impact.

AIS3+ Thorax Injury		Single Impact	Multiple Impacts	Total
No	Observed	116	50	166
	Expected	113	53	166
Yes	Observed	50	27	77
	Expected	53	24	77
			$\chi^2(1) = 0.594$, p = 0.461	

Note: Expected values rounded to nearest whole number.

Abdomen and Pelvic Injuries

Note that skeletal injuries to the pelvis are categorised under 'Lower Extremities' and therefore covered in a later section. There was no measurable relationship between the number of AIS3+ abdominal injury cases and single/multiple impact involvement, as can be seen in Table 8.

Table 8: Distribution of cases receiving an AIS3+ injury to the abdomen or pelvic contents by whether the vehicle was involved in a single or multiple impacts.

AIS3+ Abdomen/Pelvic Contents Injury		Single Impact	Multiple Impacts	Total
No	Observed	147	71	218
	Expected	149	69	218
Yes	Observed	19	6	25
	Expected	17	8	25
			$\chi^2(1) = 0.761$, p = 0.498	

Note: Expected values rounded to nearest whole number.

Spinal Injuries

Spinal injuries include the brachial plexus nerves, the spinal cord and skeletal injuries to the cervical, thoracic and lumbar spines. Table 9 shows that of the 77 cases involved in multiple impacts, only ten received spinal injuries of AIS3+. However, the expected value was just six, with this difference being statistically significant ($\chi^2(1) = 4.177$, p = 0.069).

Table 9: Distribution of cases receiving an AIS3+ injury to the spine by whether the vehicle was involved in a single or multiple impact.

AIS3+ Spinal Injury		Single Impact	Multiple Impacts	Total
No	Observed	157	67	224
	Expected	153	71	224
Yes	Observed	9	10	19
	Expected	13	6	19
			$\chi^2(1) = 4.177$, p = 0.069	

Note: Expected values rounded to nearest whole number.

Of the ten participants involved in multiple impact crashes suffering spinal injuries of AIS3+, eight had one codable injury and two had a pair of spinal injuries. Some further analysis was undertaken to identify the location of these spinal injuries and their relative occurrence in multiple versus single impact crashes. The only spinal region experiencing significantly more spinal injuries was the cervical spine, with nine cases compared with an expected value of five ($\chi^2(1) = 4.774$, p = 0.048). A variety of contact sources were attributed to the cervical spine injuries including the windscreen, left-hand B-pillar, other vehicle exterior, the ground and non-contact sources (inertial forces). The most common contact point, however, was the roof, with one-third of the nine cervical spine injuries being attributed to this contact source.

Upper Extremity Injuries

Upper extremity injuries do not exceed AIS3 and include all the systems within the arms. There was no relationship between the number of AIS3+ injury cases and whether the case vehicle was involved in one or more impacts (Table 10).

Table 10: Distribution of cases receiving an AIS3+ injury to the upper extremities by whether the vehicle was involved in a single or multiple impacts.

AIS3+ Upper Extremity Injury		Single Impact	Multiple Impacts	Total
No	Observed	149	66	215
	Expected	147	68	215
Yes	Observed	17	11	28
	Expected	19	9	28
			$\chi^2(1) = 0.844$, p = 0.391	

Note: Expected values rounded to nearest whole number.

Lower Extremity Injuries

This AIS category includes the pelvis (but not pelvic contents) and the legs. As with the upper extremities, there was no significant relationship between AIS3+ injuries to this region and the number of single or multiple impact crashes, as shown in Table 11.

Table 11: Distribution of cases receiving an AIS3+ injury to the upper extremities by whether the vehicle was involved in a single or multiple impact.

AIS3+ Lower Extremity Injury		Single Impact	Multiple Impacts	Total
No	Observed	125	63	188
	Expected	128	60	188
Yes	Observed	41	14	55
	Expected	38	17	55
			$\chi^2(1) = 1.276$, p = 0.323	

Note: Expected values rounded to nearest whole number.

CONCLUSION

In this analysis of 243 crashes from the ANCIS dataset, 32% involved more than one significant impact and showed a trend toward higher severity outcomes than for single impact crashes. In one-third of the multiple impact crashes a rollover was present, with the first impact being the most severe in the majority of cases, whether or not it happened to be the rollover event. While not yet a significant trend, there appeared to be a tendency toward higher injury severities (as quantified by the ISS) when the most severe impact occurred later in the crash sequence. Finally, head and spinal injuries of AIS3+ were significantly more likely to occur in multiple impacts compared with single impact crashes. With regard to head injuries, there was a greater than expected number of serious internal brain injury cases in multiple impacts. It was also clear that considering 'rollover' as a single event was an oversimplification and future work needs to be conducted into the different types of rollover, as they are expected to lead to widely varying injury outcomes.

Examining specific aspects of a relatively small yet rich dataset such as this frequently leads to conclusions that are not statistically significant. For this reason, the analyses will need to be refined as the quantity of data grows. Despite these limitations, there are already clear indications that multiple impact crashes lead to different injury outcomes that are more severe, particularly with regard to the head and spine, than those eventuating from single impact crashes.

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