Dynamic Research, Inc.

REVIEW OF SEA REPORTS
ON ATV ROLLOVER DYNAMIC AND SLED TESTS

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Section I

SUMMARY

All-terrain vehicle (ATV)-related fatalities and injuries in the U.S. have been declining for over ten years. According to the Consumer Product Safety Commission (CPSC), reported ATV-related fatalities declined since 2008, and injuries treated at emergency rooms also declined in a statistically significant overall trend (Ref 1). The CPSC, along with industry participants and other stakeholders, has contributed to this positive trend through efforts emphasizing ATV rider education and training. Specific efforts have promoted hands-on safety training courses, and the use of helmets and other protective gear. Campaigns also seek to eliminate warned-against behaviors, such as ATV use on paved roads, riding under the influence of alcohol or drugs, children under age 16 using adult-sized ATVs, and carrying of passengers on vehicles not intended for such use.

To study the potential for further ATV safety improvements, the CPSC has funded a series of technical studies by the engineering consulting firm SEA Ltd. (SEA), relating to stability and rollover testing of ATVs. This review encompasses SEA's reports on its two most recent studies, released by the CPSC in October 2019 and August 2020, respectively (the "SEA Reports"):

"ATV Rollover Tests and Verification of a Physical Rollover Simulator" (Ref 2). This study was an effort to correlate the rollover results for a sled simulator with the results from actual dynamic rollover testing.

"Rollover Tests of ATVs Outfitted with Occupant Protection Devices (OPDs)." (Ref 3). This set of tests attempted to determine the efficacy two particular ATV Occupant Protection Devices (OPDs) using a Hybrid III dummy to represent the rider. The tests included subjecting several ATV models to both dynamic and simulated rollovers with and without the OPDs attached.

Analysis of SEA's OPD efficacy testing found that there were no statistically significant differences between the baseline ATV model and the ATV equipped with either of the OPDs with respect to (1) "pinning" of the rider under the ATV at the end of the rollover, or (2) head injury as measured by the Head Injury Criterion (HIC).

This review took note of accounts by international media and regulatory agencies who have misrepresented the SEA Reports. For example, the Australian government recently implemented regulations that require OPD fitment on ATVs (also known as "quad bikes"). In September 2020, the Australian Competition and Consumer Commission (ACCC) and media sources incorrectly pointed to the SEA Reports as justification for the new OPD requirements. The ACCC stated that "Operator protection devices, or roll bars, on quad bikes may significantly reduce the number of times a rider is injured or killed by the quad bike when it rolls sideways in an accident, according to a new US Government study" (Ref 4). An Australian newspaper called the Weekly Times went further and cited the SEA Reports as "PROOF that [OPDs] save lives and curb injuries…" (emphasis in original) (Ref 5).

In fact, neither SEA nor the CPSC reached the conclusions that the Australian government agencies and media sources suggest. To the contrary, SEA and the CPSC did not make any findings or conclusions supportive of the use of OPDs. Readers of the SEA Reports might be making an assumption that "significant interactions," as described in SEA's test results, inevitably result in actual injuries. This is not the case. By their nature, assessments of "significant interactions" are highly subjective, and do not equate with injuries. Indeed, a more careful review of the images contained in the SEA Reports shows that, in some cases, fitment of an OPD might itself lead to more severe "significant interactions" by uplifting the ATV during a rollover, thus causing it to land on top of the dummy from a greater height.

Additionally, the ACCC has claimed that a principal safety benefit associated with OPD fitment is prevention of crush asphyxiation deaths of riders pinned underneath the ATV. (Ref 6). **However, the SEA test results do not indicate that OPDs prevent pinning. In SEA's tests, there was no difference between the OPD and non-OPD outcomes regarding the rates at which the dummy was judged to have "significant interaction" with the ATV *at the end* of the test.** The SEA test results are consistent with other research, which found that OPDs do not prevent pinning, as will be discussed subsequently.

This review of the SEA Reports also calls into question the suitability of using sled rollover tests as a repeatable surrogate for dynamic rollover testing. The SEA tests included both dynamic rollover tests and sled rollover tests. Analysis of the SEA test results indicates that the sled rollover tests produce results that are different than the dynamic tests, suggesting that the sled tests are not a suitable surrogate for dynamic rollover tests.

Finally, this review found that results from the SEA tests regarding the efficacy of ATV Operator Protection Devices (OPDs) are generally consistent with the two other research efforts that evaluated OPDs over large samples of accidents. The first was based on a Dynamic Research, Inc. (DRI) computer simulation model that was run with and without a Quadbar OPD in a sample of 770 overturn types taken from U.S. and U.K. ATV accident data (Ref 7). The second was an ATV workplace survey conducted by TARS in Australia in 2017 (Ref 8). A comparison of the SEA test results, DRI simulation results, and TARS workplace survey results is shown in Table 1.

In summary, three separate approaches -- the SEA tests, the DRI simulations, and the TARS survey – all fail to demonstrate net safety benefits from fitting an OPD. Two of the approaches – the DRI simulations and TARS survey – indicate potential harm from OPD fitment. And, although the SEA Reports does not express a view on this later point, some of the SEA tests indicate the potential for OPDs to raise the ATV to a greater height during the rollover, which can exacerbate injuries if the ATV lands on the rider. **Taken together, this research makes clear that OPDs are not valid safety devices and should not be fitted to ATVs.**

Table 1. Comparison of SEA test results, DRI simulation results, and TARS workplace survey results

	SEA test results	DRI simulation results	TARS workplace survey
Head injury	There were no statistically significant differences in the Head Injury Criterion (HIC_{15}) between the baseline ATV and either the Quadbar or the LifeGuard ATVs. The HIC_{15} values observed in these tests were relatively small values associated with either no injury or minor (AIS=1) closed skull head injuries.	There were no statistically significant differences in HIC or other head injury metrics between the baseline ATV and the Quadbar ATV.	No data available
Potential for OPDs to cause or increase injuries	There was a statistically significant higher number of subjective “significant interactions” during the rollovers for the baseline ATV than for the OPD ATVs, but this did not result in statistically significant differences in the HIC_{15} measure for the head Images from the tests indicate potential for OPDs to raise the ATV to a greater height during the rollover, which can result in injuries if the ATV lands on the rider.	The Quadbar OPD subjectively reduced contacts between the ATV and dummy in some accident types, but this did not result in statistically significant differences in recorded injuries to the head, neck, chest, abdomen, femurs, knees, or tibias. The phenomenon of the OPD raising the height of the ATV during the rollover and increasing the severity of injuries was observed in some of the simulations. A phenomenon of “spearing” of the rider occurred in some simulations when the Quadbar landed on the rider when the rider was on the ground and the ATV was in an inverted orientation.	In the “Fleet Managers Survey” sub-study, the Quadbar-equipped ATVs had a statistically significant higher rate of hospital visits resulting from ATV rollovers than the baseline ATVs.

	SEA test results	DRI simulation results	TARS workplace survey
Pinning of the rider at the end of the rollover	There were no statistically significant differences between the baseline ATV and either the Quadbar or the LifeGuard ATVs in the SEA subjective “ATV Rest Position” ratings between the ATV and rider at the end of the rollover.	There were no statistically significant differences between the baseline ATV and the Quadbar ATV in the rates of asphyxiation.	No data available
Overall injury effects of OPDs	There were no statistically significant differences in injuries or pinning (ATV Rest Position) between the baseline ATV and either the Quadbar or the LifeGuard ATVs.	There were no statistically significant differences in injuries between baseline ATVs and Quadbar-equipped ATVs across a wide range of simulations comprising 110 overturn types with 7 variations on each (770 simulations for each helmet/half helmet/no helmet rider configuration)	There were no statistically significant differences in the rates of “any injury” or “serious injury” between baseline ATVs and OPD-equipped ATVs in the “Individual Workplace Riders (main)” sub-study. Note that in the “Fleet Managers Survey” sub-study, the Quadbar-equipped ATVs had a statistically significant higher rate of hospital visits resulting from ATV rollovers than the baseline ATVs.

Section II

DISCUSSION OF SEA TEST LIMITATIONS

Although the SEA reports (Refs 2 and 3) comprise a valuable contribution to the understanding of the safety effectiveness of OPDs fitted to ATVs, it is important to note some limitations of these tests. Some of the key ones are discussed in this section, and additional ones can be found in APPENDIX A.

A. Limitations of the injury measures

1. Objective Injury Measures

The only objective injury measures recorded by SEA for the Hybrid III dummy were HIC (based on head accelerations) and chest accelerations. The MATD dummy would have allowed a much broader view of the injury outcomes because it is also capable of monitoring potential injuries to other important body regions listed in Table 2. The Hybrid III dummy used in the SEA tests is capable of monitoring head injuries due to HIC, but the measured values may not be accurate because the neck stiffnesses of the Hybrid III in vertical and lateral directions are not biofidelic.

Table 2. Monitorable Injuries Using the MATD Dummy

Body region	**Injury measure**
Head	HIC, GAMBIT (based on linear and angular accelerations)
Neck	NII (based on forces and moments)
Chest	Compression, VC (Viscous Criterion)
Chest	Asphyxiation (based on chest forces at final resting point)
Abdomen	Compression
Femur	Fracture (based on forces and moments)
Knee	Ligament tear (based on forces and moments)
Tibia	Fracture (based on forces and moments)

Because the MATD is capable of monitoring injuries to these key body regions, it is also possible to calculate an injury cost associated with a crash test (Ref 11). This is important because a “moderate” injury to one body region (e.g. a tibia) is not equivalent to a “moderate” injury to another body region (e.g. the head); as indicated in, for example, Ref 12. This allows a comparison between tests that result in multiple injuries to various body parts, which is not possible with the Hybrid III dummy.

2. Subjective Injury Ratings

The SEA report (Ref 3) has results for two subjective ratings for each test. The ratings are:

- Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head
- ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head

These ratings are defined as “the occurrence of having a significant portion of the ATV – subjectively estimated to be a load of 50% of more of the total weight of the ATV – supported by the pelvis, abdomen, thorax or head at any time (regardless of duration) during the rollover event.” SEA appears to be using these subjective ratings as a surrogate for objective measures of potential injury indices.

Importantly, not all "significant" interactions will have the same potential to cause injury, which means that simply counting them is not useful as a measure of injury. It is very common for riders involved in ATV rollovers in which there are interactions between the ATV and the rider to avoid any injury.

As just one example, images from a YouTube video of an ATV rollover are shown in Figure 1 (Ref 14). In this rollover, there is significant interaction between the ATV and rider as shown in the upper right image. However, as can be seen in the lower right image, the rider can be seen running after his tumbling ATV. The rider can be heard in the audio to say "Yeah, I'm OK".

There are several other problems with the subjective rating approach. One problem is that it is difficult for a researcher to see all potential significant interactions between the ATV and rider from a limited number of fixed camera views. Another problem is that different researchers may come to different results, and may be influenced by their own biases, because it is subjective.

a) Beginning of rollover

b) Non-injurious significant interaction

c) Separation between rider and ATV

d) Rider running toward ATV

Figure 1. YouTube example video of a rollover with “significant interaction” and no injury

In contrast to the non-injurious rollover in Figure 1, the SEA dynamic minimum energy tests with Vehicle A are shown in the sequences in Figure 2. The ATV in the Baseline test rolls over the dummy, similar to the YouTube example shown above, and this is judged by SEA to be a significant interaction. However, in the LifeGuard and Quadbar tests, the center of gravity of the ATV is raised up as the ATV goes to the inverted position, and then it falls onto the dummy from a greater height. Although all three of these events were judged to be significant interactions, it appears that the interaction from the ATV falling onto the dummy in the LifeGuard and Quadbar tests is more severe than the interaction in the baseline test. As seen in the top row of images, the LifeGuard and the Quadbar have raised the center of gravity of the ATV so that when it falls onto the dummy, as shown in the second row of images, the “significant interaction” appears to be substantially more severe.

Baseline LifeGuard Quadbar

Figure 2. SEA dynamic minimum energy tests

This phenomenon has also been observed in computer simulations (Ref 7). As discussed in subsection C below, in rearward overturns with an ATV ascending a steep hill, when the ATV pitched rearward onto the Quadbar, there was a “pole vaulting” effect where the ATV was lifted higher as it pivoted about the top of the Quadbar. When the ATV landed on the dummy, it was from a greater height than in the baseline case, resulting in maximal (fatal) injuries.

B. Correlation of dynamic tests with sled tests

In a multi-variable regression of the SEA results, the only factor that was predictive of whether or not there was a significant interaction between the dummy and the ATV at the final position was whether or not the test was a dynamic test or a sled test as shown in Table 3. This means that neither the vehicle configuration (baseline, Quadbar, or LifeGuard) nor the test energy level (minimum energy or moderate energy) had a statistically significant effect on interaction between the dummy and the ATV at the final position. This is discussed in more detail in Section IV.

Table 3. Multi-variable logistic regression of the influence of test factors on the subjective "significant interaction between the ATV and dummy at the final position" ratings

Factor	P-value[1]	Exp(B)
Quadbar[2]	0.952	0.941
LifeGuard[2]	0.952	0.941
Sled Test	0.007	0.091
Moderate Energy	0.236	2.749
Constant	0.294	0.388

Notes:

[1]A P-value of less than 0.05 indicates that the factor was statistically significant at the 95% confidence level.

[2]The OPD name was redacted in the SEA report. It is assumed that the first OPD was a Quadbar and the second OPD was a LifeGuard based on the pictures of the devices.

Because the outcome of the sled tests is different than the dynamic tests and that difference is statistically significant, the sled tests cannot be considered to accurately represent the outcomes of the dynamic tests and are not a suitable surrogate for these tests.

C. Limited overturn scenarios

The SEA tests were limited in scope to dynamic rollovers resulting from a step steer at two different speeds, and sled tests to induce lateral rollovers, at two different initial speeds. This is an important limitation because previous research (Ref 7) has found that other overturn types and directions such as overturns on slopes with forward, rearward, or lateral overturns can influence the risks and benefits associated with a Quadbar.

For example, in the rearward overturn discussed in subsection A previously and shown in Figure 3, as the ATV pitches rearward onto the Quadbar, the ATV pivots at the top of the bar, which raises the center of gravity of the ATV. When the ATV lands on the rider, it has fallen from a substantial height resulting in maximal (fatal) head and neck injuries.

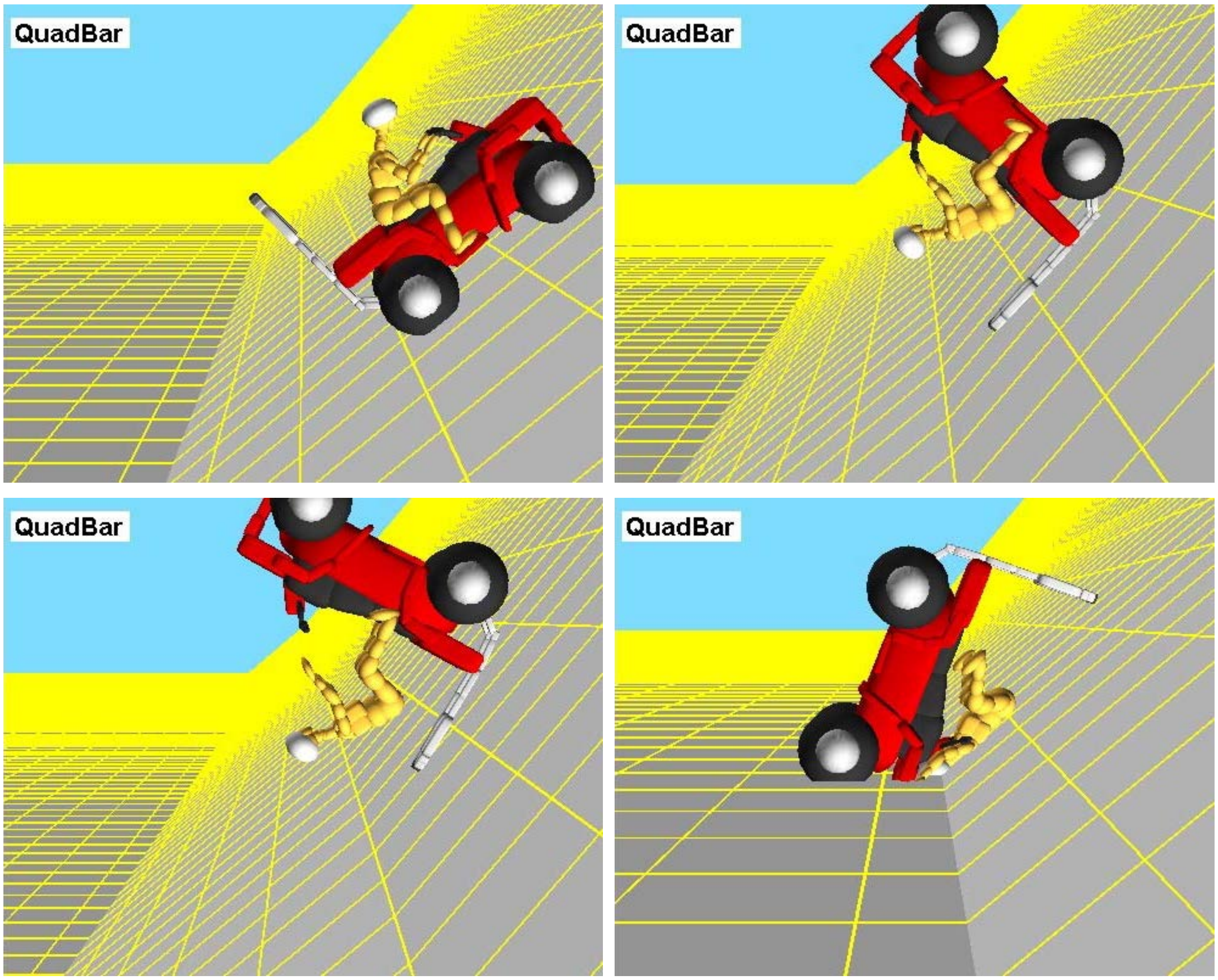

Figure 3. Simulation of an ATV with a Quadbar in a rearward overturn illustrating the "pole vault" phenomenon

The simulation also found potential for injury due to direct impacts between the rider and the OPD. One example of this is potential "spearing" of the rider in forward overturns, as shown in the simulation in Figure 4. In this case, the ATV pitched forward under braking as it traveled over a ridge. The rider was pitched toward the front of the ATV, and the Quadbar impacted the rider's head and neck causing maximal (fatal) injuries.

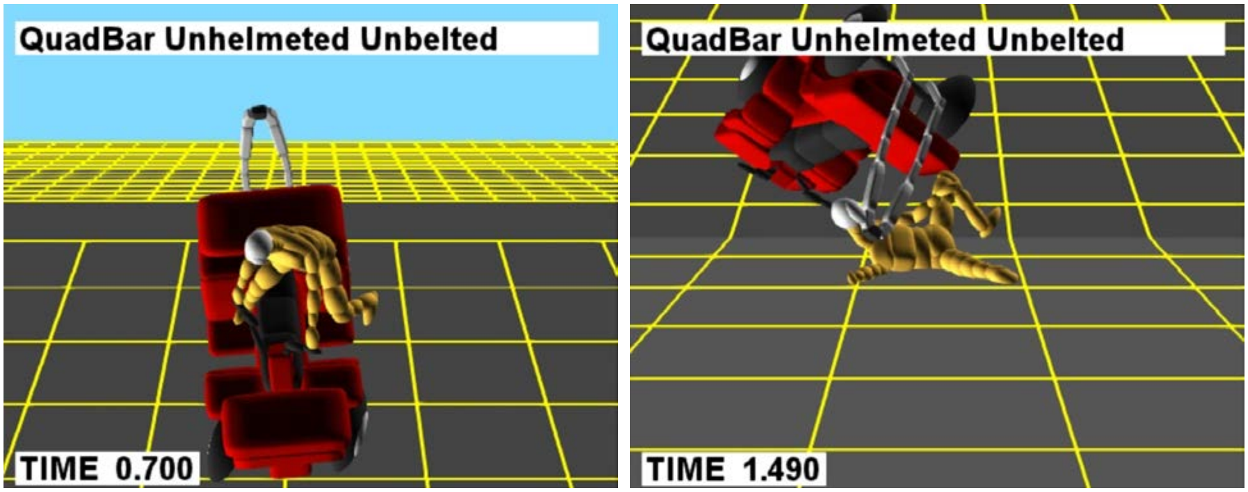

Figure 4. Simulation showing potential for "spearing" of the rider by the Quadbar in a forward overturn

This "spearing" phenomenon is known to have occurred in a real world accident. In a case from Australia that is similar to the simulation example, in a forward overturn, the rider was pitched in front of the ATV in a face down orientation, and the Quadbar speared the rider in the back fracturing four ribs and lacerating his liver (Ref 16). The rider survived, but he had to be airlifted for emergency medical treatment.

The scenarios tested by SEA also do not include high speed overturns. Some researchers have speculated that OPDs may only be effective in low-speed overturns (Ref 17). Although their speculation was not supported by the simulations discussed previously (Ref 7), it is clear that ATV speed at the beginning of an overturn has a substantial effect on the subsequent dynamics and injury outcomes.

Since the 1980s, ATVs have been designed to have minimal rigid projections in order to reduce the opportunities for injury-causing interactions between the ATV and rider in overturn accidents. Adding an OPD to an ATV violates this principle. In the computer simulations referenced above, there were numerous examples of the Quadbar impacting the rider and causing injury.

Section III

METHODS AND DATA

The technical approach involved statistical analysis of the data from Ref 3. This was accomplished in two steps. The first step involved constructing a test level dataset comprising rollover angle and rate metrics, subjective ratings, and Head Injury Criterion (HIC) results for each of 52 tests reported in Ref 3. The statistical analysis methods comprised multi-variable logistic regression analysis, cross-tab analysis, and paired comparison t-tests.

A. Data

Data were obtained for 52 total tests comprising

- 3 ATV conditions (No OPD, OPD1, and OPD2),
- 2 rollover test types (dynamic and sled),
- 2 energy levels (minimum and moderate), and
- 6 vehicle models.

There were some gaps in the overall test matrix. There were 48 tests with a matching set of 3 ATV conditions.

Rollover angle and rate metrics test results were obtained directly from Tables 8 and 9 in Ref 3. These metrics included the maximum roll rate, maximum roll angle, and final roll angle.

Subjective ratings were obtained directly from Tables 11 and 12 in Ref 3. There ratings were

- Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax, or Head
- ATV Rest Position with ATD's Pelvis, Abdomen, Thorax, or Head

These ratings were dichotomous values representing true ("X") or false ("O").

Ref 3 also reported Head Injury Criterion results where larger HIC_{15} and HIC_{36} values are associated with higher risk of closed skull brain injury. Ref 3 indicated on p 25 that the observed HIC_{15} values were greater than the HIC_{36} values, and that NHTSA FMVSS performance requirements were $HIC_{15} \leq 700$ and $HIC_{36} \leq 1000$ respectively. Therefore the HIC_{15} results in these tests are the more stringent indicators of head injury. The HIC_{15} results were digitized from the graphs in Figures 11 and 13 of Ref 3. Figure 5 and Figure 6 depict the original figures overplotted with the digitized values. The average and maximum HIC_{15} these tests were 192 and 354 respectively. According to the probability of head injury equations in Ref 11, the maximum $HIC_{15}=354$ corresponds to a 0.775 probability of no injury, 0.112 probability of AIS = 1 (minor), 0.091 probability of AIS = 2 (moderate), 0.022 probability of an AIS = 3 (serious), and 0 probability of an AIS $\geq$ 4 (severe, critical, or maximum) closed skull head injury. The average $HIC_{15}=192$ corresponds to a 0.960 probability of no injury, 0.018 probability of AIS = 1, 0.014 probability of AIS = 2, 0.009 probability of an AIS = 3, and 0 probability of an AIS $\geq$ 4 closed skull head injury. If we assume that $HIC_{36} \leq 250$ based on Figure 14 in Ref 3, then according to the probability of head injury equations for HIC_{36} in Ref 21 there is a 0.956 or greater probability of no injury or AIS = 1 (minor) injury, and less than or equal to 0.040 probability of AIS = 2 (moderate), and less than or equal to 0.004 probability of AIS = 3 (serious) injury, and less than 0.001 probability of AIS $\geq$ 4 (severe, critical, or maximal) injury.

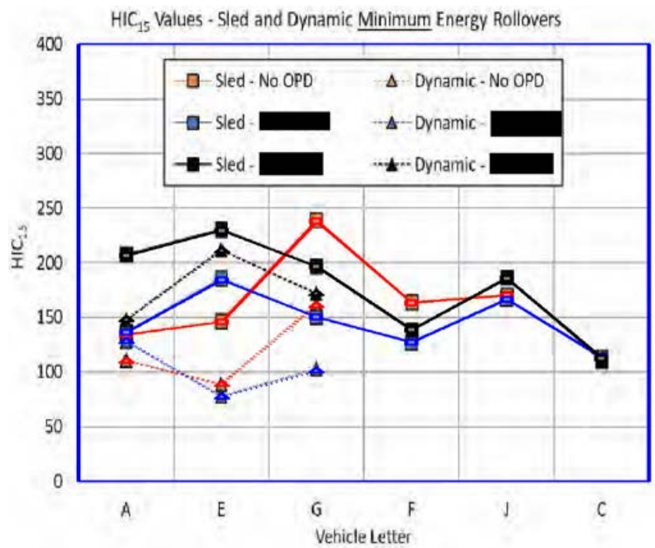

Figure 11: HIC15 Values from Sled and Dynamic Minimum Energy Rollovers

Figure 5. SEA Figure 11: HIC_{15} Values from Sled and Dynamic Minimum Energy Rollovers with Overplotted Digitized Values

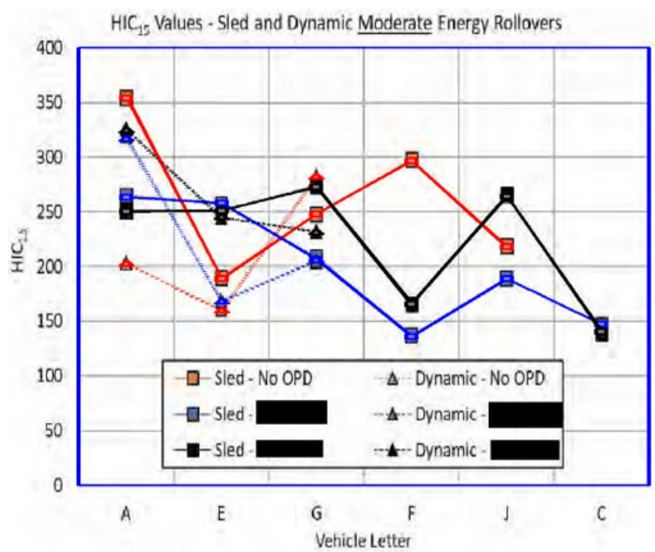

Figure 13: HIC15 Values from Sled and Dynamic Moderate Energy Rollovers

Figure 6. SEA Figure 13: HIC_{15} Values from Sled and Dynamic Moderate Energy Rollovers with Overplotted Digitized Values

B. Statistical Methods

Statistical analyses of the SEA test data were performed using the SPSS[1] statistical software package (Ref 18). The SPSS LOGISTIC REGRESSION, CROSSTABS, and T-TEST commands were used.

Logistic regression analysis was used to estimate the probability of a “X” subjective rating based on the following categorical variables:

- OPD1 = 1 if the test configuration is the OPD 1, otherwise OPD1 = 0.
- OPD2 = 1 if the test configuration is the OPD 2, otherwise OPD2 = 0.
- Sled_Test = 1 if the rollover test was a sled test, otherwise Sled_Test = 0 if the rollover test was a dynamic test.
- Moderate_Energy = 1 if the test energy level was “moderate”, otherwise Moderate_Energy = 0 if the test energy level was “minimum”.

The Logistic regression analysis were accomplished using data for all tests (N = 52) and only the tests with a complete set of ATV conditions (N = 48 = 3x16).

Cross-tab analyses were to compare the numbers of “X” and “O” subjective ratings versus OPD or no OPD. The SPSS CROSSTABS command calculates two-sided probability of the observed distribution of 2x2 table counts for the null hypothesis of equal underlying probabilities or independence using the Pearson Chi-Square test and Fisher’s Exact test. This analysis was accomplished for both subjective ratings and using data for all tests (N = 34) and only the tests with a complete set of ATV conditions (N = 32 = 2x16).

Paired t-tests were used to compare the sled versus dynamic test results, and the OPD vs no OPD test results. The paired t-test is considered more robust than other t-tests because it is based on the differences between two scalar measures, and the difference tends to be more normally distributed than the individual scalar

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[1] SPSS originally stood for the Statistical Package for the Social Sciences.

values. For the purposes of this analysis the subjective ratings “X” and “O” were recoded to be 1 and 0.

Section IV

STATISTICAL ANALYSIS RESULTS

A. Logistic Regression Results

Logistic regression analysis results for the subjective versus four variables are listed in Table 4 and Table 5. The first column of these tables lists the independent variable. The value is 0 or 1. For example, the value for OPD1 is 1 if the ATV is fitted with OPD 1, otherwise the value is 0. The results are shown for logistic regressions using data for all 52 test cases and for only the 48 test cases with matching no OPD, OPD 1, and OPD 2 conditions. The results in columns 2 and 6 list the statistical significance p-value for the variable. A value less than 0.05 indicates the result is statistically significant, which corresponds to a 95% confidence interval. The results in columns 3 and 7 list the point estimates for Exp(B) for the logistic regression coefficient B. The results in columns 4, 5, 8, and 9 list the 95% confidence interval for the estimated Exp(B) value. The value for Exp(B) indicates the relative probability of the subjective rating being "X" if the variable value is 1. For example, if Exp(B) = 0.2, then the estimated relative probability of "X" is 0.2 if the variable is 1, compared to a relative probability of 1 if the variable is 0.

Table 4. Logistic Regression Results for "Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head"

Variable	All Test Cases				Matching Test Cases			
	Sig.	Exp(B)	95% C.I.for EXP(B)		Sig.	Exp(B)	95% C.I.for EXP(B)	
			Lower	Upper			Lower	Upper
OPD1	**0.017**	0.133	0.025	0.698	**0.029**	0.156	0.029	0.828
OPD2	**0.007**	0.094	0.017	0.531	**0.012**	0.109	0.019	0.620
Sled_Test	0.057	0.255	0.063	1.040	0.095	0.301	0.074	1.231
Moderate_Energy	0.059	3.849	0.952	15.567	0.057	3.917	0.962	15.950
N				52				48

Note: **bold font** denotes the result is statistically significant (p-value≤0.05).

Table 5. Logistic Regression Results for "ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head"

Variable	All Test Cases				Matching Test Cases			
	Sig.	Exp(B)	95% C.I.for EXP(B)		Sig.	Exp(B)	95% C.I.for EXP(B)	
			Lower	Upper			Lower	Upper
OPD1	0.952	0.941	0.129	6.847	1.000	1.000	0.138	7.254
OPD2	0.952	0.941	0.129	6.847	1.000	1.000	0.138	7.254
Sled_Test	**0.007**	0.091	0.016	0.526	**0.012**	0.104	0.018	0.604
Moderate_Energy	0.236	2.749	0.517	14.619	0.235	2.755	0.517	14.665
N	52				48			

Note: **bold font** denotes the result is statistically significant (p-value≤0.05).

The results in Table 4 indicate that the probability of a "Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head" rating is statistically significantly less if the ATV is fitted with an OPD. The estimated relative probability varies from 0.094 (0.017,0.531) to 0.156 (0.029,0.828). The estimated effects of rollover test type and energy level are not statistically significant.

The results in Table 5 indicate that the probability of a "ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head" is statistically significantly less if the test is a sled test. The estimated relative probability varies from 0.091 (0.016,0.526) to 0.104 (0.018,0.604). The estimated effects of OPD and test energy level are not statistically significant.

A limitation of these logistic regression results is that the assumed rating probability model does not include any interaction effects. For example, the model assumes that the relative effect of OPD 1 or OPD 2 on the probability of an "X" rating is the same for both sled and dynamic tests, and the same for minimum and moderate energy tests.

B. Cross-Table Results

Cross-table analysis results for the number of matching SEA tests (N=32) with "X" or "O" subjective rating versus with or without OPD versus are listed Table 6 through Table 9. The top portion of each table lists the number of tests for each combination of significant rating outcome and ATV test condition. The rows and column margin totals are also listed, and the grand total is 32. The results from Pearson's Chi-Square test and Fisher's Exact hypothesis test are listed below the table. The results for the Chi-Square test include the calculated value of the Chi-Square statistic, the number of degrees of freedom (1), and the resulting asymptotic 2-sided p-value. Fisher's Exact Test p-value for the 2-sided hypothesis is also listed. Overall, these results are consistent with the aforementioned logistic regression results.

Table 6. OPD 1 versus "Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head" Ratings (Matching Test Cases)

Counts	Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head		Total
Condition	O	X	
OPD 1	11	5	16
No OPD	5	11	16
Total	16	16	32

Test	Value	df	P-value
Pearson Chi-Square	4.500(a)	1	**0.034**
Fisher's Exact Test			0.076

(a) 0 cells (.0%) have expected count less than 5. The minimum expected count is 8.00.

Note: **bold font** denotes the result is statistically significant (p-value≤0.05).

Table 7. OPD 1 versus "ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head" Ratings (Matching Test Cases)

Counts	ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head		Total
Condition	O	X	
OPD 1	13	3	16
No OPD	13	3	16
Total	26	6	32

Test	Value	df	P-value
Pearson Chi-Square	.000(a)	1	1.000
Fisher's Exact Test			1.000

(a) 2 cells (50.0%) have expected count less than 5. The minimum expected count is 3.00.

Note: **bold font** denotes the result is statistically significant (p-value≤0.05).

Table 8. OPD 2 versus "Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head" Ratings (Matching Test Cases)

Counts	Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head		Total
Condition	O	X	
OPD 2	12	4	16
No OPD	5	11	16
Total	17	15	32

Test	Value	df	P-value
Pearson Chi-Square	6.149(a)	1	**0.013**
Fisher's Exact Test			**0.032**

(a) 0 cells (.0%) have expected count less than 5. The minimum expected count is 7.50.

Note: **bold font** denotes the result is statistically significant (p-value≤0.05).

Table 9. OPD 2 versus "ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head" Ratings (Matching Test Cases)

Counts	ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head		Total
Condition	O	X	
OPD 2	13	3	16
No OPD	13	3	16
Total	26	6	32

Test	Value	df	P-value
Pearson Chi-Square	.000(a)	1	1.000
Fisher's Exact Test			1.000

(a) 2 cells (50.0%) have expected count less than 5. The minimum expected count is 3.00.

Note: **bold font** denotes the result is statistically significant (p-value≤0.05).

The Pearson Chi-Square test results in Table 6 indicate that relative proportions of "Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head" ratings for OPD 1 and no OPD are statistically significantly different. The Fisher's Exact Test, which tends to be conservative, did not indicate a statistically significant difference.

The Pearson Chi Square and Fisher's Exact Test results in Table 8 indicate that relative proportions of "Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head" ratings for OPD 2 and no OPD are statistically significantly different.

The results in Table 7 and Table 9 indicate that there are no statistically significant differences in the proportions of "ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head" ratings versus OPD or no OPD.

C. Paired T-Test Results

Potential differences in SEA test results due to Rollover Type and ATV Configuration were investigated using paired t-tests. The results of this analysis are presented in this subsection.

1. Sled versus Dynamic Tests

Results of paired t-tests to compare the results from sled and dynamic tests are listed in Table 10. The first column of this table lists the SEA test result. The results in columns 2 through 5 list the analysis of the paired differences. The t-test statistic and number of degrees-of-freedom are listed in columns 6 and 7. The last column lists the p-value for the null hypothesis that the true difference is 0 and the observed differences have a 2-tailed distribution. These results are based on 18 matched sled and dynamic test pairs. The matched pairs comprised all combinations of vehicles A, E, and G; all three ATV conditions, and both energy levels.

Table 10. Paired T-Test Comparisons of Sled and Dynamic Test Results

Paired Samples Test Sled - Dynamic	Paired Differences					t	df (N= 18)	Sig. (2-tailed)
	Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Max_Roll_Rate	-23.2	66.8	15.7	-56.4	10.0	-1.473	17	0.159
Max_Roll_Angle	-47.5	90.0	21.2	-92.3	-2.8	-2.241	17	**0.039**
Final_Roll_Angle	-51.3	85.3	20.1	-93.7	-8.9	-2.554	17	**0.021**
Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head	-0.111	0.758	0.179	-0.488	0.266	-0.622	17	0.542
ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head	-0.333	0.485	0.114	-0.575	-0.092	-2.915	17	**0.010**
HIC_{15}	32.3	55.4	13.1	4.8	59.9	2.475	17	**0.024**

Note: **bold font** denotes the result is statistically significant ($p\text{-value} \leq 0.05$).

The results in the last column of Table 10 indicate that there are statistically significant differences between the sled and dynamic tests in the maximum and final roll angles, ATV Rest Position ratings, and HIC_{15} results. The mean paired differences in column 2 indicate that the roll angles and ATV Rest Position ratings for the sled tests are statistically less than the dynamic tests. The results also indicate that the HIC_{15} values from the sled tests are statistically significantly greater than the dynamic test results. There were no statistically significant paired differences in the other variables.

2. OPD versus No OPD results

Paired T-Test comparison results for OPD versus no OPD test results are listed in Table 11 and Table 12. The formats of these tables are the same as Table 10. These results are based on all 16 matched OPD and no OPD test pairs. The results in Table 11 compare the SEA test results for OPD 1 to no OPD. The results in Table 12 compare the SEA test results for OPD 2 to no OPD.

Table 11. Paired T-Test comparisons of OPD 1 versus no OPD test results, all paired tests (N=16)

Paired Samples Test OPD 1 – no OPD	Paired Differences					t	df (N= 16)	Sig. (2-tailed)
	Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Max_Roll_Rate	-10.8	59.5	14.9	-42.5	20.9	-0.726	15	0.479
Max_Roll_Angle	46.2	96.6	24.2	-5.3	97.7	1.911	15	0.075
Final_Roll_Angle	43.8	99.2	24.8	-9.1	96.7	1.765	15	0.098
Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head	-0.375	0.619	0.155	-0.705	-0.045	-2.423	15	**0.029**
ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head	0.000	0.516	0.129	-0.275	0.275	0.000	15	1.000
HIC_{15}	-21.7	66.9	16.7	-57.4	13.9	-1.298	15	0.214

Note: **bold font** denotes the result is statistically significant (p-value≤0.05).

Table 12. Paired T-Test comparisons of OPD 2 versus no OPD test results, all paired tests (N=16)

Paired Samples Test OPD 2 – no OPD	Paired Differences					t	df (N= 16)	Sig. (2-tailed)
	Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Max_Roll_Rate	-12.9	60.6	15.2	-45.2	19.4	-0.850	15	0.408
Max_Roll_Angle	42.3	71.5	17.9	4.2	80.4	2.367	15	**0.032**
Final_Roll_Angle	41.4	93.1	23.3	-8.2	90.9	1.778	15	0.096
Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head	-0.438	0.727	0.182	-0.825	-0.050	-2.406	15	**0.029**
ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head	0.000	0.365	0.091	-0.195	0.195	0.000	15	1.000
HIC_{15}	20.7	74.6	18.7	-19.1	60.4	1.107	15	0.286

Note: **bold font** denotes the result is statistically significant (p-value≤0.05).

The results in the last column of Table 11 indicate that there are statistically significant differences in the "Significant ATV Interaction" ratings between the

OPD 1 and no OPD test results. The mean paired differences in column 2 indicate that the “Significant ATV Interaction” ratings for the OPD 1 are significantly less than for the no OPD condition. However, as noted in Section II.A, the HIC_{15} values in these tests are primarily associated with no injury or minor closed skull head injury. There were no statistically significant paired differences in the other variables.

The results in the last column of Table 12 indicate that there are statistically significant differences in the maximum roll angle and the “Significant ATV Interaction” ratings the OPD 2 and no OPD test results. The mean paired differences in column 2 indicate that the maximum roll angle for the OPD 2 condition is significantly greater than for the no OPD condition. The results also indicate that the “Significant ATV Interaction” ratings for the OPD 2 condition are significantly less than for the no OPD condition. There were no statistically significant paired differences in the other variables.

i. Sled Rollover Tests

The results Table 13 and Table 14 are similar to the results in Table 11 and Table 12 but focus in on the sled rollover tests. There were ten pairs of matched sled rollover tests. The results in Table 13 indicate that the maximum roll rate and Significant ATD Interaction ratings for the OPD 1 were significantly less than the no OPD in the sled tests. The results in Table 14 indicate that the Significant ATD Interaction ratings for the OPD 2 were significantly less than the no OPD in the sled tests. There were no statistically significant paired differences in the other variables.

Table 13. Paired T-Test comparisons of OPD 1 versus no OPD test results, Sled Rollover Tests (N=10)

Paired Samples Test OPD 1 – no OPD	Paired Differences					t	df (N= 10)	Sig. (2-tailed)
	Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Max_Roll_Rate	-35.6	48.8	15.4	-70.4	-0.7	-2.305	9	**0.047**
Max_Roll_Angle	13.3	41.5	13.1	-16.4	42.9	1.013	9	0.338
Final_Roll_Angle	18.3	73.9	23.4	-34.5	71.2	0.785	9	0.453
Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head	-0.600	0.516	0.163	-0.969	-0.231	-3.674	9	**0.005**
ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head	0.000	0.471	0.149	-0.337	0.337	0.000	9	1.000
HIC_{15}	-34.0	67.0	21.2	-81.9	13.9	-1.605	9	0.143

Note: **bold font** denotes the result is statistically significant ($p\text{-value} \leq 0.05$).

Table 14. Paired T-Test comparisons of OPD 2 versus no OPD test results, Sled Rollover Tests (N=10)

Paired Samples Test OPD 2 – no OPD	Paired Differences					t	df (N= 10)	Sig. (2-tailed)
	Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Max_Roll_Rate	-29.2	55.3	17.5	-68.8	10.4	-1.669	9	0.129
Max_Roll_Angle	22.7	50.5	16.0	-13.4	58.8	1.422	9	0.189
Final_Roll_Angle	25.5	90.5	28.6	-39.2	90.2	0.891	9	0.396
Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head	-0.800	0.422	0.133	-1.102	-0.498	-6.000	9	**0.000**
ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head	-0.100	0.316	0.100	-0.326	0.126	-1.000	9	0.343
HIC_{15}	0.4	74.0	23.4	-52.5	53.3	0.016	9	0.987

Note: **bold font** denotes the result is statistically significant ($p\text{-value} \leq 0.05$).

ii. Dynamic Rollover Tests

Paired t-tests focusing in on the dynamic rollover tests were also investigated. There were six pairs of matched dynamic rollover tests. None of these paired t-test results were statistically significant.

iii. Minimum Energy Tests

The results in Table 15 and Table 16 are similar to the results in Table 11 and Table 12 but focus in on the minimum energy tests. There were eight pairs of matched minimum energy tests. The results in these tables indicate that only the Significant ATD Interaction ratings for the OPD 1 and 2 were significantly different, and less than, the no OPD in the minimum energy tests. There were no differences in the ATV Rest Position ratings and therefore the paired t-test results were undefined. There were no statistically significant paired differences in the other variables.

Table 15. Paired T-Test comparisons of OPD 1 versus no OPD test results, Minimum Energy Tests (N=8)

Paired Samples Test OPD 1 – no OPD	Paired Differences					t	df (N=8)	Sig. (2-tailed)
	Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Max_Roll_Rate	0.9	19.6	6.9	-15.5	17.3	0.130	7	0.900
Max_Roll_Angle	3.4	48.7	17.2	-37.3	44.0	0.195	7	0.851
Final_Roll_Angle	-18.4	55.9	19.8	-65.1	28.4	-0.929	7	0.384
Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head	-0.500	0.535	0.189	-0.947	-0.053	-2.646	7	**0.033**
ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head	0.000	0.000	0.000	t cannot be computed because the standard error of the difference is 0.				
HIC_{15}	-17.6	41.5	14.7	-52.3	17.1	-1.198	7	0.270

Note: **bold font** denotes the result is statistically significant (p-value≤0.05).

Table 16. Paired T-Test comparisons of OPD 2 versus no OPD test results, Minimum Energy Tests (N = 8)

Paired Samples Test OPD 2 – no OPD	Paired Differences					t	df (N= 8)	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Max_Roll_Rate	5.9	18.8	6.6	-9.8	21.6	0.889	7	0.404
Max_Roll_Angle	7.4	48.5	17.1	-33.2	47.9	0.430	7	0.680
Final_Roll_Angle	-18.3	54.9	19.4	-64.2	27.6	-0.942	7	0.377
Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head	-0.500	0.535	0.189	-0.947	-0.053	-2.646	7	**0.033**
ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head	0.000	0.000	0.000	t cannot be computed because the standard error of the difference is 0.				
HIC_{15}	34.5	55.7	19.7	-12.1	81.1	1.750	7	0.124

Note: **bold font** denotes the result is statistically significant (p-value≤0.05).

iv. Moderate Energy Tests

The results in Table 17 and Table 18 are similar to the results in Table 11 and Table 12 but focus in on the moderate energy tests. There were eight pairs of matched moderate energy tests. The results in these tables indicate that both the OPD 1 and 2 had significantly larger final roll angles than the no OPD configuration in the moderate energy tests. There results in Table 18 also indicate that the maximum roll angle for the OPD 2 was significantly larger than the no OPD configuration. There were no statistically significant paired differences in the other variables.

Table 17. Paired T-Test comparisons of OPD 1 versus no OPD test results, Moderate Energy Tests (N=8)

Paired Samples Test OPD 1 – no OPD	Paired Differences					t	df (N=8)	Sig. (2-tailed)
	Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Max_Roll_Rate	-22.5	83.0	29.3	-91.8	46.9	-0.767	7	0.468
Max_Roll_Angle	89.0	116.0	41.0	-8.0	186.0	2.170	7	0.067
Final_Roll_Angle	106.0	95.7	33.8	26.0	185.9	3.133	7	**0.017**
Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head	-0.250	0.707	0.250	-0.841	0.341	-1.000	7	0.351
ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head	0.000	0.756	0.267	-0.632	0.632	0.000	7	1.000
HIC_{15}	-25.9	88.5	31.3	-99.9	48.1	-0.826	7	0.436

Note: **bold font** denotes the result is statistically significant (p-value≤0.05).

Table 18. Paired T-Test comparisons of OPD 2 versus no OPD test results, Moderate Energy Tests (N=8)

Paired Samples Test OPD 2 – no OPD	Paired Differences					t	df (N=8)	Sig. (2-tailed)
	Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Max_Roll_Rate	-31.7	81.9	29.0	-100.2	36.8	-1.093	7	0.310
Max_Roll_Angle	77.2	76.3	27.0	13.5	141.0	2.864	7	**0.024**
Final_Roll_Angle	101.0	86.1	30.4	29.0	173.0	3.319	7	**0.013**
Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head	-0.375	0.916	0.324	-1.141	0.391	-1.158	7	0.285
ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head	0.000	0.535	0.189	-0.447	0.447	0.000	7	1.000
HIC_{15}	6.8	91.6	32.4	-69.8	83.4	0.210	7	0.839

Note: **bold font** denotes the result is statistically significant (p-value≤0.05).

v. More Detailed Comparisons by Rollover Type and Energy Level

More detailed results for each combination of rollover type and energy level (e.g., moderate energy dynamic tests) have smaller numbers of paired differences (N) and resulting statistical degrees of freedom (N-1). For example there were only three matching pairs of medium energy sled tests for each OPD. Therefore, these results tend to be not statistically significant, as indicated in summary Table 19 and Table 20.

vi. Summary of OPD versus no OPD Paired Comparison Tests

The results for the OPD versus no OPD paired comparison tests are summarized in Table 19 and Table 20. These results indicate that the paired differences in the Significant ATV Interaction rating is statistically significant and negative for the larger aggregated datasets. The Roll Angle differences are sometimes significantly positive or negative depending on the Rollover type and Energy level. Most of the other paired differences are not statistically significant.

Table 19. Summary of OPD 1 versus no OPD Paired Test Comparison Results

Rollover type	Both	Sled	Dynamic	Both	Both	Sled	Sled	Dynamic	Dynamic
Energy level	Both	Both	Both	Minimum	Moderate	Minimum	Moderate	Minimum	Moderate
N	16	10	6	8	8	5	5	3	3
OPD1 - no_OPD									
Max_Roll_Rate	n.s.	-	n.s.	n.s.	n.s.	n.s.	-	n.s.	n.s.
Max_Roll_Angle	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Final_Roll_Angle	n.s.	n.s.	n.s.	n.s.	+	-	+	n.s.	n.s.
Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head	-	-	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.
ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head	n.s.	n.s.	n.s.	N/A	n.s.	N/A	n.s.	N/A	n.s.
HIC_{15}	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Key:
+ indicates the mean paired difference is statistically significant and positive.
- indicates the mean paired difference is statistically significant and negative.
n.s. indicates the mean paired difference is not statistically significant.
N/A indicates t cannot be computed because the standard error of the difference is 0.

Table 20. Summary of OPD 2 versus no OPD Paired Test Comparison Results

Rollover type	Both	Sled	Dynamic	Both	Both	Sled	Sled	Dynamic	Dynamic
Energy level	Both	Both	Both	Minimum	Moderate	Minimum	Moderate	Minimum	Moderate
N	16	10	6	8	8	5	5	3	3
OPD2 - no_OPD									
Max_Roll_Rate	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Max_Roll_Angle	+	n.s.	n.s.	n.s.	+	n.s.	+	n.s.	n.s.
Final_Roll_Angle	n.s.	n.s.	n.s.	n.s.	+	-	n.s.	n.s.	n.s.
Significant ATV Interaction with ATD's Pelvis, Abdomen, Thorax or Head	-	-	n.s.	-	n.s.	n.s.	N/A	n.s.	n.s.
ATV Rest Position on ATD's Pelvis, Abdomen, Thorax or Head	n.s.	n.s.	n.s.	N/A	n.s.	N/A	n.s.	N/A	n.s.
HIC_{15}	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Key:
+ indicates the mean paired difference is statistically significant and positive.
- indicates the mean paired difference is statistically significant and negative.
n.s. indicates the mean paired difference is not statistically significant.
N/A indicates t cannot be computed because the standard error of the difference is 0.

Section V

CONCLUSIONS

Although the scope of the SEA tests was limited, the results are consistent with other research that indicates that OPDs do not have any safety benefits. The SEA tests only measured dummy head and chest acceleration, and the head acceleration measures were used to calculate HIC_{15} and HIC_{36} Head Injury Criterion. The HIC_{15} values were greater than the HIC_{36} values and therefore were more stringent indicators of potential head injury. Nonetheless, the HIC_{15} values were still small and associated with either no injury or minor (AIS = 1) closed skull head injuries. There were no statistically significant differences for HIC_{15} associated with either of the OPDs. The HIC_{15} values observed in these tests were relatively small values associated with either no injury or minor (AIS = 1) closed skull head injuries. This is not surprising, since peak head accelerations occurred when the dummy first impacted the ground, which occurred before the OPD contacted the ground.

The SEA tests also did not result in any statistically significant differences between the baseline and OPD-equipped ATVs with respect to pinning the rider (defined as significant interaction between the ATV and the dummy at the final rest position). This is consistent with simulation results (Ref 7) in which the Quadbar did not change the rate of asphyxiation caused by the ATV coming to rest on the dummy's chest with sufficient force to restrict breathing. This means that the SEA test results are consistent with the simulations in this regard.

Although the SEA tests with the baseline ATV did result in a greater number of significant interactions between the ATV and dummy during the rollover events, the SEA analysis does not attempt to quantify the severity of the significant interactions. However, it is apparent from the still images taken from the test videos that there were troubling severe interactions between the ATV and rider in some of the OPD tests. This is because the OPD raised the center of gravity of the ATV as the ATV rolled over, which allowed the ATV to fall onto the dummy from a greater height. This phenomenon was also observed in simulation results in which the ATV with a Quadbar landed on the rider with greater energy than the baseline

ATV and caused severe injuries. This means that in this regard the SEA tests also can be viewed as another area of consistency with the simulations.

The SEA test results are also consistent with an Australian workplace survey of ATV riders and fleet managers (Ref 8). In this survey, riders reported injury outcomes and whether an OPD was present in their ATV accidents. As shown in Table 21, the "main" survey of riders indicates that baseline ATVs had a slightly higher rate of "any injury" and a slightly lower rate of "serious injury" than ATVs with an OPD. Neither of these differences is statistically significant.

Table 21. TARS workplace survey results from the "main" sub-study regarding the safety effectiveness of OPDs (Ref 8, Table 4)

OPD	Crashes	Any Injury	Serious Injury (hospitalizations)	Any Injury as % of crashes	Serious Injury as % of crashes
No	1,307	264	68	20.20%	5.20%
Yes	122	22	7	18.03%	5.74%
			Ratio (No OPD/OPD):	1.12	0.91

The TARS workplace survey also reports a trend analysis of the "main" sub-study data in Table 8 of their report. TARS reported that the observed counts in the 2x3 table indicated statistically significant association between fitting OPDs and a reduction in chest injuries. However, two adjacent cells in this table had 1 and 0 counts, respectively. Ott et al (Ref 19) warns on p 407 that 2x2 tables with 0 observations in one cell can give misleading information, and it is assumed that this warning would also apply to 2x3 tables.[2] The Fisher-Freeman-Halton Exact

[2] Furthermore, SPSS CROSSTABS analysis of the counts in TARS table 8 warns for the Pearson Chi-square test that "2 cells (33.3%) have expected count less than 5. The minimum expected count is 1.56."

Test, a test for independence, yields a p-value of 0.47 for the same TARS data, which indicates the differences in the injury results are not statistically significant.

A separate section of the TARS study comprised a sub-study involving survey of fleet managers. The results of this survey are shown in Table 22, and a statistical analysis of these results found that the Quadbar was associated with a statistically significant increase in the percentage of rollover crashes resulting in a visit to the hospital.

Table 22. TARS workplace survey results for the "Fleet Managers" sub-study (from Ref 8, Table 2)

OPD	**"No injury" or "Minor injury"**	**"Attended hospital" or "Admitted to hospital"**	**Percentage of rollover crashes resulting in "Attended hospital" or "Admitted to hospital"**
None	45	12	21.10%
Quadbar	3	6	66.70%

Fisher's Exact test p-value = 0.010

The Australian experience is important to the evaluation of OPD safety because of the relatively high number of OPDs in use there, and the TARS workplace survey data regarding serious injuries are not inconsistent with the very limited fatality data. Although the number of fatalities is too low to facilitate detailed statistical comparisons, an analysis of Australian fatality data found that there were two fatalities that occurred in crashes of ATVs fitted with OPDs, but only 0.84 fatalities would have been expected on an equivalent number of non-OPD-equipped ATVs (Ref 9).

Mick Keogh from the Australian Competition and Consumer Commission (ACCC) has claimed in a radio interview that the SEA study "really identified that certainly within the parameters that were included in these tests, that rollover protection devices on quad bikes look likely to be able to significantly reduce both injury and death associated with quad bike rollovers" (Ref 20). This statement, even as qualified, mischaracterizes the SEA study. The only possible test “parameters” that Mr. Keogh could be referring to are the higher rate of the subjective rating of “significant interactions” in the baseline tests compared to the OPD tests. However, as discussed previously, the rate of “significant interactions” is not an injury measure, and in the SEA tests, OPDs appear to increase the rate of ***severe*** interactions between the ATV and dummy. Neither SEA nor the CPSC reached the conclusions that the ACCC suggests from the SEA tests. To the contrary, SEA and the CPSC reached no findings or conclusions supportive of the use of OPDs, which is appropriate in view of the agreement among the SEA test results, the DRI simulations, and the TARS workplace survey.

In that radio interview Mr. Keogh continues by saying that “certainly all the expert evidence we had available, and all the prior research including by researchers at UNSW in Sydney were in agreement with these findings [that rollover protection devices look likely to be able to significantly reduce both injury and death]” (Ref 20). This statement is patently false. The ACCC was presented with extensive evidence that OPDs do not improve safety, including the DRI simulations and the TARS workplace survey, which was conducted by researchers at UNSW in Sydney. The ACCC even refers to the DRI simulations in its final recommendations regarding quad bike safety (Ref 6), so it is unclear why Mr. Keogh would make this false statement.

The SEA tests add to the body of information available about the effectiveness of OPDs, and the results of these latest tests are generally consistent with other major research. That is, neither the SEA test data, the DRI simulation results, nor the TARS survey data indicate any net safety benefits for OPDs.

OPDs are intended to prevent pinning and asphyxiation of the rider by providing crawl out space after a rollover accident. However, the SEA test data and DRI simulation results show that the rider is not generally in the protective space at the end of a rollover accident. The rates of rider pinning (significant interaction between the ATV and rider at rest) in the SEA tests was the same for baseline ATVs and OPD-equipped ATVs. This is consistent with the DRI simulation results that showed no benefit for the Quadbar with respect to asphyxiation.

None of the three different approaches to the question of OPD effectiveness, the SEA full-scale tests, the DRI computer simulations, and the TARS survey, indicate that OPDs should be fitted to ATVs. None of these approaches indicate a net benefit for OPDs, and some of the results in each of these approaches indicate potential harm that can be caused by OPDs.

Because three separate approaches all indicate potential harm from fitting an OPD and none indicate net safety benefits, it is clear that OPDs are not valid safety devices and should not be fitted to ATVs.

REFERENCES

1. Topping, J., "2018 Annual Report of ATV-Related Deaths and Injuries", Directorate for Epidemiology, Division of Hazard Analysis, U.S. Consumer Product Safety Commission, February 2020.

2. Heydinger, G. J., Zagorski, S., Yapp, J., Sidhu, A., Nowjack, J., Koevenig, J., Jebode, H., Coyle, J., Andreatta, D., Nguyen, A., Waibl, C., "ATV Rollover Tests and Verification of a Physical Rollover Simulator, Results from Tests on Six 2014-2015 Model Year Vehicles," SEA Vehicle Dynamics Division for the U.S. Consumer Product Safety Commission, April 2019 (released by the CPSC in October 2019).

3. Heydinger, G. J., Zagorski, S., Yapp, J., Nowjack, J., Koevenig, J., Jebode, H., Coyle, J., Andreatta, Sidhu, A., "Rollover Tests of ATVs Outfitted with Occupant Protection Devices (OPDs), Results from Tests on Six 2014-2015 Model Year Vehicles," SEA Vehicle Dynamics Division for the U.S. Consumer Product Safety Commission, October 2019 (released by the CPSC in August 2020).

4. Anon., "US research shows roll bars likely to reduce injuries and deaths in quad bike rollovers", 15 September 2020, https://www.accc.gov.au/media-release/us-research-shows-roll-bars-likely-to-reduce-injuries-and-deaths-in-quad-bike-rollovers, accessed 21 October 2020.

5. Hunt, P., "US safety body ATV roll-bar research backs Australian OPDs," The Weekly Times, September 2, 2020.

6. Anon., "Quad bike safety Final Recommendation to the Minister", February 2019, https://consultation.accc.gov.au/product-safety/quad-bike-safety-standard-exposure-draft/supporting_documents/Quad%20bike%20safety%20%20Final%20Recommendation%20to%20the%20Minister.pdf, accessed 21 October 2020.

7. Zellner, J.W., Kebschull, S.A., and Van Auken, R.M., Updated Injury Risk/Benefit Analysis of QuadBar Crush Protection Device (CPD) for All-Terrain Vehicles (ATVs), Dynamic Research Inc. Technical Report DRI-TR-12-06-3, Third Revision, 8 August 2016 (www.dri-atv-rops-research, accessed 11 October 2020).

8. Grzebieta, R., et al. Quad Bike and OPD Workplace Safety Survey Report: Results and Conclusions, Transport and Road Safety (TARS), Sidney, New South Wales, May 2017, http://www.quadbike.unsw.edu.au/sites/default/files/uploads/Quad_Workplace_Safety_Survey_Report.pdf, accessed 11 October 2020.

9. Kebschull, S.A., Testimony to the Quad Bike Inquest, Exhibit C52, Magistrates' Court of Tasmania, Coroner S. Cooper, Hobart, Tasmania, Australia, 10 October 2016.

10. Zellner, J.W., Kebschull, S.A., "Full-Scale Dynamic Overturn Tests of an ATV with and without a "Quadbar" CPD Using an Injury-Monitoring Dummy", DRI-TR-15-04, March 2015, (www.dri-atv-rops-research, accessed 11 October 2020).

11. Anon., "Motorcycles – Test and Analysis Procedures for Research Evaluation of Rider Crash Protective Devices Fitted to Motorcycles", ISO 13232, International Organization for Standardization, Geneva, 1996, and Revision 1, 2005.

12. Miller, TR., Pindus, NM., Leon, TS., and Douglas, JB., "Motor vehicle injury costs by body region and severity," In Proceedings of the Thirty-fourth Association for the Advancement of Automotive Medicine Conference, Scottsdale, AZ, 1990.

13. Van Ee, C. A., Toomey, D. E., Moroski-Browne, B. A., Vander Roest, M., and Wilson, A., "ATV Rollover, Rider Response, and Determinants of Injury: In-depth Analysis of Video-documented ATV Rollover Events", Traffic Injury

Prevention, 15:sup1, S190-S196, DOI: 10.1080/15389588.2014.935940. October 2014.

14. Anon., YouTube video, https://www.youtube.com/watch?v=sxCt571pnEg, accessed 11 October 2020.

15. Cassatta, S., Sevigny, J., White, J., O'Brien-Mitchell, B. et al., "Subsystem Rollover Tests for the Evaluation of ATD Kinematics and Restraints", SAE Int. J. Passeng. Cars – Mech. Syst. 3(1):467-480, 2010, https://doi.org/10.4271/2010-01-0518.

16. Shepherd, I., WSMS Incident Notification Report – 2-131627, File Number 2017/005763, Document No. D17/240259, Reference Number 2-131627, New South Wales, Australia, November 2017.

17. Grzebieta, R., Rechnitzer, G., Simmons, K., McIntosh, “A. Final Project Summary Report: Quad Bike Performance Project Test Results, Conclusions, and Recommendations”, The Quad Bike Performance Project, Report 4. Transport and Road Safety (TARS), University of New South Wales, Sydney, Australia, January 2015.

18. Anon., "PASW Statistics 18 Command Syntax Reference,” SPSS Inc., Chicago, 2009.

19. Ott, R.L., Larson, R., Rexroat, C., Mendenhall, W., “Statistics: A Tool for the Social Sciences, Fifth Edition,” Duxbury Press, 1992.

20. Western Australia Country Hour with Belinda Varischetti, 15 September 2020, https://www.abc.net.au/radio/programs/wa-country-hour/wa-country-hour/12643390, accessed 18 October 2020.

21. Kuppa, S., “Injury Criteria for Side Impact Dummies,” US Federal Docket NHTSA-2005-17694-0012, National Highway Traffic Safety Administration, Washington, DC, May 2004.

APPENDIX A

Additional Limitations of SEA Tests

Limitations of the Hybrid III dummy

The Hybrid III dummy used in the SEA tests is a frontal crash test dummy commonly used for frontal passenger car crash tests with a seated dummy. The SEA dummy included the sit/stand pelvis, which is a version of the dummy that allows the upper legs to extend into a standing position. However, even with this modification, the dummy is still intended for frontal impacts. Federal Motor Vehicle Safety Standards and the passenger car industry use different dummies for side impact tests.

Other ATV overturn research (Refs 7 and 10) has been done using the motorcyclist MATD dummy (Ref 11), which was designed for frontal as well as lateral impacts. The neck of this dummy has good biofidelity in lateral bending, torsion, and compression, unlike the Hybrid III dummy which was only designed to provide biofidelic head responses in frontal impacts.

The MATD dummy also allows the head to be positioned initially such that the dummy's head is properly facing forward. In contrast, the Hybrid III's head is positioned facing downward. Having an unrealistic head orientation at the beginning of the rollover event is likely to have an effect on the rider and ATV dynamics as well as measured outcomes.

Limitations of the Stabilizing Cables

SEA used a cable system to stabilize the Hybrid III dummy prior to the ATV reaching a 30-degree roll angle. These cables were necessary because the dummy was not postured in a "rider active" position, and the dummy would begin to fall off the ATV relatively early in the rollover sequence. However, the use of cables and the angle selected for the cable release may affect the outcomes of the tests and may not realistically represent a human rider's efforts to remain on the ATV. Perhaps placing the rider in a "rider active" initial position such that it is leaning into the turn would obviate the need for these cables. Further research may be useful in this area.

Limitations due to poor repeatability and reproducibility

SEA did not report on the repeatability of either the dynamic tests or the sled tests, which means the degree of repeatability is not known. However, research involving passenger cars has shown that the repeatability of rollover tests is extremely poor. This is because rollover events are highly chaotic (Ref 15), which means that the outcome of a rollover event is extremely sensitive to the initial conditions, and the initial conditions cannot be controlled accurately enough in order to get results that are acceptably repeatable.

A related issue is one of reproducibility. A testing methodology has limited utility unless the methodology results in similar results when applied by others using other facilities. Although SEA did not attempt to confirm the reproducibility of these tests, because the tests almost certainly have poor repeatability, they will also have poor reproducibility.

Many researchers have attempted to address the problem of poor repeatability in passenger car rollover testing. However, to date, the problem has not been solved for either passenger cars or ATVs, and it seems highly unlikely that it ever will be. Therefore computer simulations are also commonly used.

The effect of using tests that are not repeatable is that the only way to analyze the results is to have a sufficiently large sample size which allows the results to be analyzed statistically. This type of statistical analysis has been done in DRI's simulation studies (Ref 7), which were based on 4,620 simulations, but this analysis is very difficult to do with full-scale tests, such as the SEA study, which were based on only 52 tests due to the time and expense of conducting a sufficiently large number of tests to yield useful statistical results. With a small sample size, only relatively large differences can be found to be statistically significant.

Comparability of the Baseline tests with the OPD tests

A possible limitation of the SEA tests results from conducting the baseline tests separately from the OPD tests. Rollover tests have poor repeatability, which may be exacerbated by changes in the soil's moisture content and temperature.

More importantly, the mounting location of the steering motor was changed after the baseline tests were run. According to the authors of the SEA report, this was done because in some of the baseline tests contact between the steering motor guard and the ground potentially altered the motions of the ATV. This improvement to the test equipment only applied to the OPD tests, which means they are not directly comparable to the baseline tests.