safety

MDPI

Article

The Effect of Passengers on All-Terrain Vehicle Crash Mechanisms and Injuries

Charles A. Jennissen [1,*], Karisa K. Harland [2,†], Kristel M. Wetjen [3,†] and Gerene M. Denning [2,†]

Received: 31 October 2015; Accepted: 15 January 2016; Published: 20 January 2016
Academic Editor: Raphael Grzebieta

[1] Department of Emergency Medicine, University of Iowa Carver College of Medicine, 200 Hawkins Drive, 1008 RCP, Iowa City, IA 52242, USA
[2] Department of Emergency Medicine, University of Iowa Hospital and Clinics, and the Iowa Injury Prevention Research Center, 200 Hawkins Drive, 1008 RCP, Iowa City, IA 52242, USA; kari-harland@uiowa.edu (K.K.H.); gerene-denning@uiowa.edu (G.M.D.)
[3] Division of Pediatric Surgery, Department of Surgery, University of Iowa Children's Hospital, 200 Hawkins Drive, 2964 JCP, Iowa City, IA 52242, USA; kristel-wetjen@uiowa.edu
* Correspondence: charles-jennissen@uiowa.edu; Tel.: +1-319-384-8468; Fax: +1-319-353-7006
† These authors contributed equally to this work.

Abstract: Traditional all-terrain vehicles (ATVs) are designed for single riders. Although carrying passengers is a known risk factor for injury, how passengers contribute to ATV crashes remains poorly understood. To address this question, we performed a retrospective chart review of ATV crash victims at a U.S. trauma center (2002–2013). Of 537 cases, 20% were passengers or drivers with passengers. The odds of backward rollovers, falls/ejections, crashes on sloped terrain, and collisions with motorized vehicles were all significantly greater when passengers were present. In contrast, the odds of self-ejection or falls/ejections over the handlebars were significantly lower than falls/ejections to the side or rear, in crashes with multiple riders. Among all ejections, self-ejections had the lowest head and highest extremity injury scores and being ejected over the handlebars or to the rear resulted in worse head injury scores than being ejected to the side. In summary, our study found that passengers increased the odds of specific crash and injury mechanisms and that head and extremity injury severity varied by ejection type. Safety interventions including seat design changes that prevent carrying passengers, and a strict, well-enforced no-rider rule are needed to effectively prevent passenger–related deaths and injuries.

Keywords: all-terrain vehicle; injury prevention; passengers; adolescent behavior; rural; safety; helmet

1. Introduction

Deaths and injuries due to all-terrain vehicle (ATV) crashes remain a significant public health concern. The Consumer Product Safety Commission (CPSC) reports that there were 799 deaths in the U.S. due to ATV-related crashes in 2009, the last year in which data collection is considered complete [1]. In addition, non-fatal ATV-related injuries far surpass death totals; for example, over 400,000 injuries are estimated to have occurred in the U.S. in 2008 [2]. A number of risk factors for ATV-related injury have been identified including younger age, being male, driving on roads, lack of helmet use, operating under the influence of drugs or alcohol, age-inappropriate vehicle size, and carrying passengers [2–11].

ATVs are motorized off-road vehicles with three or four low pressure tires, a straddle seat and handle bars. Almost all ATVs are designed for a single rider. Despite strict warnings against multiple riders in operator manuals and on the ATVs themselves, carrying passengers appears to be a common behavior. For example, in a study of Iowa adolescent students, over 90% who had been on an ATV reported having ridden with passengers [12]. Other studies have shown similarly high reported rates of having been on ATVs with multiple riders, ranging from 50%–88% [6,13–15]. In addition, a national survey of ATV-owning households reported that for every 10 hours of ATV operation, an average of 2.5 h were with passengers on the vehicle [4]. Many people appear to be unaware or fail to fully appreciate the danger of multiple riders on an ATV [7,14,16,17].

In previous studies, passengers represented approximately 15% of crash victims [8,9,18,19], and 9% of all U.S. ATV-related hospitalizations [20]. We hypothesized that this proportion did not fully reveal the problem of passengers on ATVs, as it failed to take into account injured operators who may have been at increased risk of a crash due to the presence of additional riders. Consistent with this hypothesis, we found that from 1985–2009, 29% of all U.S. ATV-related fatalities were operators with passengers or passengers themselves [8].

Though the most common types of ATV-related injuries have been described, the circumstances under which these injuries occurred are less well defined. Similarly, although studies show that the presence of passengers represents an independent risk factor for ATV-related deaths [8], detailed analysis of the effect of passengers on crashes and associated injuries has not been reported. The objective of this study was to compare and contrast the mechanisms and injury outcomes among trauma patients in ATV crashes with and without passengers.

2. Methods

2.1. Study Design

A retrospective chart review was performed for patients presenting to a Level 1 trauma center in the U.S. Midwest who had sustained injuries from ATV crashes from 2002 through 2013. Potential subjects were identified through a search of hospital patient records using E-codes (E820–E829) and through an additional search of the hospital's records that were part of the state's trauma registry. The International Classification of Diseases (ICD) is a cataloging system of healthcare diagnoses, and E-codes are supplemental codes which identify the cause of injury or poisoning, the intent and the place where the event took place. A careful examination of the patient records for all potential subjects was performed to identify those who had sustained injuries due to an event involving a traditional straddle seat 3- or 4-wheeled ATV. Those with injuries related to other off-road vehicles such as motorbikes, scooters, snowmobiles, go-carts, golf carts, and side-by-side vehicles (utility task vehicles and recreational off-highway vehicles) were excluded. The University of Iowa Institutional Review Board (IRB) approved this study.

2.2. Variables

Coding keys were developed for all variables not already coded in the trauma registry. Variables for analysis included those related to riders (e.g., age, seating position, helmet use), vehicles (e.g., size, number of riders), crashes (e.g., time, type, mechanism), and injuries (e.g., type, severity).

The mechanism of injury was coded as a sequence of events with the "primary mechanism" being defined as the first significant event in the cascade of events leading to the patient's traumatic injury. Mechanisms were grouped first at the highest level as non-collision, collision with an object other than a motorized vehicle, and collision with a motorized vehicle. Primary non-collision events were further categorized as rollover, the vehicle going airborne due to a man-made ramp or terrain feature, and falls/ejections (including self-ejections) that were not secondary to a rollover or vehicle airborne event. For example, an ATV rolled over to the side and the rider was ejected to the side and struck a tree with their head would be coded as "rollover" as the primary crash mechanism. Conversely, if the rider fell or was ejected from the ATV prior to the vehicle rolling over or hitting an obstacle, the primary crash mechanism would be coded as "fall/ejection". Analysis was performed for falls/ejections as the primary mechanism, as well as for all rollovers and all falls/ejections that were part of the sequence of events.

Injury severity was determined based on the Abbreviated Injury Scale (AIS), one of the most common anatomic scales used to assess and compare the relative severity of traumatic injuries. In the AIS, injuries in nine body regions are classified according to their relative severity on a six-point ordinal scale (1-Minor, 2-Moderate, 3-Serious, 4-Severe, 5-Critical, 6-Maximal). Our study used the Maximum Abbreviated Injury Scale (MAIS) scores assigned to the anatomical regions of the head (which included the head and neck) and of the extremities (which included the upper and lower extremities, and the pelvic girdle), as well as the Injury Severity Score (ISS). For ISS calculations, the body is divided into six regions and the highest AIS scores in each of the three most severely injured body regions are squared and added together. The maximum score is 75 (*i.e.*, AIS scores of 5 in each of the three body regions used for calculations). If any of the three categories has a score of 6 (considered un-survivable), the individual is assigned the maximum (*i.e.*, 75).

2.3. Data Analysis

All statistical analyses were performed using SAS®software, Version 9.2 of the SAS System for Microsoft (SAS Institute Inc., Cary, NC, USA) or the VassarStats Website for Statistical Computation (http://www.vassarstats.net). All tests were two-tailed and significance was defined as a p value of <0.05. Comparisons of proportions for categorical variables were done using the chi square test. Unadjusted odds ratios (OR), and 95% Confidence Intervals (95% CI) were calculated using logistic regression. The non-parametric Wilcoxin Rank Sums test was used to compare mean injury severity scores. Patients with missing data for any specific variable were not included in comparative analyses involving that particular variable. The small number of cases precluded multivariable regression analysis.

3. Results

3.1. Demographics and Helmet Use

A total of 537 ATV-related trauma cases were identified. See Table 1. Nearly four out of five patients were males and one-quarter were children 15 years of age and younger. Twenty-one percent of victims were helmeted and 20% were passengers or drivers with passengers on the ATV. Females were a significantly higher proportion of passengers than were males ($p < 0.0001$). The seating distribution by age was also significantly different, with children 15 years old and younger having a significantly higher proportion of passengers (39/133, 29%) than those who were 16 years of age and older (39/404, 10%), $p < 0.0001$. Among adults, those 16–25 years old also had a significantly higher proportion of passengers (26/166, 16%) than adults over 25 years of age (13/238, 5%), $p = 0.002$. Passengers and drivers with passengers together were ~60% less likely to be helmeted than drivers riding alone (OR = 0.38, 95% CI 0.20–0.74).

3.2. Crash Characteristics and Mechanisms

3.2.1. Primary Mechanism

Twenty percent of crashes (109 of 537) involved passengers on the ATV. Non-collision events were the most frequent primary mechanism both with and without passengers. See Table 2. However, patients having had a collision between the ATV and a motorized vehicle (MV) had 2.4 times higher odds of having had multiple riders present on the vehicle than other crash mechanisms (95% CI 1.2–4.7).

3.2.2. Non-Collision Events

Of the 339 crashes where non-collision events were the primary mechanism, rollovers, airborne vehicles, and falls/ejections were 71%, 9% and 20%, respectively. If the direction of travel prior to the crash was reported as turning or spinning, a higher proportion of the crashes were rollovers (28/37, 78%), as compared to when the vehicle was reported to be traveling in a straight line (74/129, 57%), $p = 0.026$.

In addition, differences in the rollover direction between single-rider and multiple-rider crashes when all rollovers were included, approached but did not reach significance, p = 0.057. However, the odds of a backward rollover *versus* rollovers in other directions were 2.5 times higher in crashes with passengers than those without (95% CI 1.1–5.7).

For all crashes during which the victim was ejected at some point, the odds of a rider being ejected to the rear were more than five times greater than for other ejection types when passengers were present (95% CI 2.5–11.7). In contrast, forward or self-ejections were 86% less likely than ejections to the side or the rear in crashes with multiple riders *versus* drivers riding alone (95% CI 0.06–0.36). Finally, crashes on sloped terrain were 2.2-fold more likely than those on flat terrain to involve vehicles with passengers (95% CI 1.2–4.3).

Over half of all crashes (286 of 537) occurred from May through August. Although there was a higher proportion of multiple-rider than single-rider crashes during these months, the difference did not reach significance. There was no difference in the proportion of crashes with and without passengers when comparing crashes that occurred during the day with those occurring under limited light conditions.

Table 1. Demographics and helmet use for patients with all-terrain vehicles (ATV)-related injuries at a U.S. Midwest Trauma Center, 2003–2014[1].

	Total (N = 537)	**Seating Position of Injured**			
	n (Col %)[2]	**Driver Alone (n = 428, 80%) n (Col %)[2]**	**Driver + Passenger (n = 31, 6%) n (Col %)[2]**	**Passenger (n = 78, 14%) n (Col %)[2]**	**p-value[3]**
Sex					
Male	413 (77%)	365 (85%)	15 (48%)	33 (42%)	<0.0001
Female	124 (23%)	63 (15%)	16 (52%)	45 (58%)	
Age					
<12	60 (11%)	33 (8%)	3 (10%)	24 (31%)	<0.0001
12–15	73 (14%)	49 (11%)	9 (29%)	15 (19%)	
16–25	163 (30%)	131 (31%)	6 (19%)	26 (33%)	
26–35	95 (17%)	88 (21%)	5 (16%)	2 (3%)	
36–45	78 (15%)	67 (16%)	4 (13%)	7 (9%)	
>45	68 (13%)	60 (14%)	4 (13%)	4 (5%)	
Helmeted					
Yes	107 (21%)	96 (23%)	4 (13%)	7 (9%)	0.0052
No	411 (79%)	316 (77%)	26 (87%)	69(91%)	

[1] Abbreviation: N = total study population; n = number in subgroup for analysis; Col = column [2] Column total may not equal total n due to missing data. [3] Chi square comparison of proportions by seating position.

Table 2. Crash characteristics and mechanisms for patients with ATV-related injuries at a U.S. Midwest Trauma Center, 2003–2014[1].

	Passenger on ATV at Time of Crash		
	No n (Col%)[2]	Yes n (Col%)[2]	p value[3]
Primary Mechanism [4]			
Non-collision [5]	274 (68%)	65 (68%)	0.011
Collision with object	99 (25%)	15 (16%)	
Collision with MV	29 (7%)	15 (16%)	
Rollover Direction (All rollovers)			
Sideways	52 (43%)	10 (33%)	0.057
Backwards	45 (38%)	18 (60%)	
Forwards	23 (19%)	2 (7%)	
Fall/Ejection (As primary mechanism)			
Yes	43 (10%)	24 (22%)	0.0007
No	385 (90%)	85 (78%)	
Fall/Ejection Type (All falls/ejections) [6]			
Self-ejection	14 (10%)	0 (0%)	0.0013[6]
To the front (over handlebars)	66 (52%)	6 (16%)	
To the side	38 (30%)	13 (34%)	
To the rear	22 (17%)	19 (50%)	
Terrain			
Sloped	100 (51%)	37 (70%)	0.015
Not sloped	96 (49%)	16 (30%)	
Time of the year			
January–April	83 (19%)	21 (19%)	0.081
May–August	219 (51%)	67 (62%)	
September–December	126 (30%)	21 (19%)	
Lighting			
Day	285 (68%)	67 (64%)	0.48
Dusk/Dawn/Night	134 (32%)	37 (36%)	
Outcome	**Passengers on ATV at Time of Crash**		
	Odds Ratio	**95% CI**	**p value**
Mechanism: Collision with MV *vs.* not	2.4	1.2–4.7	0.0082
Rollover: Backward *vs.* Other directions	2.5	1.1–5.7	0.025
All falls/ejections: Rear *vs.* Other types	5.3	2.5–11.7	<0.0001
All falls/ejections: Forward/Self *vs.* Side/Rear	0.14	0.06–0.36	<0.0001
Terrain: Sloped *vs.* not	2.2	1.2–4.3	0.015

[1] Abbreviations: N = total study population; n = number in subgroup for analysis; Col = column; MV = motorized vehicle. [2] Column total may not equal total n due to missing data. [3] Chi square comparison of proportions by presence or absence of passenger on the ATV. [4] Does not include other miscellaneous mechanisms, n = 31. [5] Combined primary mechanisms of rollover, vehicle goes airborne, and fall/ejection including self-ejection. [6] Ejections in an unspecified direction not included. Self-ejection not included in chi-square analysis due to zero value.

3.3. Injury Characteristics and Mechanisms

The primary mechanism for 12% of all injured riders was a fall/ejection, including self-ejection, from the ATV. See Table 3. A significantly higher proportion of passengers had a primary fall/ejection than drivers riding alone or drivers carrying passengers ($p < 0.0001$). Overall, the odds of the primary mechanism being a fall/ejection for passengers were 3.6-fold higher than for drivers (95% CI 2.0–6.5). Almost 60% of all victims (319 of 537) fell off or were ejected at some point in the crash and 29% were struck or pinned by the ATV. There was no difference in the proportion of victims struck/pinned by the vehicle as a function of seating position.

Table 3. Injury characteristics and mechanisms for patients with ATV-related injuries at a U.S. Midwest Trauma Center, 2003–2014.[1]

		Seating Position of Injured			
	Total (N = 537) n (Col %)[2]	**Driver Alone (n = 428) n (Col %)[2]**	**Driver + Passenger (n = 31) n (Col %)[2]**	**Passenger (n = 78) n (Col %)[2]**	**p-value[3]**
Primary fall/ejection[4]					
Yes	67 (12%)	43 (10%)	2 (7%)	22 (28%)	<0.0001[4]
No	470 (88%)	385 (90%)	29 (93%)	56 (72%)	
Rider was struck/pinned by ATV					
Yes	156 (29%)	127 (30%)	8 (26%)	21 (27%)	0.81
No	381 (71%)	301 (70%)	23 (74%)	57 (73%)	
Rider lost consciousness					
Yes	205 (42%)	160 (41%)	15 (54%)	30 (40%)	0.41
No	287 (58%)	229 (59%)	13 (46%)	45 (60%)	
Injury Severity: Mean (SD)					**p-value[5]**
ISS	11.9 (9.7)	12.3 (9.8)	11.6 (12.2)	9.8 (8.0)	0.11
MAIS Head Score	1.2 (1.7)	1.3 (1.7)	1.1 (1.7)	1.2 (1.6)	0.77
MAIS Extremity Score	1.0 (1.2)	1.0 (1.2)	1.1 (1.2)	1.0 (1.2)	0.80

[1] Abbreviations: N = total study population; n = number in subgroup for analysis; Col = column; SD = standard deviation of the mean; ISS = Injury Severity Score; MAIS = Maximum Abbreviated Injury Scale. [2] Column total may not equal total n due to missing data. [3] Chi square comparison of proportions by seating position. [4] Includes crashes where falls/ejections, including self-ejections, were the primary mechanism. Odds ratio for a fall/ejection being the primary mechanism for passengers as compared to drivers, OR 3.6, 95% CI 2.0–6.5. [5] Non-parametric Wilcoxin Rank Sums comparison of means by seating position.

Over 40% of patients were reported as having had a loss of consciousness. Overall, there was no difference found in losing consciousness, ISS, MAIS Head or MAIS Extremity scores by seating position. In contrast, differences in injury severity scores were seen when falls/ejections were examined. See Table 4. Self-ejections had the lowest mean head injury score and the highest mean extremity injury score. For pairwise comparisons, mean head injury scores were significantly higher than self-ejection injury scores for all directions ($p < 0.0001$) except to the side, which approached but did not reach significance. Similarly, a fall/ejection to the side was the only direction that did not reach significance, as compared to self-ejections, for extremity injury scores. Falls/ejections to the rear had the highest mean head injury scores, followed by forward falls/ejections. As compared to side falls/ejections, backward and forward falls/ejections together had significantly higher head injury scores ($p = 0.046$) and significantly lower extremity injury scores ($p < 0.0001$).

Table 4. MAIS Head and MAIS Extremity scores for patients who fell off or were ejected from the ATV during the crash as seen at a U.S. Midwest Trauma Center, 2003–2014.[1]

Type of Fall/Ejection	**MAIS Head**		**MAIS Extremity**	
	Mean (SD)	**p-value[2]**	**Mean (SD)**	**p-value[2]**
Self-ejection	0.1 (0.3)	Reference	2.3 (0.9)	Reference
To the front	1.4 (1.7)	0.0046	0.6 (1.0)	<0.0001
To the side	0.9 (1.5)	0.086	1.6 (1.3)	0.061
To the Rear	1.5 (1.8)	0.0039	0.7 (1.1)	<0.0001

[1] Abbreviations: MAIS = Maximum Abbreviated Injury Scale; SD = standard deviation. [2] Non-parametric Wilcoxin Rank Sums comparison of means.

4. Discussion

4.1. Vehicle Design and Loss of Control

ATVs have a relatively high center of gravity and a narrow wheelbase that together make them particularly prone to rollovers, especially while turning or on inclines. This and other vehicle characteristics require ATV operators to engage in "active riding", *i.e.*, shifting of the operator's center of mass and maintaining grip and footing to counteract forces on the vehicle's center of gravity that would lead to loss of control. Loss of control can subsequently lead to rollovers, collisions, and/or riders falling from or being ejected from the vehicle. Operators must also use their bodies to absorb forces transmitted while travelling over bumps, depressions, and other obstacles [7,11,21–24].

4.2. Passengers and Active Riding

As mandated by the CPSC, ATV manufacturers place labels on all ATVs warning against carrying passengers. This is due to the fact that ATVs are designed for an operator only and passengers have been shown to be an independent risk factor for injuries [8]. Passengers could inherently interfere with active riding and can contribute to loss of control in a number of ways.

First and foremost, passengers are an additional mass that shifts the rider-vehicle center of gravity. It can also be difficult for passengers to work in tandem with the operator to effectively counteract destabilizing forces. On a side hill, for example, multiple riders would need to shift their bodies to the appropriate degree and in a timely manner toward the hillside to maintain stability. Our study found that crashes that occurred on sloped terrain were significantly more likely to have passengers on the vehicle than crashes on other terrains. Often, passengers may not be able to see and react appropriately to abrupt changes in terrain or direction. In addition, extra riders can distract the operator from the complex decision-making processes required to handle unexpected terrain features.

4.3. Single-Rider vs. Multiple-Rider Crashes

4.3.1. Demographics

We observed a number of significant differences by victim seating position and between crashes with drivers riding alone and those with passengers. As in previous studies [8–10,25], passengers were more commonly females and youth, and helmet use was significantly lower for passengers and for drivers with passengers, as compared to drivers riding alone.

4.3.2. Motor Vehicle Collision

We observed that relative to other crash mechanisms, ATV collisions with motorized vehicles had higher odds of having been carrying passengers. In previous studies using regression analysis, we found that fatal roadway crashes were more likely to involve multiple riders and to result in motor vehicle collisions than fatal off-road crashes [8]. In the future, we hope to determine whether the observed differences were completely due to exposure (more multiple rider vehicles on the road) and mechanism (more collisions on the road) or whether there is an independent contribution by a passenger (e.g., distracted driving) that increases the risk of motor vehicle crashes.

4.3.3. Rollovers

Similar to previous results [8,9,11,26], rollovers were the most common crash mechanism. In these studies, we found that backward rollovers were 2.5 times more likely to involve a vehicle with passengers, as compared to those in rollovers in other directions. This is consistent with passengers most typically being seated behind the operator near to or beyond the rear axle, which elevates the center of mass and shifts it to the rear. Normally, an operator leans forward toward the front axle when travelling uphill to prevent a backward rollover. The recommendation on steeper hills is that the operator stand and lean forward over the handle grips to keep the center of gravity in front of the back wheels.[27] With passengers, it becomes more difficult to shift the total center of mass sufficiently forward to prevent a backward rollover.

4.3.4. Falls and Ejections

Riders can be injured when they are ejected or fall off of the vehicle. Maintaining ATV stability and control not only involves proper body weight shifting, but also depends on the driver keeping both hands on the handlebars and both feet on the footrests. The forces generated during ATV operation can sometimes exceed grip strength and other compensatory mechanisms, especially during acute accelerations and sharp turns, or on steeper inclines. In addition, passengers can more easily lose their grip or seating than operators and often have no solid footing on the ATV. This might make them particularly vulnerable to being thrown from or falling off of the ATV. Consistent with these considerations, we found that passengers on the ATV increased the odds of an ejection as the primary crash mechanism by 2.5-fold, particularly a fall/ejection to the rear. In addition, passengers were significantly more likely to fall or be ejected from the vehicle than drivers riding either alone or with passengers.

On the other hand, passengers could potentially "trap" an operator between themselves and the handlebars of the ATV. This was supported in our study in that forward falls/ejections over the handle bars and self-ejections (ejection types hypothetically affected by trapping) were 86% less likely if passengers were present than were side and rear ejections (ejection types hypothetically not affected by trapping). Because ATVs lack a rollover protective structure and seatbelts, sometimes the only way to protect oneself from serious injury in a loss of control event is to self-eject to avoid being struck or pinned by the vehicle. Compression asphyxia as a mechanism of ATV-related injury and death has been becoming increasingly more frequent as ATVs have become bigger and heavier over the past 15 years [8]. Having passengers present may prevent operator self-ejection. Although the numbers are small, our study found 14 self-ejections in crashes where drivers were riding alone and no self-ejections among multiple-rider crashes.

4.4. Injury Mechanisms and Severity

There were no overall differences in injury severity scores or in head or extremity injury scores by seating position. Differences in severity, however, were seen as a function of injury mechanism, specifically, in types of falls/ejections from the ATV.

Self-ejections resulted in the lowest head injury scores and the highest extremity scores. We hypothesize that this reflects the rider's ability to clear the vehicle and land in a manner that helps protect the head from injury, but results in injuries to the arms and/or legs when breaking the fall. Falls/ejections to the side, often resulting from a sideways rollover, had intermediate scores between self-ejections and ejections to the front or rear. Like self-ejection, during a sideways fall/ejection, the rider may use their arms in an attempt to absorb crash forces, thus protecting the head. Unlike self-ejections, however, lower extremities may be more likely injured when they are struck or pinned by the ATV in side rollovers.

Falls/ejections over the handlebars and off the back of the ATV had the highest head and lowest extremity scores. These findings suggest that riders have more difficulty using their arms to break their fall and protect their head when being thrown from or falling off the vehicle in these directions. Many of the head injuries were likely exacerbated by lack of helmet use. Helmets have been shown to decrease the risk of head injuries in fatal crashes by approximately 40% and in non-fatal crashes by 60% or more [28–30].

4.5. Relevance to Injury Prevention

4.5.1. Education

Studies repeatedly show that carrying passengers is a common riding practice [4,6,12,13,15,17,31]. However, although some riders are no doubt aware that most ATVs are designed for a single rider, this knowledge is by no means universal [16,32]. Additional education and public awareness programs regarding the dangers of carrying passengers are critically needed. These programs should include targeting the highest risk groups, females and youth, who consistently account for the majority of passenger deaths and injuries [8,9,25]. Youth programming should also include a parent component and programs should be assessed for effectiveness and reach [17,32,33].

4.5.2. Seat Design

Manufacturers argue that ATVs are safe if used as designed. However, previous studies showed a wide variability in ATV seat length and placement both by vehicle type (sport *vs.* utility ATVs) and by manufacturer [34]. There was an almost two-fold difference in seat lengths between the shortest and longest seats (19.8 *vs.* 37.0 inches), and previous focus groups found that youth considered vehicles with longer seats an invitation for carrying passengers and that riding with others facilitated socializing [3]. Some ATV models had seats lengths and placement that may represent a good starting point for improved seat design standards—the front of the seat starting far enough back from the handle grips to allow proper operation by adults but not children, and the back of the seat extending no further than the rear axle. Such seat design would be an important step in engineering improved safety and decreasing the likelihood of passengers on ATVs.

4.5.3. Enforcement

Although education is essential and engineering approaches for improving safety exist, there is clearly a need for evidence-based safety laws and design standards. ATV laws vary significantly from state to state in the U.S., and many people may not know their state's laws [26,32]. This is likely to be true in other countries as well. Moreover, some ATV laws have not been as effective in changing behaviors as they might be due to the lack and difficulty of enforcement. In order for regulations to be effective, both public awareness and law enforcement are essential.

4.6. Limitations

This study was conducted at a single tertiary care center in a rural U.S. state and thus may not necessarily be generalizable to other states or countries. However, we feel our findings do shed light on some of the issues related to carrying passengers on ATVs that are likely to be true regardless of the location of ATV use. Our study is also limited in the total number of ATV crash victims available for analysis. In certain situations, we observed trends toward significance and hypothesize that with a larger sample size, these observed trends would reach significance. In addition, although a thorough review of documentation was performed, information regarding some study variables was not available in the medical record in many cases. This limitation is not uncommon in retrospective studies using hospital-based data for details of injury causing events. Some results of our study analysis could be affected by this missing data, particularly variables for which reporting bias in the medical record may be more likely such as presence of slope or direction of travel (straight/turning). For example, a crash involving a slope will often have that fact documented, while a crash occurring on flat land is less likely to have that information reported. The authors plan to conduct a prospective, multi-center emergency department study collecting data on ATV crashes, including key variables related to victims, vehicles and crashes. Analysis of such data would provide a more definitive picture of the relationship of certain risk factors to crash mechanisms and injury outcomes.

5. Conclusions

Most ATVs are designed for a single rider. This study provides insights as to how passengers may contribute to crash mechanism, as well as to injury type and severity. Multiple approaches, including education/training, safety-based engineering design changes, and regulations/laws based on our understanding of ATV crashes are clearly needed to decrease the dangerous practice of riding with passengers. Decreases in carrying passengers would, in turn, prevent some ATV-related deaths and injuries.

Acknowledgments: The authors would like to thank Ali Maarmar-Tayeb, Curtis Brown, and Josh Godding for their diligent work in reviewing charts and coding variables for this study. Funding for these studies was provided by the University of Iowa Department of Emergency Medicine and the Carver College of Medicine. No funds were received for covering the cost to publish in open access.

Author Contributions: CJ, GD, KW, and KH participated in the study's conceptualization and design. CJ and KW were primarily responsible for patient identification. CJ and GD developed the coding keys, supervised variable coding and data entry, and provided database management. KH, GD and CJ performed data analysis. CJ and GD were primarily responsible for writing the manuscript and its completion.

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

Abbreviations

All-terrain vehicle: ATV
Institutional Review Board: IRB
Future Farmers of America: FFA

References

1. Topping, J.; Garland, S. *2013 Annual Report of ATV-Related Deaths and Injuries*; U.S. Consumer Product Safety Commission: Bethesda, MD, USA, February 2015. Available online: http://www.cpsc.gov//Global/Research-and-Statistics/Injury-Statistics/Sports-and-Recreation/ATVs/2013-ATV-Annual-Rpt-of-ATV-Related-Deaths–Injuries.pdf (accessed on 18 January 2016).
2. United States General Accounting Office (GAO). *All-Terrain Vehicles: How They are Used, Crashes, and Sales of Adult-Sized Vehicles for Children's Use*; 2010 Report to Congressional Committees (GAO-10-418); GAO: Washington, DC, USA, 2010. Available online: http://www.gao.gov/assets/310/302950.pdf (accessed on 18 January 2016).
3. Aitken, M.E.; Graham, C.J.; Killingsworth, J.B.; Mullins, S.H.; Parnell, D.N.; Dick, R.M. All-Terrain Vehicle Injury in Children: Strategies for Prevention. *Inj. Prev.* **2004**, *10*, 303–307. [CrossRef] [PubMed]
4. Rodgers, G.B. The Characteristics and Use Patterns of All-Terrain Vehicle Drivers in The United States. *Accid. Anal. Prev.* **1999**, *31*, 409–419. [CrossRef]
5. Rodgers, G.B. Factors Associated with the All-Terrain Vehicle Mortality Rate in The United States: An Analysis of State-Level Data. *Accid. Anal. And Prev.* **2008**, *40*, 725–732. [CrossRef] [PubMed]
6. Campbell, B.T.; Kelliher, K.M.; Borrup, K.; Corsi, J.; Saleheen, H.; Bourque, M.D.; Lapidus, G. All-Terrain Vehicle Riding Among Youth: How Do They Fair? *J. Pediatr. Surg.* **2010**, *45*, 925–929. [CrossRef] [PubMed]
7. Consumer Federation of America. *All-Terrain Vehicle (ATV) Safety Crisis: America's Children at Risk*; Consumer Federation of America: Washington, DC, USA, 2002; Available online: http://www.consumerfed.org/pdfs/Final_ATVReportLinks.pdf (accessed on 18 January 2016).
8. Denning, G.; Harland, K.; Ellis, D.; Jennissen, C. More Fatal All-Terrain Vehicle Crashes Occur on the Roadway than Off: Increased Risk-Taking Characterises Roadway Fatalities. *Inj. Prev.* **2013**, *19*, 250–256. [CrossRef] [PubMed]
9. Denning, G.; Jennissen, C.; Harland, K.; Ellis, D.; Buresh, C. All-Terrain Vehicles (ATVs) on The Road: A Serious Traffic Safety and Public Health Concern. *Traffic Inj. Prev.* **2013**, *14*, 78–85. [CrossRef] [PubMed]
10. Denning, G.M.; Harland, K.K.; Jennissen, C.A. Age-Based Risk Factors for Pediatric ATV-Related Fatalities. *Pediatrics* **2014**, *134*, 1094–1102. [CrossRef] [PubMed]

11. Shulruf, B.; Balemi, A. Risk and Preventive Factors for Fatalities in All-Terrain Vehicle Accidents in New Zealand. *Accid. Anal. Prev.* **2010**, *42*, 612–618. [CrossRef] [PubMed]
12. Jennissen, C.; Harland, K.; Wetjen, K.; Peck, J.; Hoogerwerf, P.; Denning, G. A School-Based Study of Adolescent All-Terrain Vehicle Exposure, Safety Behaviors, and Crash Experience. *Ann. Fam. Med.* **2014**, *12*, 310–316. [CrossRef] [PubMed]
13. Hafner, J.W.; Hough, S.M.; Getz, M.A.; Whitehurst, Y.; Pearl, R.H. All-Terrain Vehicle Safety and Use Patterns in Central Illinois Youth. *J. Rural Health* **2010**, *26*, 67–72. [CrossRef] [PubMed]
14. Burgus, S.K.; Madsen, M.D.; Sanderson, W.T.; Rautiainen, R.H. Youths Operating All-Terrain Vehicles—Implications for Safety Education. *J. Agromed.* **2009**, *14*, 97–104. [CrossRef] [PubMed]
15. Jones, C.S.; Bleeker, J. A Comparison of ATV-Related Behaviors, Exposures, and Injuries between Farm Youth and Nonfarm Youth. *J. Rural Health* **2005**, *21*, 70–73. [CrossRef] [PubMed]
16. Jennissen, C.A.; Denning, G.M.; Sweat, S.; Harland, K.; Buresh, C. All-Terrain Vehicle Injury Prevention: Healthcare Providers' Knowledge, Attitudes, and the Anticipatory Guidance They Provide. *J. Community Health* **2012**, *37*, 968–975. [CrossRef] [PubMed]
17. Williams, R.S.; Graham, J.; Helmkamp, J.C.; Dick, R.; Thompson, T.; Aitken, M.E. A Trial of an All-Terrain Vehicle Safety Education Video in a Community-Based Hunter Education Program. *J. Rural Health* **2011**, *27*, 255–262. [CrossRef] [PubMed]
18. Helmkamp, J.C. Injuries and Deaths and the Use of All-Terrain Vehicles. *N. Engl. J. Med.* **2000**, *343*, 1733–1734. [CrossRef] [PubMed]
19. *All-Terrain Vehicle Fatalities—West Virginia, 1999–2006*; Morbidity and Mortality Weekly Report; Centers for Disease Control and Prevention: Atlanta, GA, USA, 2008; pp. 312–315.
20. Helmkamp, J.C.; Furbee, P.M.; Coben, J.H.; Tadros, A. All-Terrain Vehicle-Related Hospitalizations in The United States, 2000–2004. *Am. J. Prev. Med.* **2008**, *34*, 39–45. [CrossRef] [PubMed]
21. Huhlein, B.J. *Dynamic Modeling of the Polaris Sportsman 500 ATV Using Dynamic Analysis and Design System (DADs)*; Technical Report RD-PS-98-11; U.S. Army Aviation and Missile Command: Redstone Arsenal, AL, USA, 1998; Available online: http://www.dtic.mil/dtic/tr/fulltext/u2/a354423.pdf (accessed on 18 January 2016).
22. Carman, A.B.; Gillespie, S.; Jones, K.; Mackay, J.; Wallis, G.; Milosavljevic, S. All Terrain Vehicle Loss of Control Events in Agriculture: Contribution of Pitch, Roll and Velocity. *Ergonomics* **2010**, *53*, 18–29. [CrossRef] [PubMed]
23. Mattei, T.A.; Bond, B.J.; Hafner, J.W., Jr.; Morris, M.J.; Travis, J.; Hannah, G.; Webster, J.; Lin, J.J. Definition and Measurement of Rider-Intrinsic Physical Attributes Influencing All-Terrain Vehicle Safety. *Neurosurg. Focus* **2011**, *31*, E6. [CrossRef] [PubMed]
24. Thorbole, C.; Aitken, M.; Graham, J.; Miller, B.; Mullins, S. Assessment of The Dynamic Behavior of a Single Person ATV in Presence of A Passenger: Outcome on the Rider and Passenger Crash Impact Kinematics Using Computational Model. In Proceedings of The International Mechanical Engineering Congress and Exposition (IMECE), Houston, TX, USA, 9–15 November 2012; pp. 161–171.
25. Denning, G.M.; Jennissen, C.A. All-Terrain Vehicle Fatalities on Paved Roads, Unpaved Roads, and Off-Road: Evidence for Informed Roadway Safety Warnings and Legislation. *Traffic Inj. Prev.* **2015**, Epub ahead of print. [CrossRef] [PubMed]
26. Balthrop, P.M.; Nyland, J.; Roberts, C.S. Risk Factors and Musculoskeletal Injuries Associated with All-Terrain Vehicle Accidents. *J. Emerg. Med.* **2009**, *36*, 121–131. [CrossRef] [PubMed]
27. ATV Safety Institute. *Tips and Practice Guide for The All-Terrain Rider*; ATV Safety Institute: Irvine, CA, USA, 2008. Available online: http://atvsafety.org/downloads/ATV_Riding_Tips.pdf (accessed on 18 January 2016).
28. Rodgers, G.B. The Effectiveness of Helmets in Reducing All-Terrain Vehicle Injuries and Deaths. *Accid. Anal. Prev.* **1990**, *22*, 47–58. [CrossRef]
29. Merrigan, T.L.; Wall, P.L.; Smith, H.L.; Janus, T.J.; Sidwell, R.A. The Burden of Unhelmeted and Uninsured ATV Drivers and Passengers. *Traffic Inj. Prev.* **2011**, *12*, 251–255. [CrossRef] [PubMed]
30. Myers, M.L.; Cole, H.P.; Mazur, J.M. Cost Effectiveness of Wearing Head Protection on All-Terrain Vehicles. *J. Agromed.* **2009**, *14*, 312–323. [CrossRef] [PubMed]
31. Shults, R.A.; West, B.A. ATV Riding and Helmet Use Among Youth Aged 12–17 Years, USA, 2011: Results from the Youthstyles Survey. *Inj. Prev.* **2015**, *21*, 10–14. [CrossRef] [PubMed]

32. Jennissen, C.A.; Peck, J.; Wetjen, K.; Hoogerwerf, P.; Harland, K.K.; Denning, G.M. The Safety Tips for ATV Riders (Stars) Programme: Short-Term Impact of A School-Based Educational Intervention. *Inj. Prev.* **2015**, *21*, 166–172. [CrossRef] [PubMed]
33. Brann, M.; Mullins, S.H.; Miller, B.K.; Eoff, S.; Graham, J.; Aitken, M.E. Making the Message Meaningful: A Qualitative Assessment of Media Promoting All-Terrain Vehicle Safety. *Inj. Prev.* **2012**, *18*, 234–239. [CrossRef] [PubMed]
34. Jennissen, C.A.; Miller, N.S.; Tang, K.; Denning, G.M. Optimising Seat Design for All-Terrain Vehicle Injury Prevention: Wide Variability Illustrates Need for Evidence-Based Standardisation. *Inj. Prev.* **2014**, *20*, 88–96. [CrossRef] [PubMed]