ACTA SCIENTIFIC AGRICULTURE (ISSN: 2581-365X)

Volume 2 Issue 10 October 2018

Research Article

ATVs and Agriculture: A Review of the Literature

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Received: August 31, 2018 **Published:** September 28, 2018

Abstract

The purpose of this article was to provide a review of the published literature pertaining to agricultural All-Terrain Vehicle (ATV) use and injury, fatality, exposure assessment, risk estimation and interventions. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) technique was used to identify high quality relevant articles pertaining to ATV-related injury, fatality, exposure assessment, risk estimation, and interventions in an agricultural setting. Inclusion criteria for articles included publications from January 1, 2000 through August 31, 2016, use of injury epidemiology assessment tools, NIOSH hierarchy of controls and the W.K. Kellogg Foundation Logic Model Development Guide. Thirty-four articles met the full inclusion criteria. There have been more than 14,000 ATV-related fatalities since 1982 and a 90% increase in related hospitalizations between the years 2000 to 2005. Occupational ATV-related fatality rates have increased by 300% between 1992 and 2007; with the greatest burden seen in the agricultural sector. Risk factors for ATV-related injury and fatality include riding with passengers, riding on public roadways, riding adult-sized ATVs as a child, lack of formal training, lack of crush protection devices, riding at high speeds, driving up or down hills, traversing hills and modifying ATVs. There are five general types of interventions used to increase ATV safety behaviors and decrease injuries: engineering controls, computer simulations, laws, training and education. The United States lacks consistency in regulations and laws, while Australia is implementing rollover protection for existing ATVs and the Star Rating method, 'fit for use' classification system, to help inform consumers about making the best choices for safer and appropriate use.

Keywords: ATVs; Quadbikes; Agriculture; Injury; Prevention

Abbreviations

ATV: All-Terrain Vehicle; ROV: Recreational Off-Road Vehicle; SSV: Sided-by-Side Vehicle; CPSC: Consumer Product Safety Commission; SVIA: Specialty Vehicle Institute of America; ASI: ATV Safety Institute; NIOSH: National Institute for Occupational Safety and Health; ANSI: American National Standards Institute; NAGCAT: North American Guidelines for Children's Agricultural Tasks; ATVAP: Australian Terrain Vehicle Assessment Program; LOC: Loss of Control; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analysis; LLT: Lateral Load Transfer; CPD: Crush Protection Devices

Introduction

The Consumer Product Safety Commission (CPSC) collected data on 14,129 All-Terrain Vehicle (ATV) related fatalities from 1982 through 2015 [1]. The popularity of ATVs has increased with post-recession sales up 2.2%, supporting an estimated 730,000 units sold in 2015 [2]. In 2017, the ATV Safety Institute (ASI) estimated that 35 million Americans ride 11 million ATVs in the United States (U.S.) [3].

The ATV first arrived in the U.S. in the 1970s as three-wheeled vehicles and were rapidly accepted by consumers for both occupational and recreational purposes [4]. However, it was soon determined that there were significant risks associated with their use [4]. The vehicle design was characterized by large, low-pressure tires, straddle seats and handle bar steering. The units were intended for a one-person rider and were uniquely risk-interactive. Proper operation of an ATV requires the rider to actively shift their weight to maintain stability. A rider's abilities to actively ride the

ATV can increase or decrease risks associated with an ATV loss of control (LOC) event.

The agricultural community welcomed the use of ATVs for many job tasks performed on farms and ranches such as animal handling, weed control, fence mending and general transportation [5]. While an estimated 78% of ATVs are ridden for recreational purposes, 22% are used in occupational settings [3]. The agricultural community remains the largest occupational user group [6]. The versatility of ATVs has resulted in its use in construction, manufacturing, police, search and rescue, utilities, mining and land management [7].

The utility, affordability and ease of use of ATVs resulted in the agricultural community favoring the units over horses and/or pickup trucks for many job tasks. With the increased use of ATVs on the farm and ranch, the occurrence of injuries and fatalities have increased in this sector. Due to increased morbidity and mortality, ATVs have placed a disproportional and startling burden on the agricultural community compared to all other occupational sectors. Investigators identified that 59% of occupational ATV-related injuries [7] and 65% of all occupational ATV-related deaths occurred in the agricultural sector [8].

In 1988, the manufacturers discontinued the inherently unstable traditional three-wheeled units, ceased sales and promoted the four-wheeled design [4]. The body of evidence was overwhelming citing the unstable three-wheeled ATV as a major public health risk. The unacceptable risk associated with the three-wheeled design was the primary driver to redesign the units to a four-wheel vehicle. The manufacturing and sales industry established the Specialty Vehicle Institute of America (SVIA) in 1985 and charged the ATV Safety Institute (ASI) to develop, implement and expand rider education and safety awareness for buyers and users [9]. Concurrent to the ASI initiative, the SVIA began working with the American National Standard's Institute (ANSI) to develop design specifications to improve performance and safety of the four-wheeled ATVs [10]. Since its inception, the ASI's primary goals has been to promote safe and responsible use of ATVs and to reduce the numbers of LOCs, reducing injuries and fatalities.

Further investigation is needed for the physical stresses, demands and responses associated with ATV use, especially in older users [6]. The development of interventions to improve safety has been limited and emphasized laws, safety education, training and design [10].

This literature review provides an understanding and summary of the published literature pertaining to the epidemiology of ATV-related injury and fatality in agriculture. This manuscript will examine and discuss the application of exposure assessment methods to estimate risk, identification and explanation of the physical demands of ATV operation, responses and/or interactions. In this manuscript, the characterization of the interventions currently used to mitigate risks, reduce exposures, eliminate LOCs and prevent injuries and fatality will be discussed.

Materials and Methods

Our approach to this review was to use standardized and systematic methods survey the literature and identify high quality, relevant articles pertaining to ATV-related injury, fatality, exposure assessment and interventions with a focus on agriculture. The search procedures entailed to: (1) performance of a literature search; (2) selection of relevant studies through the use of inclusion and exclusion criteria; (3) further assessment of the quality of the studies; and (4) consolidation of the results.

Searches were carried out using 13 popular databases including Academic Search Premier, Agricola, Applied Science and Technology Abstracts, CAB Abstracts, CINAHL, ERIC, Family and Society Studies Worldwide, Library Literature and Information Science Index (H.W. Wilson), MEDLINE, PsychINFO, PubMed, Science Reference Center, Web of Science and the journal, Safety. Search criteria included full-length, English, peer-reviewed journal articles published between January 1, 2000 and August 31, 2016. Three separate searches were performed to incorporate injury epidemiology, exposure assessment and evaluation and safety interventions.

Search terms

1. ATV OR all-terrain vehicle OR all terrain vehicle OR quad-bike OR quad bike OR four wheeler OR four-wheeler AND farm OR ranch OR agricultural OR agriculture AND injury OR fatality OR mortality OR accident OR epidemiology OR crash OR wreck

2. ATV OR all-terrain vehicle OR all terrain vehicle OR quad-bike OR quad bike OR four wheeler OR four-wheeler AND farm OR ranch OR agricultural OR agriculture AND rating OR danger OR liability OR hazard identification OR stability OR crashworthiness OR crashworthiness protection OR fit for purpose OR operator protection device OR rollover resistance OR exposure OR risk reduction OR safety testing OR engineering controls OR operating controls OR hazard identification

3. ATV OR all-terrain vehicle OR all terrain vehicle OR quad-bike OR quad bike OR four wheeler OR four-wheeler AND farm OR ranch OR agricultural OR agriculture AND protection OR security OR safety assurance OR stability OR safeguard OR barrier OR shield OR guard OR safety equipment OR rollover bars OR instruction OR schooling OR teaching OR education OR groundwork OR guidance OR safety OR training OR industrial safety OR safety education OR safety training

Article selection was accomplished using The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). The technique was applied to accomplish a standardized, rigorous and effective systematic review [11]. The elimination process consisted of identifying and deleting duplicates and articles on unrelated topics. The initial literature search identified 631 articles. The selection procedures eliminated 597 articles, which left 33 remaining studies that met the full inclusion criteria.

Injury epidemiology articles were narrowed further using quantitative and qualitative research assessment guidelines found on the Research Connections website. To further narrow articles for inclusion, guidelines addressing each type of study were used [12]. The quantitative tool considered factors regarding population and sample and measurement and analysis [13]. The qualitative assessment tool summarized Kuzel's and Like's (1991) four techniques [14]: (1) member checking, (2) disconfirming evidence, (3) triangulation, and (4) thick description to analyze the validity and consistency of quantitative research.

Exposure assessment, hazard evaluation and safety intervention articles were initially narrowed by comparing the article methods and results to the National Institute for Occupational Safety and Health (NIOSH) Hierarchy of Controls [15]. The hierarchy of controls is advocated by NIOSH's "Prevention through Design" (PtD) strategies that increase quality and assurance of positive safety and health outcomes [15].

Quality was assessed using the W.K. Kellogg Foundation Logic Model Development Guide to further evaluate the three topic areas: injury epidemiology, exposure assessment, and evaluation and safety interventions [16]. Logic model checklists were used to assess the outcome-oriented effectiveness of current risk assessment and training programs. Safety programs with ATV users have typically been designed to address small groups. Logic model tools can help guide program planning, implementation and measurable outcomes.

Results and Discussion

Epidemiology

A review of epidemiology literature revealed patterns, trends and significant factors associated with ATV-related injuries and fatalities in the agricultural sector (Table 1). Initially, 113 articles were identified and 16 articles met the inclusion criteria. Researchers found in a survey of 1149 farm operators in Canada that 44% used ATVs with 11% of farm operators using ATVs more than 81 days per year. Researchers reported that ATV use was not significantly associated with hip or back pain, but contributed to overall exposure to whole body vibration and mechanical shock [17,18].

In 2001, it was estimated that the U.S. had 1.6 million farms with more than 850,000 ATVs in use for an average of 0.5 units per farm [21]. The investigators also found that 36% of the 1.1 million youth working on farms had ridden ATVs with a resulting injury rate of 4.3/1,000. The job task associated with the highest rate was livestock handling. Hendricks, Myers, Layne and Goldcamp (2004) reported that minority youth on U.S. farms were exposed to significant hazards including ATVs [24]. Browning, Westnear, Sanderson and Reed (2013) found after sampling 1,149 beef operations in Kentucky that ATVs and Gators were used on 18% of operations and reduced the risk of animal herding related injury (OR = 0.51; 95% CI: 0.30 - 0.86) compared to other methods [19]. Helmkamp, Furbee, Coben and Tadros (2008) reported that hospitalizations due to ATV-related injury had climbed 90% from 2000 to 2005 and death rates climbed 180% compared to previous years in the U.S. [22]. The U.S. Government Accountability Office (GAO) (2010) estimated that 400,000 ATV riders were injured each year and that over 100,000 injured riders were seen in emergency rooms from 2004 to 2008 [4].

Researchers evaluated data from the U.S. Healthcare Cost and Utilization Project to identify factors associated with injury and hospitalization. They found the highest admission and treatment rates were among youth and older groups compared to users aged 18 to 44 years. Helmkamp and colleagues (2011) reported that, "the fatality rate among agricultural production workers was significantly higher than the rates in all other industries" [6] (p. 147). ATV-related occupational fatality rates climbed 300% from 1992 to 2007 [6]. The highest fatality rates were seen in older users > 65 years at 13.5/1,000,000 workers compared to 5.73 overall rate for agriculture. ATV-related fatalities comprised 58% of youth deaths

Author(s) (Year) Title	Location	Participants (age)	Measures and Interventions	Findings
Browning., *et al.* (2013) Cattle-related injuries and farm management practices on Kentucky beef cattle farms [19].	USA (Kentucky)	1,149 completed surveys (>20)	Questionnaire	1. 157 farms had 1+ cattle-related injury within past 12 months 11.4% injured while interacting with cattle 19% of farms used ATVs while herding ATVs associated with lowest rate of cattle-related injuries for herding methods (OR = 0.51; 95% CI (0.3, 0.86))
Carman., *et al.* (2010) All terrain vehicle loss of control events in agriculture: contribution of pitch, roll and velocity [20].	New Zealand (South Otago district)	30 male farmers	Questionnaire Tri-axial gravitational accelerometer GPS	**ATV riding surfaces:** 1. Sealed road = 3% 2. Farm track = 10.2% 3. Gravel road = 11.5% 4. Paddock = 73.1% **Loss of Control Events:** 1. 63% of participants had 1 event 2. 53% of the participants above had ≥2 events 3. 6% of reported LOCs resulted in requiring medical care **Accelerometer and GPS mean data:** 1. Mean downhill pitch = 21.3° 2. Mean uphill pitch = 21.2° 3. Mean peak left roll = 18.4° 4. Mean peak right roll = 19.2° 5. Mean peak velocity = 53 km/hr
Essien., *et al.* (2016) Association between farm machinery operation and low back disorder in farmers: A retrospective study [17].	Canada (Saskatchewan)	1,149 farmers (20-75)	Questionnaire Standardized Nordic Questionnaire (SNQ)	1. 43.9% used ATVs 2. Insignificant relationship found btwn ATV use and low back disorders 3. Insignificant relationship found btwn ATV use and hip symptoms
Goldcamp., *et al.* (2006) Nonfatal all-terrain vehicle-related injuries to youths living on farms in the United States, 2001 [21].	USA	30,744 responses for the 2001 Childhood Agricultural Injury Survey (CAIS) 16,456 responses for adult injury survey	Phone surveys 2001 CAIS USDA 1997 Census of Agriculture	1. 36% of farm youths operated an ATV in 2001 2. Youth operated 88% of all ATV injuries 3. 69% of youth ATV injuries were males 4. Youth ages 10 - 15 accounted for 70% of all youth injuries
Helmkamp., *et al.* (2008) All-terrain vehicle related hospitalizations in the United States, 2000 - 2004 [22].	USA (37 states)	58,254 ATV related hospital discharges 1,004 community hospitals	Healthcare Cost and Utilization Project Nationwide Inpatient Sample Discharge Summaries	1. 80% of cases were men 2. 79% were drivers 3. 30% of cases were < 18 years old 4. 85% of cases had routine treatment and discharge 5. Fractures were most common diagnosis 6. Avg. patient cost = $19,671

Helmkamp., *et al*. (2011) Occupational all-terrain vehicle deaths among workers 18 years and older in the United States, 1992 - 2007 [6].	USA (50 states including D.C., excludes NYC)	Civilian workers (≥18)	Bureau of Labor Statistics annual Census of Fatal Occupational Injuries	1. 275% increase in ATV deaths from 1992 - 2007 2. 300% increase in ATV death rates 3. 92% of ATV deaths were males 4. ATV death rates increased with age 5. 25% of fatalities due to head injuries 6. 77% of fatalities were non-hwy incidents 7. ATV death rate in agriculture/forestry/fishing/hunting industry was 100 times greater than all other industries
Hendricks., *et al*. (2005) Injuries to youth living on U.S. farms in 2001 with comparison to 1998 [23].	USA	Youth residing on farms (<20)	Childhood Agricultural Injury Survey through NIOSH and USDA Telephone survey	1. ATV injury rates in 2001 = 1.7/1,000 2. ATV injury rates in 1998 = 1.3/1,000 3. Males comprised 65% of 2001 injuries
Hendricks., *et al*. (2005) Household youth on minority operated farms in the United States, 2000: Exposures to and injuries from work, horses, ATVs and tractors [24].	USA	Survey: 27,170 minority operated farms Interview: 19,083 racial minority operated farms, 10,862 Hispanic operated farms	Minority Farm Operator Childhood Agricultural Injury Survey Phone survey USDA 1997 census of agriculture	**Racial Minority Youth:** 1. 23% of youth operated an ATV 2. Youth injury rate = 4.5/1,000 3. Other racial minority farm youth ATV injury rate = 8.1/1,000 4. Native American farm youth ATV injury rate = 6.2/1,000 5. Injury rate of youth < 10 yrs = 8.7/1,000 6. 24% of injured youth wore a helmet **Hispanic Youth:** 1. 27% of youth operated an ATV 2. Youth injury rate = 5.1/1,000 3. 60% of youth injuries were males 4. 48% of youth injured wore a helmet
Jennissen., *et al* (2016) The effect of passengers on all-terrain vehicle crash mechanisms and injuries [25].	USA	537 trauma cases (youth and adult)	E-codes Abbreviated Injury Scale Injury Severity Score Level 1 trauma center hospital records	1. 77% involved a male 2. 25% involved patient aged ≤15 3. 21% wore helmets 4. 20% involved passengers 5. Youth ≤15 yrs were more likely to have passengers 6. 71% of non-collisions were rollovers 7. Odds of rolling bckwds = 2.5 times higher when carrying a passenger 8. Passengers = 3.6 times higher to fall or be ejected
Lower., *et al*. (2003) Agricultural motorcycle injuries in WA adolescents [26].	Australia (Western)	326 students from designated agricultural colleges (grades 11 -12)	Survey	1. 74% had access to agricultural motorcycle/ATV 2. 21% of respondents who had ATV access reported ATV injury 3. Most common injury type were cuts/lacerations 4. Traveling at speeds >101 km/hr leads to significant (p<0.01) increase in injury risk 5. Respondents that only sometimes wore a helmet were significantly (p=0.02) more likely to get injured than those who always wore a helmet

Lower and Herde (2012) Non-intentional farm injury fatalities in Australia, 2003-2006 [27].	Australia	326 cases	National Coroners Information System Keyword searchesMedia Monitors database	1. 9.2% of fatalities were ATV related 2. 8% were aged >15 yrs. 3. 13% of fatalities were aged ≤15 4. 53% of all ATV deaths were rollovers
Lower., *et al* (2016) Quads, farmers 50+ years of age, and safety in Australia [28].	Australia	82 fatalities (51 - 94)	National Coroners Information System	1. Males comprised 86.5% of fatalites 2. Work-related deaths were 83% 3. 73.1% involved rollovers a. Took > 1 hr to find individual in 63% of rollover cases b. 25% of incidents involved carrying spray-unit 4. 21% of deaths due to asphyxiation 5. 18.3% of deaths due to head injuries a. 63.3% of head injuries involved no helmet use
Milosavljevic., *et al.* (2012) Does daily exposure to whole-body vibration and mechanical shock relate to the prevalance of low back and neck pain in a rural workforce? [29].	New Zealand (South Otago)	130 farmers and rural workers (mean = 40.6)	Whole-Body Vibration Health Surveillance Questionnaire, modified Observation Workplace satisfaction questionnaire Tri-axial accelerometer	1. Mean yrs of ATV experience = 14.6 2. 48.5% lifted object immediately after ATV use 3. Mechanical shock exposure associated with a 12-month prevalance of low back pain (p = 0.092)
Milosavljevic., *et al.* (2011) Factors associated with quad bike loss of control events in agriculture [30].	New Zealand (South Otago)	130 farmers and rural workers (Mean = 40.6)	Whole-Body Vibration Health Surveillance Questionnaire, modified Observation Tri-axial accelerometer Biometrics data logger	1. Mean yrs of ATV experience = 14.6 2. 61% reported ≥1 LOCs 3. 6.5% of LOCs required medical attention 4. 5.5% of LOCs were compensated claims 5. 39% of LOCs occurred when riding on hills 6. 28% of LOCs were due to striking object 7. 13% of LOCs occurred on wet and hilly terrain
Milosavljevic., *et al* (2011) Exposure to whole-body vibration and mechanical shock: A field study of quad bike use in agriculture [18].	New Zealand (South Otago)	130 farmers and rural workers (Mean = 40.6)	Whole-Body Vibration Health Surveillance questionnaire, modified Observation Tri-axial accelerometer	1. Mean ATV experience = 14.6 yrs 2. Mean age of ATV = 3.7 yrs 3. Mean ATV engine size = 447.2 cc 4. 28 workers exceeded daily vibration dose value a. 7 workers exceeded daily vibration dose value in 1-hr timeframe 5. 41 workers reached/exceeded daily equivalent static compression dose a. 26 workers reached or exceeded the daily equivalent static compression dose in 1-hr exposure
Mani., *et al.* (2015) Effects of agricultural quad bike driving on postural control during static, dynamic and functional tasks - a field study [31].	New Zealand (South Otago)	34 male rural workers (Mean = 40.3)	Screening questionnaire Field tests	1. All participants exceeded vibrational daily value in z-direction 2. Significant increase in magnitudes for lifting tasks 3. Difficulty regaining uni-pedal stance control in post-driving period

Table 1: Summary of Epidemiology ATV articles.

on farms in Australia [27]. ATVs also posed increased risk for older riders > 50 years of age [28].

The survey of 30 male farmers in New Zealand found that 63% of ATV owners experienced at least one LOC event [20]. When evaluating the factors associated with the LOC, researchers identified that speed, pitch and roll were significant predictors of LOC events. Other variables influenced LOC, such as towing trailers, carrying loads, hitting obstacles or changes in surface friction coefficient due to terrain or road surfaces [20].

Riding with a passenger has a negative effect on vehicle control and is associated with increased risk of LOC [25]. Passengers increased the mass of the vehicle, raised the center of gravity and are less likely to be fully synchronized active riders. Passengers were associated with an increase of 2.4 times the risk (95% CI: 1.2 - 4.7) for collision compared to those LOC events without additional persons [25].

An evaluation of 130 rural farmers in New Zealand revealed that ATV riders tended to be larger, taller, drove longer distances, were exposed to increased whole body vibration and shock and thus predisposed to increased risk of injury and LOC compared to non-ATV riders [30].

Exposure Assessment

A review of the exposure assessment literature revealed themes regarding causes of LOC (Table 2). Initially, 134 articles were identified and 9 articles met the inclusion criteria. Investigators evaluated 355 cases of occupational ATV-related injury in New Zealand and concluded that driving on sealed roads, driving backwards and carrying fluid, such as pesticide tanks, all increased risk of LOC [32]. Shulruf and Balemi (2010) found that the risk of mortality was 3.9 times higher if the ATV driver was hauling a liquid load [32]. Additionally, it was found that employers, ATV owners, self-employed individuals or family members were 3 to 19.5 times more likely to have an ATV-related fatality. Cavallo, Gorucu and Murphy (2015) surveyed 104 Pennsylvanians and they reported that 67% of respondents disclosed that they personally knew of someone who had been injured or killed in an ATV LOC rollover event, suggesting that many users were acutely aware of risks associated with ATVs [33].

Author(s) (Year) Title	Location	Participants (age)	Measures and Interventions	Findings
Brann., *et al.* (2012) Making the message meaningful: A qualitative assessment of media promoting all-terrain vehicle safety [34].	USA (Arkansas and Louisiana)	88 participants within focus group 60 participants with formative research: Adults (20-59) Youth (10-16)	Educational material Focus groups Formative research group Discussion Video	**Focus groups:** 1. Safety concerns a. Improper ATV use by adolescents b. Lack of adult supervision c. Environmental factors 2. Legal responsibilities a. Lack of licensing requirements b. Lack of youth regulation 3. Lack of proper ATV use a. Understanding injury risk b. Understanding machine design **Formative research group:** Positive reported 1. Hands-on training a. Shifting safely b. Understanding difference in terrain c. Guidelines in choosing ATV 2. Proper use a. Use of safety gear and how it protects b. Not riding with passengers c. Understanding safety concerns when increase speed 3. Use of statistics a. Injuries and death b. Personalizing stories

Burgus., *et al.* (2009) Youths operating all-terrain vehicles – implications for safety education [35].	USA (Louisville, Kentucky)	624 youth (12-20)	15-item survey	1. Safety behaviors a. Lacked use of PPE b. Allowed or rode as passenger c. Rode on paved surfaces 2. Safety training 3. Lack of ATV training participation 4. Believed wasn't necessary 5. Positive association with riding alone and helmet use 6. Injuries 7. 176 participants had experienced
Cavallo., *et al.* (2015) Perception of side rollover hazards in a Pennsylvania rural population while operating an all-terrain vehicle (ATV) [33].	USA (Pennsylvania)	55 participants with simulator (≤14 – adult) 49 participants with questionnaire	ATV stability simulator Slope indicator 26-item questionnaire	1. Difficulty understanding/estimating degree of angle 2. Mean angles (degrees): a. Reported uncomfortable but would drive (28.4°) b. Measured uncomfortable but would drive (15.9°) c. Reported uncomfortable and would not drive (38.4°) d. Measured uncomfortable and would not drive (22.7°) 3. Most participants overestimated angles 4. 14/55 participants experienced rollover event 5. 37/55 participants knew someone injured/killed in ATV LOC
Clay., et al. (2016) There are risks to be taken and some just push it too far: How farmers perceive quad-bike incident risk [36].	New Zealand	8 adults (20-59)	Semi-structured interview	1. LOCs: a. Anticipating risks made riders more conscious of riding skills and tasks b. Unmanageable risk led to an inability to control the ATV 2. All participants experienced LOCs a. Positive behavior changes when ruminated, recognized potential consequences, developed sense of future susceptibility b. Lack of behavior change when thought event was 'bad luck' 3. Personal attributes: a. Overconfidence in riding ability decreased risk perception; more likely to be risk takers b. Consideration of personal and others' safety were more likely to engage in safety behaviors 4. Risk behaviors: a. Rushing to complete work b. Pushing limits of ATV capabilities c. Use of ATV on inappropriate terrain d. Common tasks
Clay., *et al.* (2014) Are agricultural quad bike loss-of-control events driven by unreaslistic optimism? [37].	New Zealand (Otago and Southland)	216 (17-85)	Structured interview	1. Lack of formal training a. Lack of helmet use 2. Employees more likely to wear helmets a. Positive unrealistic optimism score in 51% participants 3. Participants showed no tendency to fatalistic beliefs or risk-taking behaviors

Jinnah and Stoneman (2016) Age – and gender-based patterns in youth all-terrain vehicle (ATV) riding behaviors [38].	USA (Georgia)	180 youth (10-19)	Questionnaire Interview	1. Majority of participants ride adult-sized ATV 2. Lack of training 3. Rode with passenger 4. Rode on public roads 5. Lacked wearing PPE 6. Drove at higher speeds
McBain-Rigg., *et al* (2014) Why quad bike safety is a wicked problem: An exploratory study of attitudes, perceptions, and occupational use in quad bikes in northern Queensland, Australia [39].	Australia (NW Outback Queensland)	27 participants within focus group 11 participants in interview	Semi-structured focus groups Individual interviews	1. Injury accepted as farming risk 2. Modification of ATV to fit tasks 3. Used on variety of terrain 4. Perceived as easy to use and fit-for-purpose 5. Perceived to be more stable than actually is 6. Younger drivers perceived to experience more LOCs 7. PPE use dependent on work-place policy and self-regulation 8. LOCs are perceived to be unavoidable 9. Manufacturers and retailers role in advocating safety measures perceived as minimal 10. Retailers role perceived as selling ATVs and offering training courses 11. Perception of lack of evidence regarding CPDs
Myers (2016) Potential benefit of the Quadbar™ on all-terrain vehicles [40].	USA (Georgia)	N/A	Maximum Abbreviated Injury Scale Injury Severity Score	1. 100,000 ATVs fitted with Quadbar™ would prevent 5,082 injuries over 10-yr period 2. Quadbar™ is 40% effective in reducing injuries and fatalities 3. Cost of installing Quadbar™ would pay for itself within the 2nd yr
Shulruf and Balemi (2010) Risk and preventative factors for fatalities in all-terrain vehicle accidents in New Zealand [32].	New Zealand	355 cases were identified as 'serious harm'	New Zealand Dept of Labour data Circumstances associated with injury Probability of fatal outcome	1. Likelihood of injury transpiring: a. <10 yrs old b. Riding on sealed road c. Riding downhill d. Riding backwards e. Rolling sideways 2. Risk factors for fatalities: a. Employers b. Owning an ATV c. Riding on public roads d. Riding on sealed roads e. Riding backwards f. Carrying liquid load g. Being pinned under ATV h. Age i. ≥66 yrs old j. 11-15 yrs old 3. Protective factors of decreasing fatalities: a. Being an employee b. Formal training c. Wearing a helmet d. ATV maintenance

Table 2: Summary of ATV exposure assessment articles.

Formal training on safe use of ATVs was found to be lacking among most users. The ASI reported training nearly one million riders, which represents less than 10% of all owners even though training is offered at no cost with the purchase of a new ATV [41]. Similar trends are present in youth ATV operators. Only 9% of male and 3% of youth female riders reported that they had attended structured safety training for ATV operation in a survey of 180 U.S. youth that operate ATVs [38]. Of the 180 U.S. youth participants evaluated, 94% of male and 91% of female riders reported driving an adult-sized ATV regardless of age. A majority of these participants also reported driving on public roads (65% = males, 56% = females), driving at high speeds (81% = males, 76% = females), and riding as passengers (96% = males, 97% = females).

The type of road or terrain also impacts the likelihood of LOC events occurring. Based on an evaluation of 355 LOC in New Zealand, it was found that driving on public roads increased the fatality risk by 5.33 times and driving on sealed roads showed an increased risk of 3.65 times for fatality occurring [32]. ATVs have low-pressure tires that are intended to provide grip on uneven and low friction surfaces. Riding on paved surfaces results in far greater tire to road friction and/or adhesion resulting in vehicle lateral load shifting and tendency to rollover, especially when turning at higher speeds. Burgus, Madsen, Sanderson and Rautianinen (2009) surveyed 624 U.S. youth and reported that 81% of youth surveyed rode ATVs on paved surfaces [35]. Burgus and colleagues (2009) also reported that 176 youth reported that they experienced an ATV-related injury [35]. Out of the 176 youth that reported experiencing an ATV-related injury, 18.2% had experienced an LOC injury and rode on paved surfaces compared to 10.0% of youth that rode on paved surfaces and did not experience an LOC injury. ATVs are appealing because they can access a variety of terrain, including climbing, descending, and traversing hills. It has been recommended that ATVs be operated on hills < 25 degrees of slope [33]. Cavallo, Gorucu and Murphy (2015) performed a simulation study to investigate how ATV riders estimated slope angles. The mean reported "uncomfortable" and "would not drive" angles were 15.9 degrees and 38.4 degrees, respectively [33]. The researchers found that difficulty in estimating angles was common and could be a risk factor for overturn [33].

Brann., *et al.* (2012) conducted focus groups with youth riders that reported parental role modeling was lacking for risk management and safety practices when riding ATVs [34]. Youths' risk awareness is associated with parental behaviors such as safe-riding practices and use of personal protective equipment (PPE) [34]. Clay, Hay-Smith, Treharne and Milosavljevic (2016) conducted an exploratory model to explain risk perception [36]. The researchers found that high-risk behaviors associated with LOC events were: (1) rushing to complete tasks, (2) use of ATVs for inappropriate terrain and (3) inattentiveness to riding. Clay., *et al*. (2016) reported that participants who had a fatalistic belief system (e.g. reported 'bad luck') were less likely to change behaviors after experiencing a LOC event [36]. Conversely, participants who recognized safety risks were more likely to engage in safety use practices to mitigate risks for themselves and/or employees. Unrealistic optimism, a cognitive bias in which a person believes that he or she is less likely to experience a negative event, was investigated by Clay, Treharne, Hay-Smith and Milosavljevic (2014) [37]. The authors estimated incident risk ratios (IRR) associated with LOC events including younger age (IRR = 0.980; 95% CI: 0.968 - 0.991), being male (IRR = 3.998; 95% CI: 2.147 - 7.444), seeking a thrill sensation (IRR = 1.081; 95% CI: 1.012 - 1.155), and unrealistic optimism (IRR = 0.839; 95% CI: 0.751 - 0.936). Attitudes and perceptions were also studied by McBain-Rigg, Franklin, McDonald and Knight (2014) who found that LOC events were felt to be an assumed risk and not always preventable [39]. Injuries or fatalities that occur in the agricultural community are perceived to be part of the overall viewpoint and culture where risk was acceptable. Workplace policy, experience and safety attitudes affect the safety culture around the use of ATVs. Geller (1996) suggested that daily exposure to hazards and risks without adverse consequences leads to desensitization, increased risk taking and accepting unsafe behaviors [42].

Safety Interventions

A review of the literature on ATV safety interventions revealed themes and patterns associated with various approaches and methods used to mitigate and reduce ATV LOCs and resulting injury and fatality (Table 3). Initially, 123 articles were identified and 8 articles met the inclusion criteria. The interventions can be grouped into five general types: (1) engineering controls, (2) computer simulations, (3) laws, (4) training programs and (5) education.

ATVs have been in use for more than four decades, but there have been minimal engineering improvements in safety controls to reduce LOC events beyond the 2002 ANSI standards [ASVI, 2007]. Myers (2016) performed an analysis to evaluate the health and economic benefits of using a crush-protection device (CPD) on ATVs [40]. The author estimated that over a ten-year period, use of CPDs would result in saving lives, reducing injuries and lowering economic impacts of LOC events. When Myers (2016) aggregated data from a ten-year interval into a one-year time period [40], the author noted that there would be 89% fewer injuries and equiva-

Author(s) (Year) Title	Location	Participants (age)	Measures and Interventions	Findings
Bouton., *et al*. (2008) A rollover indicator dedicated to all-terrain vehicles including sliding effects and pilot behavior [43].	France	N/A	Dynamic model Field tests	1. Lateral Load Transfer (LLT) threshold value for likely rollover was 0.8 2. Active riding helped prevent exceeding the threshold value
Bouton, *et al* (2008) A rollover indicator based on a tire stiffness backstepping observer: Application to an all-terrain vehicle [44].	France	N/A	Computer simulation of Lateral Load Transfer (LLT) metric	**Advanced simulation:** 1. Observer performance a. Corner stiffness needs to be taken into account 2. Rollover risk time was 0.5 sec. a. Deceleration and reduced steering angles are not factors within simulation **Experimental results:** 1. LLT threshold was 0.8 2. Overestimation occured when velocity and/or steering angle vary quickly
Gadomski., *et al.* (2006) Efficacy of the North American guidelines for children's agricultural tasks in reducing childhood agricultural injuries [45].	USA (New York)	931 farms participated 462 farms within intervention group 469 farms within control group Study end: 810 total farms 401 farms within intervention 409 farms within control group	North American Guidelines for Childern's Agricultural Tasks (NAGCAT) Baseline survey Phone survey Farm visits	1. Percentage of ATVs on farm a. 50% owned within control farms b. 48% owned within intervention farms 2. Control farms were more likely to violate NAGCAT guidelines of minimum age using ATV
Jennissen., *et al.* (2015) The safety tips for ATV riders (STARs) programme: Short-term impact of a school-based educational intervention [46].	USA (Iowa)	4684 students (11-16)	Pre-and post-suverys ATV safety STARs programme	**Pre-test:** 1. 49% unaware that ATVs are for 1 rider 2. 76% unaware correct engine size for youth 3. 58% unaware that Iowa law prohibits ATV use on public roads, except for farming purposes **Safety behavior experience:** 1. Students who were aware of 1 rider/ATV were just as likely to have ridden as a passenger as were students who were unaware of 1 passenger rule 2. Students who were aware of public road law more likely to report riding on public roads 3. Higher proportion of students reporting LOCs answered more questions correctly compared to students that did not report LOCs **Post-test:** 1. Higher proportion of students answered questions correctly 2. 48% reported to likely/very likely to use ATV safety information 3. More females reported that they would use information 4. Students who reported riding ATVs regularly reported they were 69% less likely to use safety information 5. 42% of students who reported LOCs reported were unlikely to use safety information 6. 53% students who reported using 1-2 unsafe riding behaviors reported were likely to use safety information 7. 37% of students who reported using 3 unsafe riding behaviors reported they were likely to use safety information

Lagerstrom., *et al.* (2015) A case study: The development of safety tip sheets for ATV use in ranching [5].	USA (Montana)	5-7 volunteers/focus group (16-80)	4 focus groups 13-item questionnaire	**Questionnaire response regarding Tip Sheet:** 1. 97% read 2. 64% reported lacked new information 3. 78% provided ATV awareness 4. 77% reported did not change future behavior of ATV operation 5. 49% shared with others 6. 93% reported high quality information **Comments/Short answer:** 1. New information on spray tanks with baffles and active riding 2. Reasons cited for behavior change: a. ATV fatality of friend b. Safety importance c. Requirements regarding helmets 3. Reasons cited for no behavior change: a. Already operated safely b. Lack appropriate equipment c. Time constraints
Lower and Trotter (2014) Adoption of quad bike crush prevention devices on Australian Dairy Farms [47].	Australia	11 dairy farmers (Mean = 43.2)	Pre- and post-interview surveys CPDs fitted onto ATVs 2 focus groups Phone i nterviews	**Pre-Intervention survey:** 1. 36% experienced LOCs a. 50% of injuries due to rollovers 2. 1 participant took formal rider training course 3. 72% never wore helmet **Post-Intervention survey:** 1. 82% use ATV daily 2. 85% little to no impact to ATV with CPD **Focus groups and interviews on CPDs:** 1. Safer 2. Opened discussion on other safety issues 3. No visual reminder of CPD height 4. CPDs reasonably priced 5. Manufacturers provide inconsistent information on CPDs 6. Perceived lack of incentives to use CPDs
Myers (2016) All-terrain vehicle safety – potential effectiveness of the quad-bar as a crush prevention device [48].	USA (collected articles and data world-wide)	N/A	Articles and reports	1. CPDs reduce stability in longitudinal and lateral direction in simulated situations a. Rider's weight affects stability more than CPD 2. CPDs decrease severity of injuries in simulated situations 3. Snook tests found QuadBar (QB) may prevent ATV from rolling over multiple times 4. Provides a survival space for the rider 5. Stops rear overturns 6. Information from simulations are limited 7. Potential to reduce fatalities by 70%

Yang., *et al*. (2012) At what age should children engage in agricultural tasks? [49].	USA (Iowa)	264 families	Interviewed parents Compared responses to NAGCAT	**Families with sons:** 1. 54.5% of males drove ATV 2. Mean age for 1st time driving was 9.8 yrs. 3. 53% of males drove ATV younger than NAGCAT recommended age **Families with daughters:** 1. 37.2% of females drove ATV 2. Mean age for 1st time driving ATV was 10.1 yrs. 3. 36% of females drove ATV younger than NAGCAT recommended age **Parent perceptions:** 1. Mean appropriate age to drive ATV was 12.4 yrs

Table 3: Summary of ATV safety intervention articles.

lent cost-savings. Helmkamp, Biddle, Marsh and Campbell (2012) estimated the economic impact of U.S. occupational ATV-related fatalities is in excess of $100 million for years 2003 to 2006 [8].

Engineering controls were primarily CPDs that were retrofitted to the ATV to protect the rider from a crush injury or suffocation in the event of a LOC. The CPD is designed to provide the rider increased protection by creating a survival space [50]. One CPD, the Quadbar™ [51], has shown promise in early tests to be effective at reducing crush injury (Figure 1). Simulations indicate the Quadbar™ could reduce fatalities due to asphyxiation by as much as 53% [48]. The authors of a study of ATV-related fatalities in Australia between 2000 to 2013 found farmworkers are more likely than recreational riders to become pinned under an ATV and die of asphyxia [57]. The researchers' tests indicated that the Quadbar™ had minimal detrimental effects on ATV stability and provided a protective effect by preventing the ATV from completely flipping backwards or rolling over in low-velocity events and crushing the rider [48]. Researchers studying Quadbar™ effectiveness have estimated a 70% reduction in ATV-related fatalities in Australia and New Zealand where ATVs are commonly used within the agricultural community. Further research is needed to fully understand the positive and negative effects of CPDs on ATVs and users. One investigation, which included CPDs that were installed on ATVs used by eleven dairy farmers in Australia, yielded positive feedback and acceptance by users [47]. Study subjects reported that their ability to carry out regular job tasks on ATVs remained efficient and effective [47]. The farmers reported that the positive benefits of a CPD far outweighed any potential negatives.

Computer simulation studies have been carried out to estimate the kinetics associated with LOC events. A computer simulation study by Bouton, Lenain, Thuilot and Martinet (2008) was conducted to ascertain the lateral load transfer (LLT) metric to predict rollover events [44]. This study was carried out to validate the LLT model using simulation measures against actual forces from ATV test rides. A number of variables were identified to impact control, including steering direction, speed and yaw.

Figure 1: QuadbarTM fitted onto an ATV.

Training and education may be an effective way to reduce ATV LOC eventsand injuries in youths. It has been shown that active dissemination of the North American Guidelines for Children's Agricultural Tasks (NAGCAT) reduced the likelihood of a child injured while operating an ATV [45]. There were data from 264 farm families in Iowa showing that parents and children were generally unfamiliar with but did not follow the NAGCAT [49]. Data collected from farm parent interviews revealed that 53% of boys and 36% of girls operated an ATV while they were younger than the NAGCAT recommended age for safe ATV operation [49]. A study by Jennisson *et al* (2015) found that 4684 students in Iowa that participated in the Safety Tips for ATV Riders (STARS) program demonstrated improved understanding and knowledge of safer ATV riding behaviors [46]. Brann, Mullins, Miller, Eoff, Graham, and Aitken (2012) conducted focus groups with 88 participants in the southern U.S. and found that when training consisted of personalized stories and injury statistics, participants were more apt to relate to the training message [34].

Training and education may be effective at reducing risks for adults who use ATVs. A series of ATV safety tip sheets were developed by Lagerstrom., *et al*. (2015) and provided to ATV operators on ranches in Montana [5]. After receiving the tip sheet, study subjects were asked to complete a survey. Nearly all subjects reported that the tip sheet was high quality and provided valuable information [5]. Over half of the subjects indicated the tip sheet would not change their behavior. The subjects indicated various reasons for not changing their behaviors such as they already operated ATVs safely, they lacked the required equipment and/or they experienced time constrains that prohibited safe use practices [5].

ATV-related injuries and fatalities are a public health crisis. The application of ATVs in the occupational environment is on the rise with a 300% increase in fatality rate reported between 1992 through 2007 [6]. Helmkamp, Biddle, Marsh and Campbell (2012) examined occupational ATV-related fatalities in the U.S. that occurred between 2003 through 2006 and found that 65% of occupational ATV-related fatalities were in agricultural production [8]. This sector remains the largest occupational user group with increasing expansion into other industries [7]. The ASI (2017a) estimated that 35 million U.S. citizens use ATVs for recreation (78%) and various work tasks (22%) with post-recession sales on the rise [2,3]. The CPSC has investigated over 14,000 ATV-related fatalities since 1982 and determined the units to be inherently unstable [4].

Exposure assessment and risk estimation research has been limited and does not fully explain all of the possible factors associated with ATV use, LOC events and adverse outcomes. Studies have not investigated the rider demands, exposures, interactions and responses to explain, predict or prevent LOC events. Speed, pitch and roll are major factors associated with LOC events [20]. Study authors have demonstrated that ATVs may be interactive and passengers may degrade optimal stability by raising the center of gravity and impair real-time compensating weight shifts to prevent LOC and rollover [30]. Researchers have identified numerous factors including adverse environments and conditions [4], lack of training [10,28], towing trailers, carrying loads, hitting obstacles or changes in surface friction coefficient, driving backwards [20], carrying fluid loads and passengers [25,32].

Unfortunately, there are no universally consistent safety intervention programs in the U.S. Current interventions range from regulations, training, education, engineering controls and computer simulations. With regard to regulations, there is a ubiquitous lack of awareness and enforcement. In the U.S., state laws and regulations regarding ATVs vary widely between states and regions. Variations in laws and regulations exist in size and age restrictions, PPE use and enforcement. In most states, the agricultural community is exempt. In some states, there are no ATV laws or regulations. While driving ATVs on public roadways is a known risk factor for a LOC events [32], thirty-eight U.S. states have passed laws that allow ATVs to be driven on public roadways [52]. In Queensland, Australia, laws barring children under the age of eight from riding on ATVs as passengers and enforcing helmet wearing while operating ATVs were passed [53]. However, this law only applies to public roads and not to farms. The NAGCAT provides guidance for which agricultural tasks that are appropriate for a child to perform. Farm families do not seem to follow the NAGCAT recommendation that children under 16 years should not operate ATVs. Researchers have shown that children between the ages of 11 and 15 are at the greatest risk for an ATV-related fatality, which supports the NAGCAT recommended age for ATV operation [32].

Most of the studies reviewed focused on didactic educational training as opposed to hands-on training. To our knowledge, there are no studies that evaluated the long-term impact of the ASI or equivalent hands-on ATV safety training. Despite the lack of evidence for training effectiveness, the ASI reported that 2,500 certified trainers are active in over 500 locations nationwide offering 150 - 200 hands-on safety-training courses each week [41]. Educational training has been shown to be effective at gaining knowledge. However, the literature suggests that a gap is present between the gain of knowledge and the change to safer behaviors [46]. Focus groups of adults and youth ATV riders indicated a desire for applicable hands-on training [34]. Future research studies should be done on the efficacy and effects of hands-on training to improve rider performance and prevent LOCs.

Crush protection devices were the primary type of engineering safety control aimed at protecting users. There exist economic, social and cultural barriers when advocating for broad installation of CPDs on ATVs in the U.S. Fortunately, manufacturers have begun to offer CPDs at the point of sale and aggressive retrofitting programs in Australia and New Zealand [54]. Israel has a standard that mandates the installation of CPDs. Once the ATV was outfitted with the safety device, users reported minimal complaints and that the positives far outweighed the negatives [54]. Operators that have installed the Quadbar™ on their ATVs have already credited the Quadbar™ with saving their lives [55].

The Australian Terrain Vehicle Assessment Program (ATVAP) has developed an evaluation process that assigns a Star Rating to all vehicles including ATVs, side-by-side vehicles (SSVs) or recreational off road vehicles (ROVs) [56]. The ATVAP Star Rating method consists of three parts: (1) static stability tests, (2) dynamic handling tests, and (3) rollover crashworthiness tests. The scores from the three parts are equally weighted and summed to generate a Star Rating from one to five. Bonus points can be applied for vehicles that have additional safety features, such as an open rear differential or a seat belt warning light [56]. The ATVAP tested five SSVs and eight ATVs. A recreational ATV was defined as one that had no physical way to carry loads (e.g. load rack). Researchers noted that SSVs demonstrated exceptional static stability, dynamic handling, rollover crashworthiness and nominal disturbance when traveling over a bump compared to ATVs [56]. This was reflected in the Star Rating. Eighty percent of SSVs tested received a rating of 4 while all the ATVs tested received a 2 rating [56]. These early results demonstrate that SSVs are a safer alternative to ATVs.

The CSPC proposed a rule or standard to improve ATV safety that included [1]: (1) lateral stability and vehicle handling requirements that specify a minimum level of rollover resistance for ROVs and required that ROVs exhibit sublimit understeering characteristics; (2) occupant retention requirements that would limit the maximum speed of an ROV to no more than 15 miles per hour (mph), unless the seat belts were made available for both the driver and front passengers, and would require ROVs to have a passive means, such as a barrier or structure, to limit further the ejection of a belted occupant in the event of a rollover; and (3) information requirements. The proposed rule would have modified the 16 CFR Part 1422. The document was submitted with over 500 pages of supporting documentation but was not passed. The CPSC has stated that ATVs are inherently unstable and supports the use of SSV and ROVs over ATVs [1,4].

The Star Rating system is a monumental step forward to promote the "fit for use" and associated safety to help consumers make more informed and appropriate purchases based upon their anticipated applications. Similar to the National Highway Traffic Safety Administration's vehicle safety ratings for automobiles, the ATVAP Star Rating program can be used by consumers, to make more informed ATV and SSV purchases and motivate manufacturers to make their vehicles more attractive to consumers. As Australia continues to develop this testing protocol, other countries may incorporate the safety data into developing specifications and regulations to increase ATV safety.

Limitations of the Study

A review of the literature has inherent limitations as it does not require original research by the investigators but rather interpretation of published information. The protocols for review required that an interpretation be made about others' findings and the authors may have misinterpreted findings, inferences and impacts. We limited the search terms to focus on areas of interest pertaining to ATVs and agriculture in specific databases and time frames. The search terms may not have captured all published studies during the period evaluated. Study limitations also included the choice of databases that may have resulted in missed articles available only through proprietary databases or other protected repositories. Additionally, publication bias may exist. We did not review the literature prior to 2000 or after 2016 and may have missed relevant literature for this study prior or following the time period examined.

Conclusion

A review of the literature on ATVs in agriculture focusing on epidemiology, exposure assessment, risk estimation and safety interventions has yielded a deeper understanding and insight into the problems and solutions surrounding this public health crisis. Published evidence confirms that the agriculture community is at greatest risk for injury and fatalitiy. Significant knowledge gaps exist as more has been written and published about the consequences of ATV LOC events than investigating exposure assessment to measure the interaction, demands and responses of users in the wide array of conditons in which ATVs are used. Very little is known about the dynamic nature of the rider interactive risk associated with ATVs and LOC events. Less progress has been made toward engineering controls to reduce or eliminate risks associated with LOC events until the recent Quadbar.

The longterm solution appears to be a migration from ATVs to SSVs or ROVs with rollover cage designs, wider stability and restraint systems. The Australian Star Rating system has transformed the understanding of "fit for use" and will significantly support the migratation away from ATVs to SSV and ROVs. More research, however, is needed to understand the effectiveness of ATV safety training; 11 million units are being used in the U.S. with less than 10% of owners having hands-on training. Laws appear to be expanding the use of ATVs and SSVs onto roadways. These authors predict LOC events will increase because of the expanding use of ATVs and SSVs on public roadways. Additional time and data collection are needed to verfiy the added safety of SSVs and resulting mordibity and mortablity.

Acknowledgements

The authors acknowledge the High Plains Intermountain Center or Agriculture Health and Safety (HICAHS) and the National Institute for Occupational Safety and Health (NIOSH) who funded this project. We also acknowledge the work and contributions from Drs. John Rosecrance, Clara Key, Drs. Elise Lagerstrom and Mr. Brian Kim.

Conflict of Interest

We declare no conflicts of interest.

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