Identifying Postural Control and Thresholds of Instability Utilizing a Motion–Based ATV Simulator

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SAFETY RESEARCH USING SIMULATION

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Abstract

Our ATV simulator is currently the only one in existence that allows studies of human subjects engaged in “active riding,” a process that is necessary for ATV operators to perform in order to maintain vehicle control, in a virtual reality environment. Our previous ATV simulator version had a number of limitations, and a major goal of this project was to add functionality to the simulator. We wanted the additional capability to measure other important aspects of operator-vehicle dynamics along with the operator’s movement in relationship to the vehicle as determined by motion capture, and to have the subject operate the vehicle in a virtual reality environment that would be perceived as authentic. This was accomplished with the addition of various force sensors on the simulator, creating an improved vehicle-platform configuration, developing an integrated visual component, updating the computer software of the platform to allow vehicle movement that would match that of the terrain in real time, and integrating these new components so that the rider’s operation of the simulator in the virtual environment was realistic. With this improved ATV simulator, we conducted proof-of-principle studies to test the simulator’s ability to measure operator-vehicle dynamics. Six subjects who were experienced ATV riders participated in our study, and the data obtained is being evaluated. By identifying operator postural control and the forces generated at operator-vehicle contact points, we will be able to determine the thresholds of instability and loss of vehicle control. In this study, we also determined the tolerability of the subjects’ use of Oculus Rift virtual reality goggles as compared to a large screen in providing the simulator’s visual input. Although subjects did not report severe symptoms with the use of the virtual reality goggles, they did not tolerate the use of the Oculus Rift as well as using the screen and particularly reported problems with nausea and eyestrain. Future studies will allow us to investigate a number of known risk factors for ATV-related injuries and how they impact ATV riding. Such investigations should shed light on how these factors increase the risk of loss of ATV control, vehicle rollover, and/or ejection from the machine.

1 Introduction

1.1 The High Toll of ATV-Related Deaths and Injuries

ATV-related deaths and injuries have been an increasing public health problem over the past four decades, and there remains a disturbing lack of safety culture around these vehicles.[1-4] In 2013, the Consumer Product Safety Commission estimated that ATV crashes resulted in approximately 650 deaths and 100,000 emergency department (ED) visits in the United States (U.S.) alone.[5] The total annual U.S. cost of these crashes is estimated to be over $4.3 billion.[6,7]

A number of risk factors for ATV crashes and injuries have been identified, among them being male, being under 16 years of age, riding an inappropriately sized vehicle for the age and maturity of the operator, not using a helmet, riding with multiple people on single-person machines, and riding on the road.[8-12] Additionally, survey studies suggest that engaging in high-risk activities, like carrying passengers and riding on the road, is relatively common.[13-19]

1.2 ATV Riders Are Vulnerable Roadway Users

Despite most riding taking place off the road, over half of all ATV-related deaths have resulted from roadway crashes.[20] Moreover, from 1998-2006, roadway deaths increased at more than twice the rate of off-road deaths. Non-fatal roadway crashes were associated with increased risk and severity of injury as compared to those off the road.[21] Although rollovers are the predominant mechanism of injury both on and off the road, studies suggest that ATVs also represent a traffic hazard to other vehicles.[20,21] Most worrisome is the growing trend by states and counties to legalize recreational riding of ATVs on public roads.[22,23] As part of a rapidly emerging public awareness, the Insurance Institute for Highway Safety released a report emphasizing the public health issues surrounding fatal ATV crashes on the road.[24] Similarly, ATV riders were recently defined as vulnerable road users in a report presented at the 2013 Governor's Highway Safety Association Annual Meeting.[25]

1.3 Simulation: A Novel Approach in ATV Injury Research and Prevention

ATVs require "active riding," which means operators must rapidly assess changes in vehicle stability and adjust body position in order to maintain vehicle control as they negotiate various terrains and obstacles. Ethical issues related to the instability of the vehicle essentially prohibit controlled research studies of ATV riding. Most rollovers occur from loss of control due to unexpected motions. Simulation can safely replicate changes in vehicle center of mass, and the operator's biomechanical responses to these changes can be measured.

We previously developed the only ATV simulator in existence that allows for the study of human subjects engaged in "active riding." The earlier simulator had an ATV mounted to a six-degree-of-freedom man-rated Moog ECU-624-1800 electric motion system. Computer ride files for the system were computer generated, and motion capture technology collected subject and vehicle movements.

1.4 Preliminary Studies

Pilot studies using our previous simulator have been published.[26] Computer-generated ride-file programs were developed that were composed of vibration files generated in the field and included sudden, acute platform movements for pitch (upward/downward angle changes) and roll (side-to-side angle changes) that simulated acute unexpected terrain changes. Motion capture was used to collect subject and vehicle movements. Accelerometers and gyroscopes were used to measure acceleration and angular velocity at different locations on the rider's body, as well as the vehicle. Measures of rider-vehicle dynamics were analyzed using 3D modeling software (see Figure 1.1).

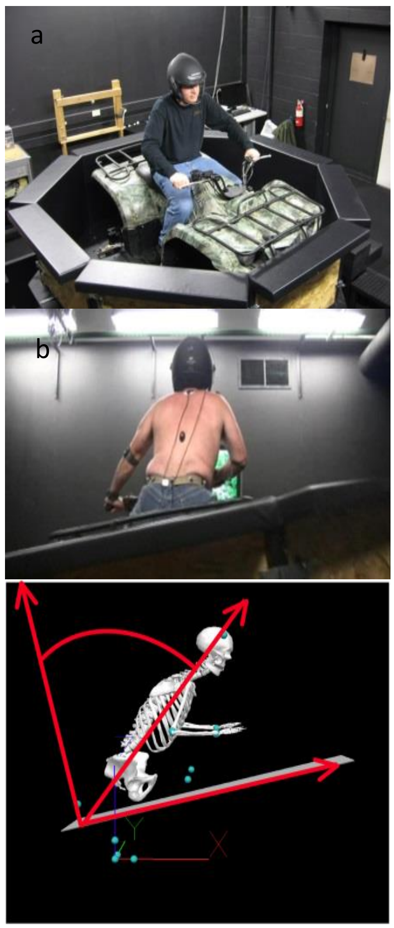

Figure 1.1 – Previous simulator: (a) original simulator used in pilot studies showing rider and safety features; (b) rider with motion-capture sensors and accelerometer instrumentation; (c) displayed model from data imported into 3D analysis software.

Five adult males with >200 hours of ATV riding experience were studied. Each pitch-and-roll ride-file program had three repetitions of the respective movement, and values for the three repetitions were averaged. Subjects were run through two identical pitch and two identical roll programs, and results for the two runs were compared. We found that subject movements to maintain their center of gravity followed the rapid movement of the simulator fairly closely. More torso movement variability between subjects was seen with sudden roll movements (to the side) than was noted with upward/downward pitch. A comparison between operator angle change and time to maximum operator angle for the two identical runs showed a common pattern for all subjects. Namely, compared to sudden pitch movements in the first run, all subjects shifted their torsos to a greater degree and later during the second run. The opposite was true for roll movements. All subjects shifted to a lesser degree and sooner with rapid roll movements during the second run, as compared to the first. The maximum acceleration at the seventh cervical vertebrae (C7) during left and right roll movements was 1.32 and 1.61 m/sec^2, respectively.

This study provided proof of principle for the use of ATV simulation with motion-capture technology to study active riding. Data also demonstrated that there were common patterns of responses among experienced adult ATV operators to which the active riding of other groups could be compared.

1.5 <u>Limitations of Previous ATV Simulator</u>

Although study subjects affirmed that riding the simulator favorably reflected ATV riding, our previous simulator had a number of limitations. The reasons for the observed differences in subject response to acute changes in pitch and roll between the first and second rides remained unclear in our pilot study. We hypothesized that subjects may have compensated for less-than-optimal body positioning in the first ride by having a tighter grip on the handlebars and/or by gripping the side of the ATV seat with the inner aspects of their legs. However, finances did not allow for the purchase of pressure sensors for placement over key areas of operator contact with the ATV, such as the handle grips, seats, and footrests. Sensors to measure forces were one of the critical improvements needed in our simulator and would allow us to determine whether our hypothesis is true, i.e., the degree of shifting is inversely related to compensating forces, such as grip.

Also, a movie of an ATV traveling through a wooded area from the operator's perspective was shown on a wall-mounted, large-screen television and served as a visual focus for the subject during testing in our previous simulator. The movie didn't provide visual cues of potential acute simulated terrain changes, which did allow us to observe operator responses to unexpected ATV movement. However, sophisticated graphics simulating a riding environment with matching simulator movements would offer a much more realistic simulator experience.

The software of the motion platform was another limitation, as acute severe angle movements could not be added to the ride files without a subsequent oscillation of movement in both directions that significantly affected the reality of the simulation.

2 Aims and Purpose of Project

1.6 Make Significant Advancements in ATV Simulator Design and Function

A major aim of this project was to improve the features of our ATV simulator so that it could provide a much more realistic ride and to measure other important features of operator-vehicle dynamics with the simulator, particularly the forces and pressure exerted by the rider at the handle grips, seat, fuel tank, and footrests.

1.7 Assess the Improved Simulator's Ability to Measure Operator-Vehicle Dynamics

With our improved ATV simulator, we wanted to demonstrate how we could effectively determine operator-vehicle dynamics and identify operator postural control and the thresholds of instability.

1.8 Determine the Tolerability of Virtual Reality Goggles Versus a Wall-Mounted Screen

We wanted to determine what side effects, if any, subjects experienced with visual input delivered by Oculus Rift visual reality goggles versus the use of a large screen during ATV simulator operation.

3 Advancements in the ATV Simulator Design and Function

One of the major project accomplishments was the marked improvement achieved in the functionality of our ATV simulator. We were able to address a number of the limitations encountered with the previous ATV simulator version. The present design provides a much more realistic ride and is able to measure other important operator-vehicle dynamics not possible with the previous simulator, particularly the forces and pressure exerted by the rider at various points on the vehicle. With the funding provided by SAFER-SIM, we were able to create a significantly more versatile and sophisticated simulator. The following describes some of the additional features of our present ATV simulator.

1.9 Vehicle Instrumentation

A used Yamaha Bruin 4x4 ATV was purchased as well as a variety of pressure sensors to measure the forces generated by the simulator's operator during a ride, including those required to maintain ATV stability. These pressure sensors were added to the handle grips, seat, fuel tank, and footrests. The sensors were further tested to verify their ability to successfully measure the counter forces exerted by the operator in response to acute changes in the vehicle's position as related to the simulated terrain being traveled.

1.10 Vehicle-Platform Configuration

Our original simulator consisted of an ATV whose tires and engine had been removed, and then an iron frame was built by which the vehicle was secured to the MOOG platform. Our new simulator includes an intact ATV with the tires in place. A unique tire pivot was designed and fabricated and attached to the MOOG platform. The vehicle's tires fit into the pivot system and allow the ATV simulator operator to affect a more natural movement of the vehicle's wheels with realistic resistance/friction when turning the handlebars. In addition, the ATV's connection to the MOOG platform prevents overturning and sliding of the vehicle, but still allows one or more tires to lose contact with the platform surface as might occur during a loss-of-control event such as a potential rollover during a simulated ride.

1.11 Visual Component

The previous simulator had a visual element that had no relationship to the movement of the vehicle and allowed observation of operator responses to unexpected ATV movement but not to a real environment. In the present version of our ATV simulator, we wanted to provide simulator operators a more immersive experience during which they might appreciate a more realistic sense of motion visually and perceive the vibrations and the effect of the terrain they were traversing in virtual reality. This was achieved by creating a virtual test course for the simulator using a purchased software package called Unreal Engine 4.9 (UE4).

1.12 Component Integration

As stated earlier, the software of the motion platform for our previous ATV simulator did not allow a significant abrupt angle change in the platform to occur without a subsequent oscillation in movement of the platform back and forth until it returned to baseline. One of the big accomplishments of the present project was to purchase, install and test software for the MOOG FCS 1800-660 simulation table that allowed the platform to accurately and realistically reflect the changes occurring in the virtual terrain in real time. In addition, integration and fine tuning of the ATV's throttle, brakes and turning mechanism were performed with relationship to the new Moog platform software and the ATV test course developed with the Unreal Engine software. This allowed for vehicle movement within the virtual environment that appeared and felt more true-to-life and matched the operation of the ATV by the subject. We constructed a screen to project the simulator's environment and also purchased Oculus Rift Virtual Reality headsets to compare the subjects' responses to each (see Figure 3.1). The Oculus Rift was tested and integrated as part of the simulator.

Figure 3.1 – Simulator rider placing on his Oculus Rift with his harness attached.

4 Demonstrating the Simulator's Ability to Determine Operator-Vehicle Dynamics

One of the project's aims was to demonstrate proof of principle that our improved ATV simulator could effectively determine operator-vehicle dynamics and identify operator postural control. Data collection is complete, and analysis is underway.

1.13 Methods

The simulator as described in Section 3 was utilized to study operator-vehicle dynamics of six subjects who were experienced ATV riders. Motion-capture technology, accelerometers, and pressure sensors were utilized to quantify "active riding" parameters.

4.1.1 Subjects

Study inclusion criteria required adult males, 18-45 years of age, who were experienced ATV operators, which was defined as having at least 100 hours of ATV driving experience. Although not an absolute exclusion, subjects recruited were to be between 5'6" and 6'2", and to weigh between 160 and 220 pounds. Exclusion criteria included being a non-English speaker, having a previous diagnosis of adult Attention Deficit Disorder (ADD)/Attention Deficit Hyperactivity Disorder (ADHD), or a having a positive screen for adult ADD/ADHD defined as four or more positive responses to questions in Part A of the Adult ADHD Self-Report Scale v1.1.[28] None of the recruited subjects were excluded based on exclusion criteria. The study was approved by the University of Iowa Institutional Review Board, and informed written consent was obtained from all subjects.

1.14 Simulator Session

Subjects were asked to refrain from alcohol, over-the-counter medications affecting alertness, and recreational drug use for the 24 hours prior to the study. Upon arrival, the subject was administered a written questionnaire, and anthropometric measurements were obtained.

Subjects wore an approved helmet, long pants, and closed shoes. The subjects wore a harness vest system that was attached to a safety line securely connected to a structure near the ceiling (see Figure 4.1). Investigators closely monitored subjects in order to stop platform movements if any problems arose during the ride. In addition, subjects were instructed to depress the emergency button that was located between the handlebars to stop simulator movement, if they felt unsafe or had any problems during the session.

Figure 4.1 – ATV simulator. Note: This research assistant had his photo taken on the simulator without the helmet used by subjects during the study.

Passive reflective markers were attached to the participant over bony landmarks such as the wrist, elbow, collarbone, pelvis, and spine. Those on the head were attached to the subject's helmet. Four markers were attached to the vehicle. Accelerometers or inertial sensors were placed on the helmet, over the spinal process of the seventh cervical vertebrae (C7) at the base of the neck, on the ATV, and on the simulator platform.

Subjects were provided an orientation on how the simulator works and were given safety instructions. A programmed practice trail ride was done by subjects to familiarize them with the simulator. Once comfortable, the subjects performed an experimental programmed ride, first utilizing a large screen on which the visual of the simulated ride was projected and then by wearing a Oculus Rift virtual reality headset. The experimental trail ride included platform movements creating inclines up to 25 degrees (uphill, downhill, and side hill), curves and 90 degree intersections on the trail, and obstacles such as a tree branch on the trail. The platform utilized vibration ride files collected from the virtual field to simulate speed and acceleration. Subjects were asked to react to simulator movements as they would if they were operating an actual ATV.

A Vicon Motion Capture System composed of 12 infrared cameras with a resolution of 0.3 megapixels per frame each and the passive reflective markers were used to track subject and vehicle movements during the rides. Data were collected at the camera's peak capture rate of 200 Hz to optimally capture the high-frequency components of the motion signals, which were then low-pass filtered at 16 Hz. This cut-off frequency was based on power spectrum analyses of tri-axial accelerometers attached to the simulator, helmet, and over the seventh cervical vertebra.

4.1.2 Data Analysis

The Cartesian locations of the markers on the subject and the simulator were exported to and are being analyzed with NIH-approved Visual 3D™ software. A line running through the C7 reflective marker and the midpoint between the pelvic markers is being used to determine changes over time in the angle of the subject's torso during upward pitch (Figure 4.2(a)), downward pitch (Figure 4.2(b)), and roll (Figure 4.2(c)). The subjects' maximal torso shifting (in degrees) for each type of simulator movement is being determined. Additionally, the mean time for each subject to reach their maximum torso shift relative to the time the simulator platform reached its maximum angle will be calculated for each incline change during the ride. The forces generated at the handle grips, seat, fuel tank, and footrests will also be determined and compared to the degree of subject shifting and simulator angle change over time during upward pitch, downward pitch and roll.

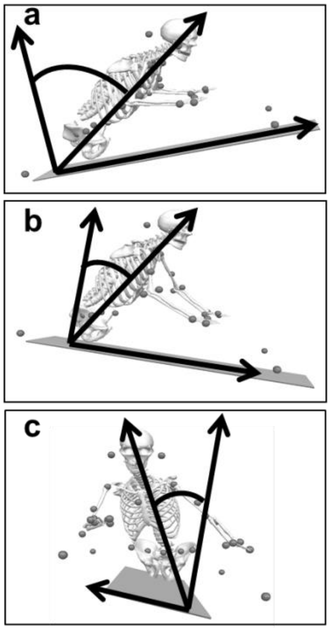

Figure 4.2 – Torso shift: computer representations of a subject's torso shift in response to changes in vehicle angle are shown for (a) upward pitch, (b) downward pitch, and (c) roll.

There are three additional calculations being performed that will help determine thresholds for loss of vehicle control, i.e., conditions that could result in a crash. These include the following.

Calculation 1: The reflective-marker-based position data of the rider will be used to compute the rider's center of mass. The balancing moment (Mb) of the rider will be calculated using the rider's center of mass, weight, inertial forces, and reaction forces at the hands, feet, and buttocks. Inertial forces on the rider's body will be determined using measurements from the accelerometers. Similar calculations using motion capture and the accelerometers on the ATV will be performed to determine the center of mass and inertial forces on the vehicle. These will be used to calculate the rolling moment (Mr), i.e., the work required to turn the ATV. The relative operator-ATV stability is the difference between the two (Mb – Mr). A larger difference predicts a higher risk of instability.

Calculation 2: Acceleration data for the rider's head, lumbar region, hands, and feet will also be determined, as it relates to the input motion from the ATV, i.e., vibration, using the concept of transmissibility. Transmissibility is a biodynamic measure that represents the complex ratio between the input acceleration to the system and the output acceleration measured at specified locations on the rider's body. These calculations will indicate how much vibration is transmitted through the rider's body. More severe vibration would be predicted to reduce operator-vehicle stability and increase risk of a crash.

Calculation 3: The combined effect of vehicle velocity and forces at the hands, feet, and seat-buttock locations using motion capture and pressure/force monitors will be determined. These calculations result in a biodynamic measure called the impedance, a measure of the complex ratio between the applied forces divided by the velocity at the point of application of the forces. Decreased impedance would be associated with a higher risk of losing vehicle control.

1.15 Preliminary Results

Six healthy subjects with a mean age of 24.5 years, ranging from 19 to 37 years of age, were recruited. The mean height was 69.4 inches (176.2 cm), and the mean weight was 178.8 lbs. (81.1 kg). The subjects started riding ATVs at an average age of 9 years, and the subjects' families all owned an ATV when they were growing up. None of the subjects owned an ATV at the time of the study. The subjects' average number of hours estimated riding an ATV over their lifetime was 620 hours (range 100-2500) and over the past five years was 137 hours (range 10-250 hours).

The master's degree student involved in the project is currently performing data analysis and calculations as described above. Preliminary data demonstrates that we can quantify "active riding" parameters using our present simulator. The pressure sensor data will be valuable as it will provide a more complete picture of operator-vehicle dynamics, and it will be useful for determining the point at which the generated forces might overcome compensatory mechanisms, thus leading to rider loss of control.

5 Tolerability of Virtual Reality Goggles Versus a Wall-Mounted Screen

Some individuals who have utilized virtual reality goggles have experienced symptoms that have been called virtual reality sickness or sometimes simulator sickness. A variety of things may contribute to these symptoms in the virtual reality environment, but one of the primary causes is the visual and vestibular mismatch that users may experience. The vestibular system involves sensory organs in the inner ear that helps maintain balance and spatial orientation. We measured the symptoms subjects experienced with the Oculus Rift virtual reality goggles vs. those seen when a large screen was utilized to display the projected images.

1.16 Methods

Subjects completed an Initial Wellness Survey prior to the simulated experimental programmed rides described in Section 4 of this report. In the survey, participants were asked to rank eighteen symptoms by four different levels of severity including None, Slight, Moderate and Severe. The eighteen symptoms were: general discomfort, fatigue, headache, eye strain, difficulty focusing, salivation increased, sweating, nausea, difficulty concentrating, fullness of the head (an awareness of pressure in the head), blurred vision, dizziness with eyes open, dizziness with eyes closed, vertigo (a loss of orientation with respect to vertical upright), stomach awareness (feeling of discomfort with is just short of nausea), burping, vomiting and other.

The subjects then performed the experimental ride while watching the visual images projected on a large screen. Once the ride was done, the subject completed a Post-Screen Wellness Survey. The participants then repeated the experimental ride while wearing Oculus Rift goggles. Following this ride, the subjects completed a post–Oculus Rift wellness survey. The wellness surveys were completed immediately after the experimental rides, and no longer-term assessment of Wellness Survey symptoms was conducted.

The wellness surveys were scored for each subject, with each symptom receiving a number as follows: 0 for none, 1 for slight, 2 for moderate, and 3 for severe. The totals of subjects' scores were added for all initial surveys, post-screen surveys and post–Oculus Rift surveys. Symptoms most commonly experienced by subjects were noted.

1.17 Results

Five subjects completed all three wellness surveys. One subject failed to complete the post–Oculus Rift survey and was excluded from data analysis. The total scores of the five Initial wellness surveys was 1, with one individual reporting "slight sweating." The total score of the post-screen wellness surveys was 7. Most of these were attributed to "sweating." Several subjects noted to the researchers that they felt the room containing the ATV simulator was warm. The total score of the post–Oculus Rift wellness surveys was 27. This was significantly greater than the total score post-screen. The symptoms with the greatest increase after use of the Oculus Rift goggles as compared to the subject's symptoms post-screen were as follows: nausea (5), eye strain (4), difficulty focusing (3), dizziness with eyes open (2), and general discomfort (2). Despite this, all the symptoms were rated as "slight" except for "moderate nausea" in one subject. "Sweating" was ranked as "moderate" by one subject as well, but that was true for both post-screen and post–Oculus Rift. Thus, there were some symptoms experienced by subjects that appear to be consistent with mild virtual reality sickness with use of the Oculus Rift, and subjects tolerated the simulated rides better with use of the screen for visual input.

6 Conclusions and Future Directions

Our simulator provides a unique and powerful methodology to investigate the dynamic response of ATV operators to acute changes in vehicle angle and acceleration. Improvements completed with support from the SAFER-SIM grant have made our simulator a much more realistic ATV riding experience and markedly improved our ability to measure "active riding" parameters. The simulator is now able to determine the movement of riders as well as the forces generated by riders at key points on the vehicle, i.e., handle grips, footrests, and seat. With these data, we will be able to identify thresholds of instability that could lead to loss of vehicle control and an ATV crash.

Known risk factors for ATV-related crashes and injuries include alcohol use, younger age, inexperience, age-inappropriate vehicle size, and carrying passengers.[8, 31-33] It is not clear how these risk factors impact "active riding" and increase the risk of vehicle rollover and/or of falling from or being ejected from the ATV. There are no published human-subject studies that have evaluated these contributing factors. Our simulator provides a unique opportunity to investigate these risk factors and to determine how and when they might increase the likelihood of losing ATV control and subsequent injury in a virtual reality environment.

In addition, our simulator will allow us to explore decision-making while operating an ATV. With a terrain that is always changing and the potential for obstacles to present at any time, assessment and reassessment needs to be done continuously by ATV operators. One scenario that we plan to study is operator decision-making with regard to where, when, and how they cross public roads when on an ATV. Our simulator will allow us to assess the effectiveness of ATV operators in making those type of decisions and what factors might affect that process, such as age, inexperience, the presence of passengers, medications, alcohol, and recreational drugs.

We have observed common patterns of dynamic responses among experienced, adult ATV operators when faced with changes in terrain (uphill, downhill, side hill). This suggests that active riding of other groups (e.g., inexperienced operators, children, drivers with passengers) could be compared to an experienced control group and that distinct differences may be found. In summary, future studies will allow us to investigate a number of known risk factors for ATV-related injuries and how they impact active riding. Such investigations should shed light on how these factors increase the risk of loss of ATV control, vehicle rollover, and/or ejection from the machine.

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Appendix A: University of Iowa Media Event

The Office of Strategic Communication at the University of Iowa hosted a media event at the Department of Engineering's Center for Computer-Aided Design in June 2016 to introduce the new ATV simulator. Improvements in the simulator were mostly funded through a SAFER-SIM grant. The media event led to a number of articles being published, and some of these articles were picked up by other online and print media. See Figure A.1 for photos from this event.

Figure A.1 – Media event introducing our new and improved ATV simulator. From left to right: Kyle Losik, Jake Michael, Dr. Salam Rahmatalla. Note: the research assistant on the simulator had his photo taken on the simulator without the helmet used by subjects during the study.

Some of resulting articles included:

- "ATV simulator drives research on accidents" in *Medicine Iowa: The Magazine of University of Iowa Health Care*
- "University of Iowa unveils ATV simulator" in the *Cedar Rapids Gazette*
- "UI unveils new ATV virtual reality simulator" in *Iowa Now*
- "How the Oculus Rift lets researchers simulate ATV crashes" at technobuffalo.com
- "Researchers unveil new ATV virtual reality simulator" at phys.org

- “Oculus Rift ATV Simulator is more than a crazy video game – it could actually save lives” at digitaltrends.com

Appendix B: "Legislators in the Lab" Event

The University of Iowa Office of the Vice President for Research and Economic Development included the new ATV Simulator as part of the agenda for the "Legislators in the Lab" event held November 10, 2016. The recent improvements in the simulator were largely funded by a SAFER-SIM grant. During this annual event, Iowa legislators have the opportunity to see some of the innovations and research that is occurring at the University of Iowa. The legislators heard about ATV-related crash and injuries in Iowa and across the country, and the variety of research and injury prevention efforts being performed at and by the University of Iowa regarding this area. The development of the simulator was discussed, and the simulator was demonstrated to attendees. See Figures B.1 and B.2.

Figure B. 1 – "Legislators in the Lab" ATV safety discussion. From left to right, team members Dr. Jonathan DeShaw in the blue shirt, Dr. Charles Jennissen in the tie, student researcher Ulysses Grant in the plaid shirt, and Dr. Salam Rahmatalla in profile, talk to the legislators.

Figure B.2 – "Legislators in the Lab" simulator demonstration. Team member Dr. Jonathan DeShaw, in blue shirt, describes the operation of the simulator prior to the demonstration.