Advancing All-Terrain Vehicles Safety in Agriculture: An Insightful Summary from Global Experts

Review

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HIGHLIGHTS

- Decrease fatalities and injuries in agricultural ATV incidents.
- Protect youth ATV riders in agricultural incidents.
- Use engineering controls to reduce agricultural ATV crashes.
- Comprehensive perspectives on ATV incidents (Australia, Canada, Israel, Sweden, and the USA).

ABSTRACT. *All-terrain vehicles (ATVs) or quad bikes have raised serious concerns, especially in rural areas where they are used for occupation (i.e., agriculture and forestry) and recreation (i.e., hunting and recreational riding). ATVs are unstable vehicles, and their incidents have been linked to factors such as the rider's physical capabilities (such as strength, anthropometry, and visual acuity) and behavior, safety awareness (training), application of personal protective equipment, lack of protective structure, and regulations. This manuscript*

Submitted for review on 28 June 2024 as manuscript number JASH 16119; approved for publication as a Review Article by Associate Editor Dr. S. Dee Jepsen and Community Editor Dr. Michael Pate of the Ergonomics, Safety, & Health Community of ASABE on 4 March 2025.

Citation: Khorsandi, F., Farhadi, P., Denning, G., Grzebieta, R., Gibbs, J., Godler, Y., . . . Yoder, A. M. (2025). Advancing all-terrain vehicles safety in agriculture: An insightful summary from global experts. *J. Agric. Saf. Health, 31*(3), 173-202. https://doi.org/10.13031/jash.16119

presents perspectives of ATV safety experts from several countries, including Australia, Canada, Israel, Sweden, and the USA. The topics include the state of the art in youth riders, engineering control methods, stability, protective structures, safety rating systems, training and education, personal protection equipment, and new regulations.

Keywords. *Agriculture, ATV, Comprehensive perspective, Quad bikes, Safety, Youth.*

All-terrain vehicles (ATVs) or quad bikes have become a serious concern in most parts of the world, especially in rural areas where they are used for occupation (agriculture, forestry) and recreation. ATVs cause fatalities and injuries around the world. For example, in the United States (U.S.) alone, the Consumer Product Safety Commission (CPSC) reported a total of 15,744 ATV-related fatalities between 1982 and 2018. Additionally, 264 deaths and an estimated 81,800 ATV-related injuries were treated in U.S. emergency departments in 2018 (CPSC, 2020). ATV incidents are also prevalent in other places such as Australia, New Zealand, Israel, and Europe (Godler et al., 2022; Mulligan et al., 2022). For instance, in New Zealand, ATVs are the leading cause of fatalities and injuries in the agricultural industry (Wood et al., 2013). Furthermore, ATV incidents result in a significant number of fatalities and injuries in Australia, with youth being particularly vulnerable (Mulligan et al., 2021).

This manuscript presents the perspectives of nine experts from several countries, including Australia, Canada, Israel, Sweden, and the U.S., participating in an online Agricultural ATV Safety Symposium, an online event on 28 June 2022. The event represents a wide range of fields about ATV safety. Each expert was invited based on their expertise and experience in ATV safety research, ensuring comprehensive and diverse coverage of various related topics. Their participation provided a platform for exchanging knowledge and insights on the current state of ATV safety research. The event was well attended by over 200 participants, including researchers, policymakers, and industry representatives. Topics covered include the state of the art in youth riders, engineering control methods, stability, protective structures, safety rating systems, training and education, personal protection equipment, and new regulations. After the symposium, a summary of each panelist's presentation was prepared, highlighting the critical insights and contributions of the experts.

This manuscript represents a significant advancement in improving ATV safety for all stakeholders. It provides essential insights and actionable recommendations with the aim of reducing injuries and fatalities related to ATV usage. Each section includes a summary of the latest and significant studies and regulatory updates in several countries: Australia, Canada, Israel, Sweden, and the U.S. The manuscript is categorized based on country and topic. Each section includes an outcome section that presents a summary and conclusion of each study. The end of the manuscript includes a conclusion that gives an overall recommendation based on all studies. Considering that the terms ATV and quad bike are used in different countries, both will be used in this manuscript. However, Australian and New Zealand coroners and the USA's federal government (CPSC) have stated that the term 'all-terrain vehicles' is misleading, resulting in false assumptions as to the terrain that such vehicles can safely traverse (Ministry of Justice, 2011).

Australia: Quad Bike Performance Project, Safety Survey, and CPD Consumer Protection Law

Background

Quad bike and side-by-side vehicle (SSV) incidents are the leading cause of fatalities and serious injuries on Australian farms and similarly in many other countries. There are 10 to 11 fatalities per year in Australia resulting from quad bike incidents, most of them rollovers (Safe Work Australia, n.d.).

In Australia, the term for vehicles commonly used on farms over rougher terrains is quad bikes or SSVs, depending on their size, weight, and farming task. Quad bikes (fig. 1a) are distinguished from SSVs (fig. 1b) in Australia by their design, namely, the quad bike's straddle seating, steering via handlebars with a small thumb-operated throttle on the right side, and low-pressure tires. This compares to the SSV's operator configuration, which is more akin to a traditional car where seating is upright with seat belts within a roll cage, a steering wheel is used to direct the vehicle, brakes and accelerator are operated by the driver's right foot, and wheel tire pressures are higher.

Results of one study show that quad bikes are particularly susceptible to rollover crashes in typical farm terrains and do not meet 'Fit for Purpose' criteria for farm work activities in contrast to SSVs, which are more stable, carry larger loads than a quad bike and offer occupant protection in the event of a rollover (Hicks et al., 2018a).

A detailed study of Australian fatalities involving quad bikes and SSVs, based on data from the Australian National Coronial Information System (ANCIS) from 2001 to 2012, was conducted to examine injury mechanisms associated with their use. The authors analyzed 109 fatality cases in detail, of which 106 (97.2%) were related to quad bikes. Approximately 75% of the 109 fatalities occurred on farms. A rollover occurred in 71% of all cases, and of these, 85% of the work-related fatal cases involved a rollover compared to 56% of recreational cases. Around 28% involved mechanical asphyxia, where 50% were pinned by the quad bike, and for the 53 farm cases identified, 68% were 'pinned.' Regarding quad bike and SSV injuries, based on hospital and other injury databases, approximately 1,400 visits at hospitals were estimated for Australia, from minor to severe injuries (Grzebieta et al., 2015b; McIntosh et al., 2016; Mitchell et al., 2015).

In response to the incidence of fatal and serious injury rollovers involving quad bikes, it was proposed by some regulatory authorities and other safety stakeholders that, as a minimum, Operator Protection Devices (OPDs) (also referred to as Crush Protection Devices

(a) (b)

Figure 1. (a) Quad bike with rollbar and (b) SSV, both fitted with an anthropomorphic test device (ATD), subjected to lateral, rear, and forward pitch tests (Grzebieta et al., 2015a).

or CPDs) such as those devices highlighted by the authors in a previous paper (Rechnitzer et al., 2013) and shown in figure 2 be installed on all workplace quad bikes. It shows how the Quadbar and Lifeguard OPDs (these are secondary manufacturer products and are retrofitted for the device) are fitted in such a manner so that riders can still actively ride the quad bike. Several designs of CPDs are commercially available, including Quadbar, Quadbar Flexi, ATV Life-Guard, and Air-Quad, which are explained in detail in the Khorsandi et al. (2021) study. While in principle, it appears that such systems may have a protective benefit in some rollovers, it is also clear that fitment of OPDs will not prevent rollovers from occurring in the first instance, and OPDs may not be effective in all rollover situations (Rechnitzer et al., 2013), as active separation or ejection still occurs and impact or crush by stiff areas on the quad bike or the OPD itself may result.

Over the past two or so decades, there has been little agreement on the way forward in improving quad bike safety regarding rollover. The Australian industry manufacturers represented by the Federal Chamber of Automotive Industries (FCAI), have a policy position for quad bikes that while some design and safety performance measures have been standardized and introduced, they remain focused on rider training, active riding, and administrative controls such as Personal Protection Equipment (PPE), e.g., helmets (FCAI, 2012, 2021). The authors note that in the hierarchy of control measures for managing risks, engineering controls that design out the hazard are considered a more effective control measure than training courses that seek to change human behavior. Controls should include engineering approaches such as increasing rollover resistance (e.g., wider track width) and enhancing rollover crashworthiness design (e.g., roll bars and seat belts), while still maintaining the operational capabilities of the vehicles. Administrative controls are typically considered the least effective in a Vision Zero (no deaths) Safe System Approach, consistent with the hierarchy of safety controls similar to the United States' hierarchy of controls (OSHA, 2023).

Quad Bike Performance Project (QBPP)

The QBPP was funded by the New South Wales Workcover Authority with a contribution from the Australian Competition and Consumer Commission (ACCC). The series of tests was carried out on a selection of 16 production vehicles consisting of eight quad bikes, three recreational quad bikes, and five SSVs. Testing was carried out at the NSW state government's Roads and Maritime Services Crashlab testing facility. The test program essentially consisted of three parts, namely, Part 1: Static Tests (Grzebieta et al., 2015a); Part 2: Dynamic Handling Tests (Grzebieta et al., 2015c); and Part 3: Rollover Crashworthiness Tests (Grzebieta et al., 2015d). A summary report that synthesizes all three parts

(a) (b)

Figure 2. Operator Protective Devices (OPDs): (a) Quadbar and (b) Lifeguard (Grzebieta et al., 2017).

along with the supplemental report focusing on the injuries and deaths was also written (Grzebieta et al., 2015e; McIntosh et al., 2016).

Initially, the project was limited to testing quad bikes. However, it became apparent early in the program that SSVs should also be included, as they were increasingly being used on farms. This was a fundamental decision made early in the program to expand the mix of 'workplace' and 'recreational' quad bikes and SSVs. This was also the first time that such a comparison of vehicle stability, handling, and crashworthiness was made across such a diverse range of terrain vehicle types. This decision has proved to be valid. It has enabled the focus of the testing to broaden from just considering what improvements to quad bikes could be made by manufacturers. What has resulted is a much more fundamental approach to risk reduction/management options involving, in principle, appropriate vehicle selection and 'fitness for purpose' criteria and provision of previously unavailable comparisons between quad bikes and SSVs for consumers.

Figure 3 provides a comparison of the authors' postulated rollover crash rate versus the Static Stability Factor (SSF) for quad bikes and SSVs. It also presents the stability of quad bikes and SSVs in the lateral roll direction compared to all other motorized vehicles involved in rollover crashes. The U.S. National Highway Traffic Safety Administration's (NHTSA's) rollover crash rates for cars and sports utility vehicles (SUVs) (Mengert, 1989) and New Zealand's rollover crash rates for heavy articulated and rigid trucks (Department of Infrastructure, Energy and Resources, 2006) were superimposed to create this graph. It is essentially a composite with the addition of the authors' postulated curve, showing the relationship between the Tilt Table Ratios (TTR) measured for quad bikes and SSVs (Grzebieta et al., 2015e; Grzebieta et al., 2015a) versus the relative rollover crash rate. Furthermore, it shows that the stability of quad bikes based on the TTR (SSF and TTR are similar measures (Grzebieta et al., 2015a)) is in the lower range and not dissimilar to a

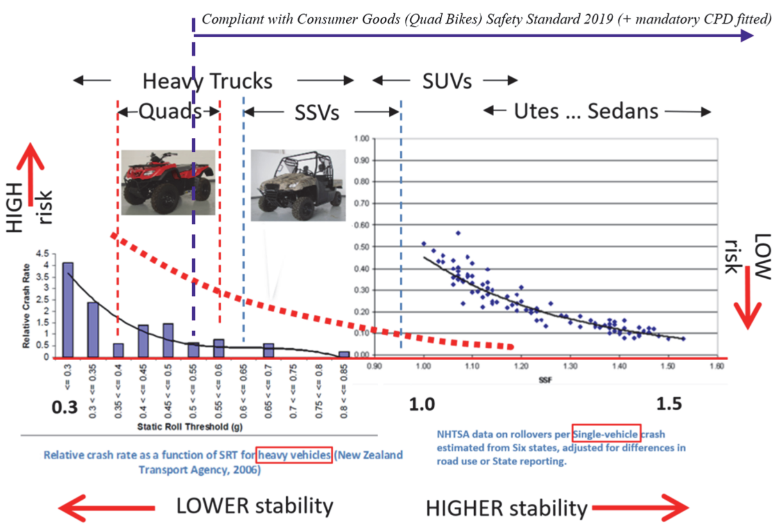


Figure 3. Authors' postulated crash rate versus Static Roll Threshold (SSF ≈ TTR) for quad bikes and SSVs (static) tested in QBPP (Grzebieta et al., 2015a; Grzebieta et al., 2015e) with rider/driver (95th% ATD) compared to NHTSA's Mengert chart for relative rollover crash risk for cars and SUVs (Grzebieta et al., 2015e) and to New Zealand Transport Agency's relative rollover crash rate for trucks (Department of Infrastructure, Energy and Resources, 2006).

heavily loaded truck (articulated prime mover or a heavy construction tipper trucks); whereas the TTR (SSF) for higher stability SSVs overlaps with a four-wheel drive (4WD)/SUV. The authors postulate that the likely rollover risk for lower stability quad bikes could be as much as four times (or higher) that of the highest stability SSVs. Better data collection is required for quad bike and SSV crashes to determine the actual rollover risk curve for these vehicles, as has been done for the other vehicle types.

Fit For Purpose Rollover Study

Another revealing study demonstrating how quad bikes are not suited to farming or indeed any other workplace (parks, surf lifesaving, etc.) environment, has been demonstrated (Hicks et al., 2018a). Australian Coronial data revealed that fatal and injurious events are associated with riding over bumps such as rocks, tree stumps, grass tufts, tractor tire ruts, etc. (Grzebieta et al., 2015b; McIntosh et al., 2016). Specifically, positioned bumps such that one wheel track of the quad bike can ride over the bump which in turn can result in a rollover as shown in figure 4, eventually trapping the rider (Hicks et al., 2018b). A seated rider traveling over a bump on flat terrain can induce sudden steering and yawing that consequently triggers a rollover event. Using a laboratory-calibrated Finite Element (FE) model of a Honda TRX500 with a seated 95th percentile Anthropomorphic Test Device (ATD) (Hicks et al., 2018b ; Hicks et al., 2015; Mongiardini et al., 2014). Hicks et al. (2018a) study identified which combination of speed, slope, and bump size causes a quad bike with a seated rider to rollover incident. A surface was used to graphically represent when the combinations of speed, slope steepness, and bump height for which the simulation indicated that the quad bike and rider would roll over, as shown in figure 5a. A linear interpolant was used to create the surface. The two-dimensional lines indicating the transition between non-rollover and rollover used to produce the surface are shown in figure 5b.

Two different rollover mechanisms occur depending on the speed, slope angle, and bump height: a rear wheel impact steering-induced rollover mechanism and a front wheel

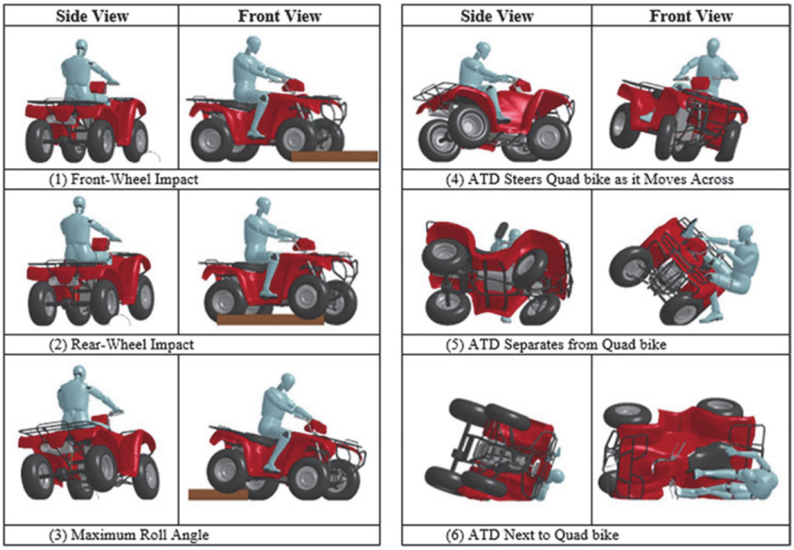


Figure 4. Sequence of events of a simulated FE quad bike with ATD rider model impacting a bump along one wheel track side of the quad bike and subsequent rollover (Hicks et al., 2018a).

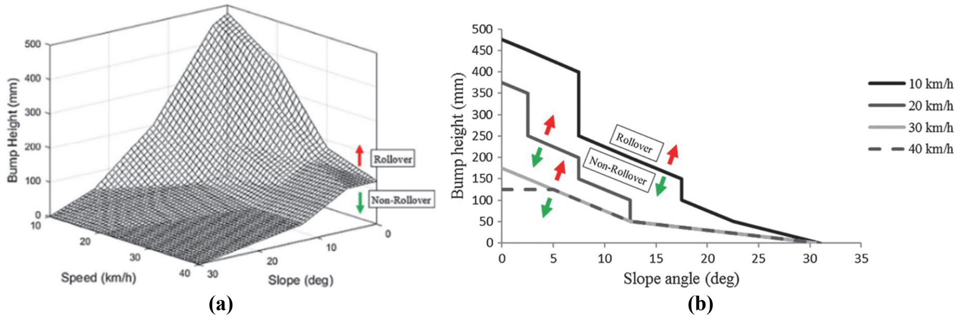


Figure 5. (a) Surface indicating the transition between non-rollover and rollover considering bump height, speed, and slope steepness. (b) Lines indicating the transition between non-rollover and rollover for each of the four investigated initial speeds (Hicks et al., 2018a).

impact tip-over mechanism. When quad bike speed and the slope steepness are increased to typical values (e.g., 20 km/h and 12.5 degrees), the bump size needed to cause a rollover quickly reduces (e.g., around 100 mm or the height of a tuft of grass). Quad bikes are particularly vulnerable to a rollover event when traveling around farming environments where they traverse relatively small bumps on typical grassy slopes at moderate speeds. This suggests that a quad bike should no longer be considered as a vehicle fit for farming tasks and alternate safer vehicles such as SSVs should be considered.

Quad Bike Workplace Safety Survey (QBWSS)

While there is considerable interest in the farming community and workplace for the fitment of OPDs to reduce harm in rollover incidents with quad bikes, there is also controversy regarding the claimed harm of OPDs and their effectiveness (FCAI, 2012). Figures 6a and 6b show how the OPDs provide crawl-out space in the tests carried out as a component of the QBPP (Grzebieta et al., 2015d; Grzebieta et al., 2016; Grzebieta et al., 2015e). An overview of the QBPP project and some of the tests carried out are provided in YouTube videos (SafeWork NSW, 2014). Figure 6c also shows how an SSV's ROPS (Rollover Protective Structure) in conjunction with seat belts and the rider wearing a helmet provides the best protection in the event of a lateral rollover and should be considered the 'fit for purpose' vehicle to be used in the workplace, including farms (ranches).

Included in the University of New South Wales (UNSW) research work focusing on the effectiveness of OPDs (Grzebieta et al., 2017) to reduce rollover harm was a case study of 20 years of crash history obtained from a quad bike tour company operating rides for up to 25,000 yearly patrons over 20 years. In 2005 the company fitted all quad bikes with OPDs, to redress their major injury incidents (70% were rollovers) in the prior ten years. The company reported no cases of serious injury in the subsequent ten years resulting from OPDs and their experience is that OPDs are effective in reducing harm to patron riders.

Also included in the UNSW study (Rechnitzer et al., 2013) was a survey of quad bike fleet managers from 12 Australian and 4 NZ companies covering a total of 436 quad bikes, where most quad bikes were fitted with either a Quadbar (n = 167) or a Lifeguard (n = 150). The survey of these companies intended to identify from these large users of quad bikes with OPDs fitted (hence high exposure) whether riders' use of OPDs in the field was resulting in serious injuries. There were 57 rollover crashes involving a quad bike with no OPD and 12 crashes with an OPD. When managers were asked whether the OPD prevented

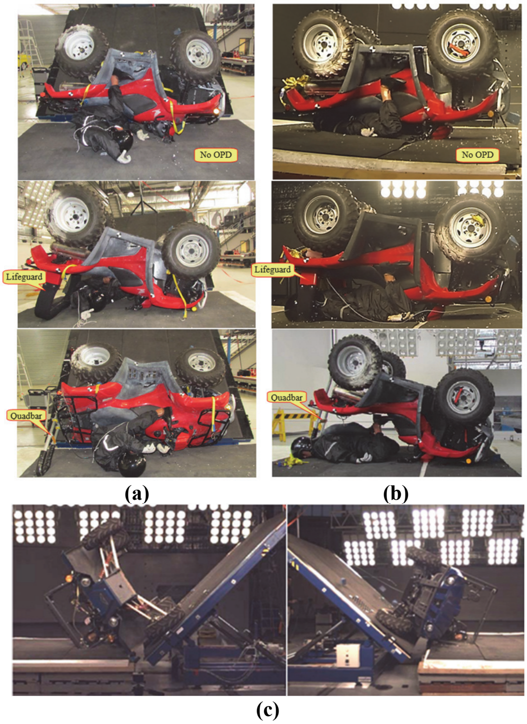


Figure 6. (a) Lateral rollover: top – no OPD; middle - with Lifeguard OPD; bottom – with Quad-bar OPD. (b) Forward pitch: top - no OPD; middle - with Lifeguard OPD; bottom – with Quadbar OPD. (c) Lateral rollover of Tomcar (left) and Yamaha Rhino (right) SSVs, both with ROPS and seat belts (Grzebieta et al., 2016; SafeWork NSW, 2014).

injury or caused injury, the company manager responded that the OPD prevented injury or more serious injury in 10 of the 12 rollover cases. This survey identified that overall, the fleet managers considered the Quadbar generally protective.

While these three studies (online survey of 1,546 riders, quad bike tour company case study, and survey of quad bike fleet managers) identified that a few riders received injuries they attributed to the OPD, from all the infield data, the authors concluded that neither Quadbar nor Lifeguard OPDs were causing serious chest or head injuries in rollover crashes. Further, the infield data suggests that these OPD types reduce, to some extent, serious chest injuries in rollovers. However, statistical significance was not able to be obtained because of the small sample size of riders receiving injuries when using these OPDs. Importantly, no fatalities were identified in this study (Grzebieta et al., 2017) or elsewhere so far where a Quadbar or Lifeguard OPD fitted to a quad bike was casual to a fatal injury.

Consumer Product Safety Law

To improve quad bike safety and prevent injuries and deaths, the Australian Federal Government introduced into legislation the ‘quad bike’ product safety law (Australian Government*, 2021*) that now applies to all quad bikes sold in Australia from 11 October 2020. All new and imported second-hand quad bikes must (ACCC, 2019):

- Be fitted with an OPD or have one integrated into its design.
- Meet the U.S. standard for quad bikes, ANSI/SVIA 1-2017 (2017), or the European standard, EN 15997: 2011 (British Standards Institution, 2011).
- Be tested for lateral static stability and display the angle at which they tip on 2 wheels on a hang tag to inform purchasing decisions as well as meet the minimum stability requirements, which include:
  (a) Lateral stability – a minimum Tilt Table Ratio (TTR) of 0.55 (28.81 degrees) (see fig. 3);
  (b) Front and rear longitudinal pitch stability – a minimum TTR of 0.8 (38.65 degrees);
  (c) Have a durable label affixed that is visible and legible when the quad bike is in operation, alerting the operator to the risk of rollover; and
  (d) Include rollover safety information in the owner's manual or information handbook.

Outcome

The authors believe that history has demonstrated that advances in safety for all types of land mobile vehicles are correlated with improvements in stability, handling, and crashworthiness. There is no reason why quad bikes and SSVs should be any different and not obey the same laws of physics and vehicle dynamics as any other motorized vehicle that has been researched over the past many decades.

Quad bikes cannot traverse "all terrains" as indicative of the term "ATVs." With their very high propensity to roll over onto a rider and asphyxiate them, quad bikes are not fit for purpose when being used in the workplace and on farms (ranches). Fundamentally, quad bikes have difficulty satisfying the well-known principles of reasonable stability over rough terrains and occupant protection in a rollover crash, especially when compared to SSVs (which offer wider track width, good containment, restraint of the occupant, higher payloads, impact management, and crush prevention). Nevertheless, there may be situations where a quad bike is the only vehicle that can access a location because of its narrower wheelbase. Under those circumstances, a risk assessment should be done to ensure that the vehicle will not roll, and if it does, that there is another worker within eyesight to pull the rolled quad bike off the operator in the event it pins the operator down in a rollover.

Regarding the effectiveness of OPDs in protecting quad bike riders, field study data indicates that with increasing rollover crash severity, the Quadbar or Lifeguard OPDs become increasingly protective of the rider receiving serious chest injuries. No fatalities or serious chest injuries have been recorded in any previous studies or this study can be attributed to or associated with an OPD.

Israel: ATV-Related Injury Among Israeli Children: Regulation and Data

In Israel, ATVs are predominantly utilized for recreational purposes, constituting approximately 56% of the total ATV sales in the country (Godler et al., 2022; Mulligan et al., 2022). Whereas researchers had previously indicated that about 680 ATVs and quad bikes were sold annually in Israel, informal and unofficial estimates reported in the news media exceed these numbers dramatically, ranging between 800 in 2019 and 4579 in 2020 (Levy, 2021; Peleg and Siman Tov, 2018; Siman-Tov et al., 2020).

Since there are severe legal ambiguities surrounding ATV use by children and adolescents, Beterem—Safe Kids Israel surveyed both the incidence of pediatric ATV-related injury and some of the regulatory backdrop for this phenomenon (Beterem, 2019). Before detailing this information, it should be borne in mind that Israel is comprised mainly of two ethnic groups: approximately 7 million people of Jewish descent, constituting the ethnic majority, and approximately 2 million people of Arab descent, the largest ethnic minority. An additional half a million people belong to smaller ethnic groups. In 2020, Israel's population of children (aged 0–17 years) amounted to about 3.049 million. 72.4% (or 2.207 million) children of Jewish descent and 24.2% (or 737,000) of Arab descent (Central Bureau of Statistics, 2021; Jewish News Syndicate, 2022).

This is notably significant when considering the disparities in the representation of these two ethnic groups among children experiencing ATV-related injuries. Out of the 267 children who suffered such injuries from 2012 to 2021 (individuals aged 0–17 years), Arab children comprised 70% of those involved as pedestrians and 29% of those injured while riding ATVs. Since in the relevant years, Arab children constituted between 24%–26% of Israel's population of children, these data point toward an incidence of Arab children that is higher than their share in the population, as well as a dramatic overrepresentation among those Arab children who were injured as pedestrians.

In addition, previous research pointed towards a dearth of data on crash mechanisms in the context of ATV-related injury in Israel aligned with findings from existing research; in 112 out of the 260 cases (or 41%), the primary cause of injury resulting from ATV riding was a fall from the device. Indeed, data from around the world points toward the prevalence of falls, collisions, and rollovers as the leading crash mechanisms (Siman-Tov et al., 2020). Meanwhile, rollovers occurred in Israel in at least 43 of the cases (or 16%). More marginally, collisions while riding ATVs occurred in only 10 of the cases (that is, 3%). In Israel, ATVs must be equipped with an OPD, such as a safety frame or back arch, attached to the rear of the vehicle. The design and installation of these safety devices require approval from the Ministry of Transport, with testing conducted by an accredited laboratory (Israel Ministry of Transport, 2005).

Besides the distribution of ethnic background and crash mechanisms, of the 267 children injured while riding ATVs, at least 191 (or 71%) were males, while only 75 (or 28%) were females (the rest were missing data). Further, approximately half of the ATV-related injuries for the studied time period occurred among adolescents. Indeed, many of the ATVs in Israel have so far been classified as toys under the law (Sade, 2021b; Soroker, 2020). For children under the age of six, ride-in toys are defined as vehicles traveling at the maximal speed of 8 km/h, whereas for children older than six, ride-in toys encompass vehicles whose settings allow for the maximal speed of 16 km/h (Soroker, 2020). Still, many vehicles that exceed the maximal speeds are nevertheless marketed as toys for children older than four years of age. Meanwhile, the Standards Institution of Israel (SII) does not, at present, offer standards for children's vehicles traveling at speeds that exceed 8 km/h (Soroker, 2020).

Electric ATVs are considered toys by Israeli law, which only requires non-electric ATVs to be licensed, registered, and insured. This criterion applies regardless of the technical similarities an electric ATV might share with non-electric ATVs, aside from the presence of an engine (Sade, 2021a, b). Despite these regulatory gaps, the Israeli police implemented a policy to impound and destroy electric ATVs and open criminal investigations against riders without licenses, registration, or insurance. This policy was revealed through a leaked police document reported by the media (Sade, 2021a, b).

Finally, Israel's National Road Safety Authority proposed in 2020 a measure that may address the legal ambiguities. It recommended the adoption of an Organization for Economic Co-operation and Development (OECD) standard proposed by the International Road Traffic and Accident Database (IRTAD). According to the mentioned standard, the risk posed by a vehicle should be ranked according to four types: light and slow (Type A), light and fast (Type B), heavy and slow (Type C), and heavy and fast (Type D). Thus, the heaviest and fastest ATVs—those exceeding 25 km/h and/or weighing over 35 kilograms (or types B-D)—would become treated legally as larger vehicles in the same speed and weight categories (Soroker, 2020). Although the standard has not been implemented yet, decision-makers may be moving in this direction.

Outcome

The analysis of ATV usage in Israel showed significant safety concerns, particularly for children and adolescents because of regulatory gaps and ethnic disparities in injury incidence. While ATVs are primarily used for recreational purposes, the lack of a specific standard for children's vehicles has allowed faster and more dangerous ATVs to be known as toys, which causes higher risks for young users.

The results indicated the necessary need for updated regulations, including a clear distinction between toy and non-electric ATVs, stricter enforcement of safety equipment, including OPDs, and consideration of international standards. Implementing these steps, along with mandatory safety training and licensing for all ATV riders, can significantly reduce the risk of incidents and provide better protection for youth operators.

Sweden: ATV Safety—Swedish Perspectives

ATVs in Sweden can be registered in several different ways, with different rules on how they can be used, on or off the road, and what permissions are required (age and driver's license) (Trafikverket, 2020). This system may be perceived as quite confusing and difficult to understand without specific guidelines. According to the Swedish Transport Administration (Trafikverket, 2020), there were about 85 fatalities on or off-roads involving ATVs from 2008 to 2017. Approximately 90% of the reported incidents were single-vehicle incidents, with a notable majority (90%) of the victims being male and 10% falling under the age of 16. A significant portion (around 70%) of the fatalities resulted from vehicle rollovers. Additionally, nearly 70% of the cases involved individuals under the influence of alcohol or drugs. The data regarding the occupation of the deceased is unavailable.

A Joint Swedish Strategy

The Swedish Transport Administration took the initiative to gather all major stakeholders to join forces to achieve progress regarding the safe use of ATVs (Lundqvist et al., 2022; Trafikverket, 2020). Among the stakeholders were authorities, ATV and rural organizations, insurance companies, researchers, employers, and employee organizations. All stakeholders have their tasks as parts of this strategy to work with, and there are upcoming follow-up meetings each year to evaluate progress. The strategy includes a goal to reduce the number of injuries and fatalities by 50% by the year 2030. The "Joint Strategy" also agreed on the following recommendations: (a) increase the use of helmets, (b) increase the use of CPDs and other technical solutions, (c) increase the use of alco-locks (a device installed in a vehicle that prevents the engine from starting if the driver has consumed alcohol above a predefined limit) when it is practically possible, (d) less use of ATVs on public roads, (e) less use of ATVs among children, and (f) improve information and increase training and education on risk awareness and safe driving.

Recent Research and Development in Sweden

To evaluate the practical use of CPDs among farmers and forest owners, 50 ATV users were asked to use this device for a 12-month period during their ordinary use of their vehicles. One of the study's conclusions is that the tested protective device generally seems to have worked well for most of the participants, and it can increase both the perceived and actual safety of quad bike use. The participants' positive attitude towards recommending the CPD to acquaintances can be assumed to contribute to an increased interest among more people in acquiring this or similar protective devices (Edlund et al., 2019; Kronlund et al., 2023).

Another project focuses on a warning system for users of ATVs on uneven terrain, which means that the driver gets a warning signal if they are driving on a steep slope with an increased risk of a rollover. In the event of a rollover, an automatic message will be sent to either a designated relative or an alarm center, providing essential information about the incident's precise position (Lundqvist, 2020). The evaluation of this solution was positive, but due to the pandemic, the manufacturing of this device was delayed, and it is not yet on the market.

Another solution is in the planning stage but not yet fully funded, with a Swedish manufacturer (Tenstar Simulation) to develop a training program with an advanced simulator for ATV drivers. Such simulators work well for operators of farm tractors, combine harvesters, forest machines, and other vehicles.

To deal with the problems of minor children and their use of ATVs in rural areas, a study has been focusing on the role of parents and their attitudes. Results showed that most parents seemed to misjudge their children’s maturity and that they showed a very optimistic view of the child’s abilities to handle large ATVs. Risk acceptance was a common issue among these families due to the normalization of ATV use among children in these environments. The results showed that there is a need for an age limit for the use of adult-size ATVs (Lundqvist et al., 2022).

Outcome

To make agriculture and forestry a safe workplace when using ATVs, we need to think outside the box when we discuss and promote solutions. We believe that there could be progress by the Swedish initiatives, but the users may also consider alternatives that might be safer for their work tasks, using side-by-side vehicles or small tractors. New technologies are enabling innovative solutions, with some farmers and forest owners now using drones instead of ATVs to perform essential work tasks. Finally, there is a need for further international collaboration and development to make a real change in the situation.

The United States of America (USA): Capabilities and Limitations of Youth Operating ATVs

Several resources provide safety recommendations for youth riding ATVs, including the American Academy of Pediatrics (AAP), American College of Surgeons (ACS), American National Standards Institute/Specialty Vehicle Institute of America (ANSI/SVIA), Consumer Product Safety Commission (CPSC), British Standard Institution (BSI), National Children's Center for Rural and Agricultural Health and Safety (NCCRAHS), and National Safe Tractor and Machinery Operation Program (NSTMOP).

All the aforementioned safety organizations agree that children aged under 6 years should not operate or ride as passengers on any ATV (British Standards Institution, 2011; Burd, 2009; Denning and Jennissen, 2018; Greenberg and Shah, 2009; Grzebieta et al., 2017; Hegazy et al., 2017; Murphy, 2006; Murphy and Harshman, 2023; NCCRAHS, 2024). For children aged 6–16, organizations like the AAP and ACS recommend they not operate any ATV (Burd, 2009; Greenberg and Shah, 2009). However, standards from ANSI/SVIA, CPSC, and BSI as well as youth-serving organizations such as 4-H suggest that this group of children can ride child-sized ATVs under certain restrictions (ANSI/SVIA, 2017; British Standards Institution, 2011; CPSC, 2006; Henwood et al., 2011). Furthermore, they should not operate utility ATVs (adult-sized) on farms, as recommended by NCCRAHS and other researchers (Denning and Jennissen, 2018; Grzebieta et al., 2017; Hegazy et al., 2017; NCCRAHS, 2024). In contrast, the NSTMOP and BSI state that children aged 6–16 may operate utility ATVs on farms if they have received proper training (British Standards Institution, 2011; Murphy, 2006).

Among all these organizations, CPSC and SVIA have released specific parameters to evaluate the fitness between youth drivers and different ATVs (ANSI/SVIA, 2017; CPSC, 2006). The focus of CPSC is on engine size, while ATV speed is the criteria in the SVIA standard for matching ATVs with youths in different ranges of age. According to the CPSC recommendations, for children under the age of 6, ATV use is not recommended, and children aged 6 to 11 should only operate ATVs with an engine size under 70 cc. The range of engine sizes is variable, from 70 to 90 cc for youth between 12 and 15 years old. Finally, individuals 16 years and older are recommended to use ATVs with engines over 90 cc (CPSC, 2006). On the other side, based on the ANSI/SVIA standard, youth-sized ATVs have specific speed limits depending on the age of the operator and whether the ATV is equipped with a speed governor. For children aged 6 and older, the maximum speed with a speed governor is 16 km/h, while without a governor, it can reach up to 24 km/h. For those children aged 10 and older and 12 and older, the speed limit with a governor is 24 km/h, but it increases to 48 km/h without a governor. Finally, for youths aged 14 and older or the transition category, the maximum speed ranges from 32 to 48 km/h with a governor and can reach 61 km/h when unrestricted (ANSI/SVIA, 2017). The 4-H program includes educating youth about ATV safety as part of broader youth development activities. It also covers a wider range of safety topics, including caring for the environment, riding responsibly, and understanding local laws and regulations (Henwood et al., 2011).

Recent studies have emphasized the importance of matching each youth to the appropriate ATV, ensuring the vehicle's size and power are suitable for the rider's age, size, and skill level (Araujo et al., 2022, 2024, 2023). The details of this study are explained below.

Three separate studies were carried out to determine whether youth's physical abilities (strength, anthropometry, and field of vision) are sufficient to safely operate agricultural ATVs, or utility ATVs used on farms or ranches.

In the strength evaluation study, researchers assessed the activation forces required to engage the primary controls of an ATV, including activation forces required to engage the primary controls of an ATV, including handbrake, footbrake, handlebar, throttle lever, ignition switch, headlight switch, and both hand and foot gearshifts (if any) (Araujo et al., 2023). The researchers used specialized tools such as a handheld force gauge, a button load cell, and a pressure glove to measure these forces. The study then compared the required ATV activation forces with youth strength data from existing resources. Findings showed a significant physical mismatch, which indicated that the strength required to activate ATV controls often exceeds the capabilities of youth riders. Results of this study showed that turning the handlebar and pressing the footbrakes were the most difficult tasks for ATV operation. Based on NCCRAHS, youths should be able to push an ATVs off their body in case of rollover incidents. Results of this study showed that almost none of the youth can push ATV off their body if they are trapped under that ATV. The authors recommended following CPSC recommendations and keeping the weight of ATVs less than three times the weight of youth (Araujo et al., 2023; CPSC, 2006).

In the reachability study, researchers investigated a potential mismatch between the operational needs of the adult-sized agricultural ATVs and the anthropometric dimensions of youth riders. Researchers developed three-dimensional (3D) mockups of humans and ATVs. Using virtual simulations in ergometric software (SAMMIE CAD), 11 interactive and reach-based ATV fit criteria established by various ATV safety organizations were evaluated. The results showed a youth could not reach different ATV controls properly, as most youths failed to satisfy at least one of the 11 fit criteria (Araujo et al., 2022).

In the field of vision evaluation study, researchers developed 3D mockups of ATVs, humans, helmets, windshields, and sprayer tanks using SAMMIE CAD. This allowed researchers to quantify and assess the field of vision for young operators while using agricultural ATVs. The windshield and spray tank were virtually added to the simulated ATV. The spray tank was located on the front rack of the ATV, which is common in agricultural activities. The findings showed that youth typically have a more limited field of vision compared to adults, which may reduce their ability to see obstacles or bystanders around the ATV. Additionally, the study indicated that wearing a full-coverage helmet does not significantly affect the operator's field of vision, while a dirty or frosted windshield and sprayer can limit the field of vision significantly (Araujo et al., 2024).

Outcome

There are serious concerns about youth operating ATVs, and several criteria are recommended to be considered to ensure a proper match between the rider and the ATV (e.g., speed and engine size). The results of the latest study on youth and ATV compatibility indicate that each youth's abilities should be individually assessed before allowing them to operate a specific ATV (Araujo and Khorsandi, 2020; Araujo et al., 2024; Araujo et al., 2021).

The main conclusion from these complementary studies is that the physical capabilities of youth are not enough for safely operating agricultural ATVs. The findings from this project offer quantitative and systematic evidence to inform updates to existing ATV safety guidelines. Additionally, future ATV safety programs should emphasize more on considering the physical capabilities of operators rather than focusing solely on their behaviors.

USA: ATVs in Agriculture—An American Heartland Perspective

All-terrain vehicles (ATVs) are extremely popular in rural areas for both recreation and work purposes. A study of news reports collected and available on AgInjuryNews.org found ATVs to be the second most common cause of agricultural fatalities and injuries overall and the leading cause of deaths and injuries among those 17 years of age and younger (Weichelt and Gorucu, 2018).

Agricultural ATV-Related Injuries Resulting in University of Iowa Hospitalization

ATVs have become increasingly valuable assets in many work settings, but few studies have reported on ATV-related trauma associated with occupational activities (Weichelt et al., 2020). Some of the dangers associated with ATV use may not be easily recognized by rural workers and families (Jennissen et al., 2016; Jennissen et al., 2021). The objective of this study was to explore farm work-related injuries associated with ATV use that resulted in hospitalization at the University of Iowa Hospitals and Clinics (UIHC). A retrospective chart analysis of patients in the UIHC Trauma Registry from 2002 to 2008 was conducted to identify those who had suffered an agricultural work-related injury. A descriptive analysis was performed.

A total of 331 patients with ATV-related injuries were admitted to the UIHC during the study period. Of these, only 14 (4%) had a farm work-related injury, although many of the recreational injuries occurred in rural areas, including on farms. Most were males with ages ranging from 5 to 69 years, with a mean of 36.4 years. There was a wide range of occupational injuries sustained, including pneumothorax (air leakage from the lungs into the chest cavity), intracranial hemorrhages (bleeding around the brain), brain contusions, lung contusions, a pancreatic contusion, liver lacerations, hemoperitoneum (blood in the abdominal cavity), tracheal tear (windpipe), shoulder separation, compartment syndrome in the leg, abrasions, skin lacerations, and fractures. Among these injuries, the most common were broken bones, which included fractures to the face, clavicle, ribs, scapula (shoulder blade), long bones, and vertebrae (back).

The mechanism of injury was a rollover in nearly four-fifths of cases (11/14, 79%). Two events involved a collision with a stationary object, and the other was an ejection from the vehicle. For six cases (40%), the work activity involved transportation or hauling items for farm work, usually in the fields, and one case involved spraying. In the majority of the cases (8/14, 57%), the injury occurred while herding cattle.

Many farmers and ranchers may not consider it particularly hazardous to herd cattle with an ATV. However, it makes some sense that herding cattle is a higher-risk work activity. Unpredictable animal behavior, unexpected terrain changes, and distraction from the task at hand are all likely contributing factors to this increased risk. Farmers and ranchers need to be aware of this and should take extra precautions, including the use of helmets and having others around when performing this task.

Occupational Deaths Due to ATVs in Iowa

Over two-thirds of ATV work-related fatalities in the U.S. are in the agriculture industry (Helmkamp et al., 2011). The objective of this study was to describe work-related fatalities from ATVs in the state of Iowa and determine their mechanisms of injury and contributing risk factors.

The Iowa Fatality Assessment and Control Evaluation (FACE) Program database was utilized for this study. State FACE programs have cooperative agreements with the National Institute for Occupational Safety and Health (NIOSH) for conducting surveillance, targeted investigations, and prevention activities at the state level. Basic information on all occupational fatalities in the state of Iowa was collected by the FACE program, and in-depth investigations were collected on select fatal injuries from 1995 until the end of the program in 2012.

There were 29 Iowa occupational deaths identified in the FACE database that involved an ATV; 45% of them occurred in the last four years of the study (2009–2012). All cases involved agricultural activities. Most victims (86%) were male. About half were 60 years and older; only 5 (17%) were younger than 40 years. The most common mechanism was a rollover (79%). Excluding cases where the terrain was unknown, all rollover fatalities were due in part to uneven or sloped terrain. This was often exacerbated by a shift in the center of gravity, either due to a change in operator positioning or the movement of materials being hauled.

Over one-third of ATV-related occupational fatalities occurred during spraying activities, with the shifting of fluid in a tank being carried or towed likely contributing to a rollover while on a slope or ditch. All individuals were pinned against the ground or an immobile object and died of traumatic asphyxiation and/or internal organ injuries. Almost all deaths while spraying (9/10) were 55 years of age and older, with 50% being 70 years and older. All spraying-related ATV deaths occurred during the day or near sunset, but many were found hours after the event. Other work activities at the time of death included checking fields, livestock, or fences (38%), herding cattle (14%), and roadway transit (14%).

The conclusions were that ATVs appear to be accounting for an increasing number of Iowa work-related fatalities in agriculture. The high number of traumatic asphyxiation cases is likely due in part to the dramatic increase in the size of ATVs sold in the last decade of the study, resulting in individuals being unable to free themselves once pinned by the vehicle. Occupational ATV/ROV-related deaths are much less likely to have alcohol or drug use as a contributing factor as compared to recreational fatalities and also appear to have a different age distribution. Certain groups, such as elderly farmers, may be at increased risk and should be targeted for ATV safety education.

Iowa Private Pesticide Applicator ATV Use and Crashes

It was very intriguing that the Iowa FACE study of ATV-related occupational fatalities showed that over one third had been involved in spraying activities at the time of their death. This led to a study to further investigate the experiences of Iowa private pesticide applicators in using ATVs for spraying.

To maintain certification, private pesticide applicators must attend an in-person continuing instruction course each year or pass the Iowa Department of Agriculture and Land Stewardship certification exam every three years. Most opt to maintain certification by attending the yearly instruction courses conducted by Iowa State University Extension and Outreach in each of the 99 counties in Iowa. A total of 6,322 private pesticide applicators completed the course and the evaluation form. Nearly two thirds (65%) reported having used an ATV for spraying. Of these, 8% had been in a crash while spraying with an ATV.

We concluded that most private pesticide applicators in Iowa use ATVs for spraying and that having a crash while spraying was not uncommon (nearly one in ten had experienced a crash). Spraying with ATVs appears to be a significant risk factor for ATV work-related death, and workers who utilize ATVs for spraying should be targeted for safety education.

The ATV Exposure and Crash Experiences of Iowa FFA Members

Youth are a significant portion of those injured and killed in ATV crashes, often being the vehicle operator despite manufacturer warnings on the vehicle that they should not be driven by children <16 years of age (Jennissen et al., 2022a,b). Youth are at higher risk for ATV injury than adults (Rodgers and Adler, 2001) and are often not abiding by basic safe riding behaviors (e.g., no passengers, helmet use, staying off public roads) (Denning and Jennissen, 2018; Jennissen et al., 2022c; Jennissen et al., 2014; Wymore et al., 2020). Attendees of the 2017 and 2018 Iowa FFA Leadership Conference in Ames, Iowa, were surveyed at the Iowa ATV Safety Task Force booth by members of the University of Iowa Stead Family Children's Hospital Injury Prevention Program. FFA, formerly Future Farmers of America, is a youth organization that prepares its members for leadership and careers in the science, business, and technology of agriculture. The objectives were to better understand the ATV-related exposure and crash experiences of rural Iowa adolescents.

A total of 1,573 FFA members from 12 to 19 years old participated, with 70% being 15 to 17 years old. Females were slightly more than one-half (54%). Just over one-half (53%) were from a farm, 19% were from the country but not on a farm, and 29% were from a town. The vast majority (95%) had ridden on an ATV, and of these, nearly all reported having ridden as a passenger (93%). Of those who took the 2018 survey ($n = 971$), only 2% had completed an organized safety training course either online or with hands-on training. Almost one-fifth (17%) stated they taught themselves to drive an ATV, and the majority (72%) stated they were taught by a family member.

Over one-third (35%) had been in at least one ATV crash, defined as hitting an object, rolling over, or being thrown/ejected from the vehicle. Of those having crashed, almost three-fifths (59%) had more than one lifetime crash, and nearly a quarter (23%) had more than 3 crashes. The mean age of those reporting crashing when riding as a passenger was 9.9 years and when crashing as an operator was 10.7 years. Males were significantly more likely to have been in a crash than females (46% vs. 24%, $p<0.0001$). Of those that had crashed, males were also more likely to have had 3 or more crashes (45% vs. 19%, $p<0.0001$).

Survey participants from farms had higher percentages that owned an ATV (farm 89% vs. country/not a farm 74% vs. town 60%, $p<0.001$). As compared to participants from towns, those who lived on farms and in the country (not on a farm) had higher proportions that had ridden an ATV (97% vs. 90%, $p<0.001$) and had been in an ATV crash (38% vs. 26%, $p<0.001$). Of riders reporting having had crashes, those from farms had the highest proportion (40%) of having ≥3 crashes as compared to those that lived elsewhere (29%), $p = 0.025$.

Having been in a crash or having more than one crash was associated with first driving ATVs at younger ages. For example, the average age of ATV riders who reported having no crashes when they first started operating an ATV was 9.5 years, while for those who had had a crash it was 8.3 years and for those having had more than one crash it was 6.8 years. Fifteen percent of those in an ATV crash required medical attention, and the mean age at the time of their first crash that required medical attention was 11.3 years.

Questions regarding supervision while driving ATVs were asked in the 2018 survey ($n = 971$), and found that over two-thirds stated they first drove unsupervised when they were 11 years of age or less. Almost half (46%) stated that the ages they first drove and first drove unsupervised were the same. Almost all that had been in a crash (91%) stated their first ATV crash occurred after they were driving unsupervised. Respondents from farms drove ATVs unsupervised at younger ages (<9 years) than those who lived elsewhere (41% vs. 28%, $p<0.001$).

Our conclusions from this study were that Iowa FFA members surveyed reported nearly universal exposure to ATVs and commonly practiced unsafe riding behaviors (e.g., riding as passengers). We recognized that rural families were routinely not enforcing safe ATV practices and were allowing children to ride and drive ATVs at ages that were not developmentally appropriate and against manufacturer recommendations. This was particularly true for respondents who lived on farms, and our results emphasized the importance of educating rural families regarding ATV safety and injury prevention.

Outcome

ATVs are associated with a significant and growing percentage of U.S. agricultural work-related deaths and injuries. Further study and input from rural community members and agricultural producers are needed to understand how to increase ATV safety behaviors among this population, including youth. Developing effective ATV safety education and training programs that target agricultural populations is crucial.

USA and Canada: Self-Reported ATV Safety Behaviors and Safety Awareness Among Young Adults in U.S. and Canadian Agriculture

This study was conducted in partnership with the Ag Health and Safety Alliance (AHSA) to examine self-reported quad bike use for agricultural purposes, safety behaviors, and awareness of safety design features by more than 600 young adults enrolled in Gear Up for Ag Health and Safety (Gear Up for Ag) programs in the U.S. and Canada). The Gear Up for Ag program is unique in that although it addresses overall agricultural health and safety topics, ATV safety is a compulsory educational component. AHSA found that overall reported awareness of engineering features on quad bikes among young adults was low; less than 20% of these young adults working in agriculture were aware of safe design features such as wide frames, stability ratings, CPDs, and the impact of using accessories made by the original equipment manufacturer. The findings also showed that young adults who stated they had begun working with ATVs on farms before the age of 14 were also more likely to report engaging in dangerous behaviors such as not wearing a helmet and allowing extra riders. These findings support the Agricultural Youth Work Guideline (AYWG) (2020) for occupational quad bike use at age 16.

A more in-depth description and analysis of these young adult participant responses was previously reported (Gibbs et al., 2023). This work highlighted a tremendous need to educate the future agricultural workforce about the importance of selecting and demanding ATVs with safer design features. In response, AHSA revised their ATV safety curriculum to focus more on engineering controls rather than only emphasizing operator behavior.

In addition, extension and education faculty at the University of Nebraska presented some tips and advice from the University of Nebraska Extension “ATV Aware” program and several other programs in Nebraska promoting quad bike safety (ATV Aware, 2020, 2021, 2022). These included programs at rural schools (K-12), 4-H programs, the National FFA Convention, and other health fairs and safety days. Nebraska Extension uses a unique tabletop demonstration to highlight the quad bike’s center of gravity, stability, hitching, vehicular size, and effectiveness of CPD. These tactile tools allow the community to visually “experience” the rollover prevention of multiple features.

The main takeaway from this study was that future ATV safety programs should continue to strongly emphasize engineering controls. Educational campaigns should target specific audiences in agriculture and should be designed to promote awareness about the importance of CPDs, wider frames, and understanding the general stability of different

ATV models. The findings in this presentation also highlighted the crucial role of parents when it comes to deciding what age quad bike use should begin for farm tasks and educating young quad bike users about safe design features.

USA: Overview of the U.S. Consumer Product Safety Commission (CPSC) ATV Rollover Test

This section is focused on the test results derived from three test reports, specifically evaluating the performance of OPDs in protecting operators in various ATV rollover incident scenarios (Heydinger et al., 2022, 2020, 2019). These tests were conducted for the U.S. CPSC.

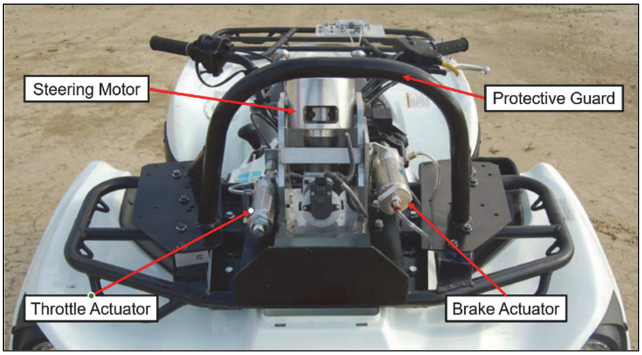
ATV Rollover Tests and Verification of a Physical Rollover Simulator

The focus of this study was on testing various ATVs in different dynamic conditions and developing an indoor sled that can be used later as an indoor simulator. In the dynamic tests, ATVs with no OPD were studied. The investigation was conducted in multiple parts. The first phase was rollover testing with an autonomous ATV on a groomed soil surface. During these tests, an ATD acted as a surrogate rider. The investigation then moved on to utilizing a rollover simulator to examine ATV sled rollovers. In the final phase, the results from the actual rollover simulator were validated using the outcome of the results from the field experiments on the groomed soil surface (Heydinger et al., 2019).

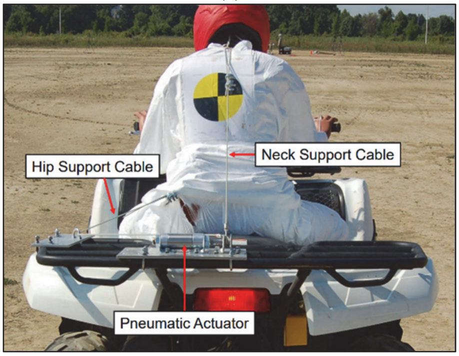
Three levels of energy rollover tests (Minimum, Moderate, and Moderate with a Trip Feature) depending on the anticipated degree of rollover severity, were carried out in the first phase of the study. To initiate a rollover, the ATV had to drive autonomously in a straight line and apply a quick left steer input at a steering input rate of 40 deg/s at the handlebars (Heydinger et al., 2019).

The minimum energy rollovers were achieved by selecting vehicle speeds and steering inputs that resulted in a rollover with a roll angle of at least 90 degrees but not more than 180 degrees. The plan was to conduct all the minimal energy rollovers using a steering input of 40 deg/s at the handlebars and a dropped-throttle speed (the speed of a vehicle when the throttle or accelerator pedal is suddenly released or dropped) of 20 mph on a groomed soil surface. The goal of the moderate energy rollovers was to create rollover events that produced a roll angle of at least 180 degrees. For the moderate energy rollovers, the same steering inputs (40 deg/s) were used; however, the throttle was not released until 0.6 seconds after the start of the steering. The purpose of the moderate energy rollovers with a trip feature was to investigate how a trip feature would affect the vehicle's rollover dynamics and increase the severity of the rollover. In this case, the trip feature was a trench dug into the groomed soil surface that was at least 22 feet long, 16 to 24 inches wide, and 6 to 10 inches deep. The moderate energy rollover runs were used to determine the location of the trench and the angle at which it crossed the vehicle's path, and as the ATV went through it, the right front tire would be parallel to the trench. The location of the trench was chosen in a place where the roll angle of the vehicle would be close to 10 degrees and thus in its rollover phase. As a result, during each vehicle's moderate energy rollover run, the trench orientation was adjusted to the vehicle's heading angle (referring to the direction in which the vehicle is traveling relative to a reference axis) plus steering angle whenever the vehicle experienced a 10-degree roll angle. The same throttle commands as moderate energy rollover were used in the trip feature tests; however, the actual test speeds differed slightly (by 1.1 mph). As for the moderate energy rollover tests, the throttle was dropped 0.6 seconds after the start of steering input for the tests with the trip feature (Heydinger et al., 2019).

For doing these tests and achieving the goals, some equipment was added to the ATV, including a computer-controlled electric motor that mounts to the front rack of an ATV for steering control and pneumatic actuators to apply the throttle and brake at the end of the maneuver (fig. 7a). The ATV was also equipped with a GPS, a National Instruments (NI) CompactRIO (the on-vehicle computer with the motor and valve controllers and data acquisition software), antennas for wireless communication, an engine kill system, and batteries. For rollover testing, an ATD "secure and release" system including a pneumatic actuator, cables that reach the ATD's hip and neck, and cable ties that fasten the ATD's hands to handlebars was designed (fig. 7b). The hip and neck cables are held in place by the actuator rod until the on-vehicle controller sends a signal that opens the actuator and releases the hip and neck cables to the vehicle when the roll angle of the vehicle reaches 30 degrees. The cable ties' handhold (pull-away) strength allows for over 80 pounds of pull-away force before breaking. All the dynamic rollover tests were conducted with an instrumented Hybrid III 50th percentile male ATD with a standing pelvis, which mimics the posture of a human driver in a seated position as the loading condition. The ATD was equipped with a triaxial acceleration sensor (three linear accelerometers) in its chest and a



(a)



(b)

Figure 7. Attached equipment and actuators on the ATV: (a) ATV dynamic rollover steering controller motor, protective guard, dynamic rollover brake, and throttle pneumatic actuators; (b) pneumatic portion of secure and release system (Heydinger et al., 2019).

six-degree-of-freedom sensor (three linear accelerometers and three angular rate sensors) in its head (Heydinger et al., 2019).

Both the moderate energy runs and the moderate energy runs with a trip feature produced rollover events with maximum roll angles greater than 180 degrees, while all the minimum energy runs produced rollover incidents with maximum roll angles between 90 and 180 degrees. Furthermore, test results obtained with the specific trip feature employed in this study did not show significant differences compared to the results obtained without the trip feature. This is because of the absorption of energy from the trench by the vehicle suspension system. Moreover, passing over the trench had a minimal influence on the roll angles of the vehicles (Heydinger et al., 2019).

During the second stage, all possible scenarios of the ATV dynamic tests were simulated using a rollover simulator (fig. 8). The main components of this simulator included a steering angle block that was placed between the ATV's right front tire and the trip rail to simulate left steering and the position of the upper body and arms during dynamic rollovers, a yaw platform for operating intended yaw angles, and a helper spring for setting the ATV's initial roll angle (Heydinger et al., 2019).

The ATV rollover simulator proved to be a reliable instrument for testing ATV and ATD reactions in ATV rollover incidents, based on comparisons with full-scale dynamic rollover testing carried out on a groomed soil surface. The verification of minimal energy and moderate energy rollovers suggests that the sled includes elements, such as operating processes and settings, which can be adjusted to replicate a particular kind of rollover test maneuver. Overall results from this study provide a baseline for evaluating the safety benefits of equipping an ATV with an OPD during J-turn-steering rollover incidents (Heydinger et al., 2019).

Evaluating Aftermarket (AM) OPDs

This study concentrated on testing AM OPDs to protect operators in ATV rollover incidents, because it is necessary to ensure whether employing AM OPDs on ATVs is practical and effective or not. So, the research tests were conducted in two steps. The ATV sled rollover was tested using the verified physical rollover simulator (described in the previous research) with an ATD and equipped with AM OPDs (Heydinger et al., 2020).

The first step involved conducting autonomous ATV dynamic rollovers on a groomed soil surface, and the second stage was to test the ATV sled rollover using the verified rollover simulator. In both conditions, the ATVs were equipped with AM OPDs and an ATD acting as a surrogate rider. The same ATVs, speeds, and amounts of steering input rate (40 deg/s) were used as in the previous research to conduct minimum energy rollovers and

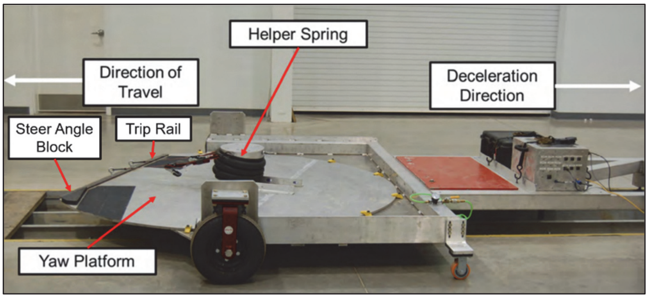


Figure 8. ATV Rollover Sled Components (Heydinger et al., 2019).

moderate energy rollovers. However, this study did not consider moderate energy rollovers with a trip feature (Heydinger et al., 2020).

One of the results was that in some cases of dynamic and sled rollover incidents, the vehicles outfitted with AM OPDs rolled more than the vehicles with no OPDs. The reason was that the outside edges of the OPD hit the ground and changed the normal dynamic behavior of the ATV. A major part of the ATD, consisting of the pelvis, abdomen, thorax, and head, usually remained in the position between the seat and the rear axle during the dynamic and sled rollover events. When the ATD became detached from the vehicle and the vehicle rolled onto, and occasionally over, the ATD practically remained laterally parallel with the ATV. Moreover, roll rate and roll angle results also vary depending on how the vehicle's side and/or the OPD structure interact with the test surface during the rollover sequence (Heydinger et al., 2020).

Significant interaction was defined as an indicator of the presence of a substantial portion of the ATV at any point (regardless of duration) during the rollover event that is subjectively estimated to be a load of 50% or more of the total weight of the ATV supported by the pelvis, abdomen, thorax, or head. By this criterion, the AM OPDs were more effective in minimizing the interactions between the ATV and ATD during minimum energy rollover than moderate energy rollover. Thus, in the next research, only moderate energy severity rollovers were conducted during the subsequent Proof-of-Concept (POC) OPD study (Heydinger et al., 2020).

Testing Rollover of ATVs Outfitted with POC OPDs

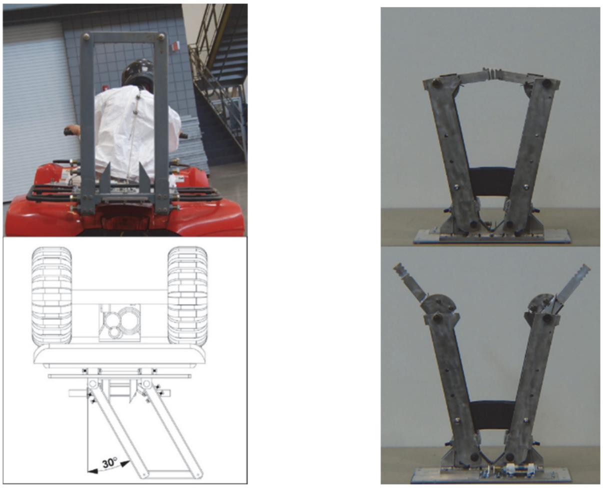
The aim of the POC OPD designs was to minimize interactions between the ATV and ATD in tests using a moderate energy sled. In creating the final design of POC OPDs, a few factors were considered, such as (a) providing survival space for the ATD when the ATV is in an upside-down orientation, (b) preventing the ATV from rolling to 180 degrees or far enough past 180 degrees to end with a final roll angle of 270 degrees or more, and (c) providing clearance between the driver and ATV/OPD in the event of overturn with a final rollover angle of 270 degrees or more (Heydinger et al., 2022).

This study considered two distinct OPD styles: energy-absorbing OPDs and extended-span OPDs. In the first category, two types were used: a simple energy-absorbing OPD and an energy-absorbing OPD with an extra energy-deflection feature (fig. 9). In the second category, three extended-span OPDs, including OPDs with fixed geometry, telescoping extensions, and scissors extensions (with and without feet), were used (fig. 10) (Heydinger et al., 2022).

The results of sled test simulations of moderate energy lateral rollovers of ATVs outfitted with POC OPDs showed that the amount of energy absorbed by POC OPDs was as well as or better than the AM OPDs. The energy-absorbing POC OPDs did absorb some of the ATV rolling energy, but in three out of four tests conducted using energy-absorbing OPDs, the ATV rolled over to nearly 270 degrees of final roll angle. Furthermore, the extended-span POC OPDs performed better than the AM OPDs and the energy-absorbing OPDs. All tests conducted using the extended span OPDs resulted in final ATV roll angles of less than 180 degrees (Heydinger et al., 2022).

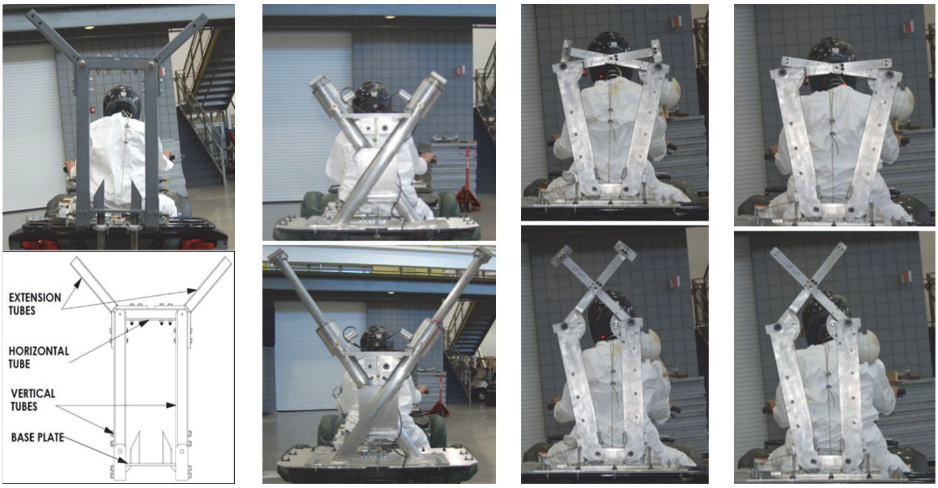
Outcome

In conclusion, these studies provided an advancement in understanding and addressing the challenges that an ATV operator is faced with. By conducting cutting-edge testing methodologies and multiple designed structures, the process of development of the next



(a) (b)

Figure 9. Energy-absorbing OPDs: (a) simple energy-absorbing OPD (b) energy-absorbing OPD with an extra energy-deflection feature (Heydinger et al., 2022).



(a) (b) (c) (d)

Figure 10. Extended-span OPDs: (a) with fixed geometry, (b) telescoping extensions, (c) scissors extensions with feet, and (d) scissors extensions without feet (Heydinger et al., 2022).

generation of OPDs, which are more focused on enhancing operator safety and decreasing the impact of rollover incidents in the ATV industry, has started.

Conclusion

This manuscript presents perspectives from ATV safety experts in several countries, including Australia, Canada, Israel, Sweden, and the USA. The topics include the state of the art in youth riders, engineering control methods, stability, protective structures, safety rating systems, training and education, personal protection equipment, and new regulations. We have summarized below the common topics/trends we identified while reviewing the experts' summaries.

Elimination and Substitution

It is recommended to eliminate ATVs, whenever feasible, and replace them with SSVs, as ATVs are less stable and more prone to rollovers compared to SSVs, which offer better protection (Hicks et al., 2018a).

Engineering Control

There are ongoing studies worldwide to evaluate the effectiveness of CPD in protecting operators in ATV rollover incidents on farms. In Sweden, a study evaluates the practical use of CPDs among 50 ATV users in the farming and forestry sectors. Ongoing research in the USA evaluates the effectiveness of CPD on agricultural ATV rollover incidents (Chou et al., 2022). Results of several studies showed that OPDs like Quadbar and Lifeguard are effective in reducing serious injuries (Heydinger et al., 2022; Rechnitzer et al., 2013). Heydinger et al. (2022) developed several designs of OPDs that have better performance in protecting the operator compared to commercially available OPDs. There is a lack of knowledge about CPD in the USA. As findings revealed that less than 20% knew about key safety features like wide frames and OPDs (Agricultural Youth Work Guidelines (AYWG), 2020).

Administrative Control

The Australian Federal Government introduced safety laws in 2020, mandating OPDs and stability tests for all quad bikes sold by law (Australian Government, 2021).

The Swedish Transport Administration (Lundqvist et al., 2022; Trafikverket, 2020) took the initiative to develop a "Joint Strategy" and also agreed on the following recommendations: (a) increase the use of helmets, (b) increase the use of CPDs and other technical solutions, (c) increase the use of alco-locks when it is practically possible, (d) less use of ATVs on public roads, (e) less use of ATVs among children, and (f) improve information and increase training and education of risk awareness and safe driving (Lundqvist et al., 2022; Trafikverket, 2020).

Despite exceeding speed limits for children's vehicles, some ATVs (including electric ones) in Israel are classified as toys (Soroker, 2020). A policy proposed by the Israeli police involves impounding and destroying electric ATVs and prosecuting unlicensed riders (Sade, 2021a,b). The National Road Safety Authority proposed adopting an OECD standard to address legal ambiguities around categorizing the size of ATVs, though it has not yet been implemented (Soroker, 2020).

Training and PPE

There are increasing efforts to raise awareness about ATV safety and the use of safety features, such as helmets, wide frames, and crush protection systems (CPDs). Training courses offered through the US ATV Safety Institute (ASI, 2024) and the national peer-reviewed project book on 4-H ATV Safety (Henwood et al., 2011) provide experiential training to increase youth knowledge and maneuvering aptitude. However, the current situation of using PPEs and knowledge about ATV safety behaviors is very low. As an example, only 2% of Iowa FFA members had completed an organized safety training course, either online or with hands-on training (Jennissen et al., 2022b), which explains the high percentage (35%) of Iowa FFA members experiencing a crash (Jennissen et al., 2022a, b).

Youth and ATV Safety

According to the three interconnected studies focusing on youth ATV safety within the agricultural context, critical safety concerns based on significant disparities between the physical capabilities of youth and the operational demands of agricultural ATVs were highlighted. Mismatching between the required forces to operate ATV controls and the strength of youth, inconsistencies between ATV operational requirements and youth's anthropometric dimensions, and the limitation in youth operators' field of vision while operating ATVs were investigated. A crucial need for updating ATV safety guidelines was concluded, including the physical limitations of youth operators in turning the handlebar and pressing the footbrake and the ability to meet fit criteria and detect obstacles or bystanders (Araujo et al., 2022, 2024).

Acknowledgments

Researchers would like to acknowledge the Central States Center for Agricultural Health and Safety, NIOSH/CDC (Grant Number 5 U54 0H007548), and the Western Center for Agricultural Health and Safety and NIOSH/CDC (Grant Number U54OH007550).

The TARS research unit, located in the School of Aviation at UNSW, carried out the Australian projects mentioned in this summary article. It should be noted that Dr. Hicks was a PhD student and employed entirely by TARS at UNSW, at the time of his working on this project and that TfNSW was not involved in this project. The authors would like to gratefully acknowledge Safework NSW (previously WorkCover Authority of NSW), in particular Mr. Tony Williams and Ms. Diane Vaughan, for funding the majority of the experimental research and the associated analysis and research work, as well as funding the QBWPSS research work. The Australian Consumer and Competition Commission (ACCC) also contributed funds for some of the QBPP test programs. The authors are also grateful to the staff, in particular, Mr. Ross Dal Nevo and Mr. Drew Sherry at the Roads and Maritime Services Crashlab crash test facility for their assistance with testing. The authors would also like to gratefully thank all members of the Project Reference Group and other individuals who are named in the reports referenced above.

Also noted is the passing away on 21 November 2023, Adjunct Associate Professor George Rechnitzer (Ph.D.), project manager of the Australian QBPP, who made a significant contribution to the knowledge and advancement of quad bike and SSV safety both in Australia and internationally.

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