Journal of Safety Research 94 (2025) 216–228

Contents lists available at ScienceDirect

Journal of Safety Research

journal homepage: www.elsevier.com/locate/jsr

Is it safe for children to ride youth-sized all-terrain vehicles?

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ARTICLE INFO

Keywords:
ATV
Children
Farm
Quadbike
Rollover
Strength
Youth-size

ABSTRACT

Introduction: All-terrain vehicles (ATVs) contribute significantly to fatalities and injuries among young individuals. This is despite the availability of youth-sized ATVs in the market, suggesting that these vehicles may not be as suitable for young riders as their name implies. This study aims to assess the suitability of youth-sized ATVs for their intended demographic. *Method:* Five youth-sized ATV models from the most common manufacturers across various age groups were evaluated for mismatches between vehicle riding requirements and the physical capabilities of youth. Our assessment included factors such as physical strength, anthropometric characteristics, field of vision capabilities, and which computer simulations were used for simulating youth and ATVs. *Results:* The results indicated that, while there were varying degrees of compliance among different ages, genders, and percentiles of youth, no single youth-sized ATV was suitable for safe operation by young riders in terms of physical, anthropometric, and visual capabilities. Notably, youth subjects struggled significantly in simulated rollover scenarios, with the majority of subjects being unable to free themselves from the most common rollover situations. *Conclusions and practical applications:* The current youth-sized ATVs are designed based on the rider's age and the ATV's engine size. These findings underscore significant design shortcomings in current youth-sized ATVs, emphasizing the need for user-centric designs that cater to diverse ages and genders to enhance safety and the overall experience for young ATV users, while also highlighting the necessity to evaluate the compatibility between specific individual youth and specific ATVs.

1. Background and introduction

All-terrain vehicles (ATVs) are a significant cause of fatalities and injuries among youth, particularly in the agricultural industry (Burgus et al., 2009). Around 103,100 youth were hospitalized and 3,000 died in ATV-related incidents between 2014 and 2017 (CPSC, 2018).

A significant portion of youth ATV incidents (more than 90%) involve adult-sized ATVs, which are typically designed for individuals aged 16 and older (Denning et al., 2014). Although youth-sized ATVs are designed and available for younger riders, there are serious concerns regarding their appropriateness and safety for youth. It is recommended that youths under the age of 16 not ride any size of ATV (American Academy of Pediatrics, 2018; IPCH, 2018; Jennissen et al., 2022). Several studies have shown a strong relationship between children's injuries in ATV-related incidents and their ages, anthropometric characteristics, and developmental abilities (Brison et al., 2006; Hard & Myers, 2006; Hendricks et al., 2005). This is likely because youth under 16 years of age do not have the physical abilities, cognitive maturity, and adequate judgment to safely operate those vehicles (American Academy of Pediatrics, 2018; Anson et al., 2009; Burd, 2009; Dolan et al., 1989; Mattei et al., 2011; Murphy & Harshman, 2014; Scott et al., 2011; Shults et al., 2005). The Consumer Product Safety Commission (CPSC) and the Specialty Vehicle Institute of America (SVIA) have established criteria to evaluate the fit between youth and ATVs (ANSI/SVIA, 2017; CPSC, 2006). These criteria primarily focus on the engine size (Table 1) and speed of the ATVs, yet there is growing concern that these parameters alone may not adequately ensure the safety of young riders (Araujo et al., 2022, 2023). It has been highly recommended that children under the age of six not operate ATVs (American Academy of Pediatrics, 2018; CPSC, 2006). Therefore, in this study, we will not evaluate youth under six.

Results of a comprehensive study showed that youth do not have the necessary strength and control to operate utility ATVs (adult-sized) safely (Araujo et al., 2022, 2023; Araujo et al., 2024). Bernard et al. (2010) conducted a study to evaluate the reachability of controls (five criteria) on only one model of youth ATV and one model of adult ATV. Results showed that youths aged 12–15 years fit the adult-sized ATV better than the youth model. Youths aged 6–11 years fit poorly on both

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https://doi.org/10.1016/j.jsr.2025.06.006
Received 14 June 2024; Received in revised form 2 March 2025; Accepted 4 June 2025
Available online 27 June 2025

Table 1
Age of the operator and the ATV engine size, as recommended by the CPSC (CPSC, 2006).

Age of Operator	ATV Engine Size
Under age 6	not recommended
Age 6–11	under 70 cc
Age 12–15	70–90 cc
16 years & older	over 90 cc

ATVs. This study was limited and did not account for other critical factors such as strength and field of vision (Bernard et al., 2010). Therefore, a more comprehensive evaluation of youth-sized ATVs is needed. This evaluation should consider multiple factors, including the strength required to control the vehicle, the rider's reach to controls, and the operator's field of vision. Such an assessment is needed to determine whether youth ATVs are safe for their intended users. This study answers these five questions:

1. Can youth effectively activate the controls on ATVs? (Strength evaluation)
2. Are youth strong enough to push an ATV off their body in case of a rollover? (Strength evaluation)
3. Can youth effectively reach the controls on ATVs? (Anthropometry evaluation)
4. Is the field of vision for youth more limited than that of adults when operating ATVs? (Field of vision evaluation)
5. Can youth safely operate youth-sized ATVs, which are categorized based on CPSC recommendations (Comprehensive evaluation)?

The long-term goal of this study is to decrease the number of fatalities and injuries in youth-size ATV-related incidents. It has been hypothesized that many ATV-related injuries occur because children ride ATVs that exceed their physical capabilities. Four specific aims were followed to answer the research questions and evaluate the mismatch between requirements for riding ATV and youth physical capabilities.

Specific Aim 1: Assess whether the required forces to activate controls of youth-sized ATVs are appropriate for the strength levels of different age groups. (Strength evaluation).

Specific Aim 2: Verify if the body measurements (anthropometry) of youth across age groups match ATV safety standards set by safety organizations. (Anthropometry evaluation).

Specific Aim 3: Evaluate the field of vision for youth operating ATVs and compare it to adult visibility, identifying any age-related risks. (Field of vision evaluation).

Specific Aim 4: Conduct a comprehensive assessment to determine whether engine size is an appropriate criterion for categorizing ATVs based on youth age.

The results of this study can also enhance safety measures, improve ATV design, and inform policies to better protect young ATV users.

2. Methods

To achieve the three specific aims of this project (strength, anthropometry, and field of vision evaluation), we assessed the fit of five youth-sized ATVs for two genders (male and female) aged 8–16. To capture the inherent variation among youth subjects, we considered three height percentiles (5th, 50th, and 95th), ranging from the smallest to the largest potential subject.

The scope of this project is outlined in Fig. 1. The study focused on three main areas: physical strength, anthropometric dimensions, and field of vision.

2.1. Physical strength

The required physical strength for a safe ATV ride includes the strength to activate the ATV's different controls and, in case of a rollover, push the ATV off the operator's body. Forces are required to activate various ATV controls, including pushing the foot brake, turning the handlebar, operating the ignition switch, using the throttle lever, and shifting gears with the foot gearshift.

In our previous study (Araujo et al., 2023), we evaluated whether young riders are strong enough to operate utility (adult-sized) ATVs and to extricate themselves if trapped under an upside-down ATV. The findings showed that the main concern was the force required to push the ATV off the youth operator's body. This result shows the need to evaluate the capability of youth to push youth-sized ATVs off their bodies in rollover incidents.

ATV rollovers are the leading cause of fatalities and injuries among ATV riders. In Australia, approximately 85% of agricultural ATV-related incidents involve rollovers. In 60% of these cases, the operator dies from asphyxiation (McIntosh et al., 2016). Operators must have the strength to push the ATV off their bodies in the event of a rollover.

In this study, we evaluate the forces required to push the ATV off the entrapped operator under the ATV. The following sections detail the data collection procedures for the rollover scenarios and explain how the strength data from youth informed these scenarios.

2.1.1. Data collection for ATV controls

A handheld force gauge (model 475055, EXTECH Instruments, Waltham, MA, USA) was utilized to measure the activation forces for various ATV controls, including the foot brake, ignition switch, throttle lever, and foot gearshift. The gauge was applied directly to the control, ensuring that the force was exerted perpendicularly to the control surface (Fig. 2). To ensure accuracy, both continuous and peak force measurements were recorded for each control, with three replicates for each. This approach is consistent with the procedures used in two previous studies involving agricultural ATVs and tractors (Araujo et al.,

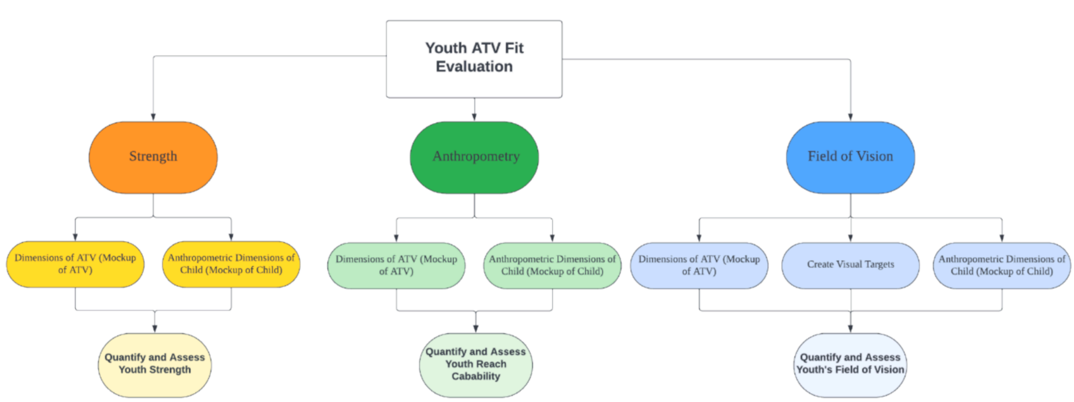


Fig. 1. The project scope – Three areas for rider-ATV fit assessment: physical strength, anthropometric dimensions, and field of vision assessment.

Fig. 2. A handheld force gauge is used to measure the forces that push the ignition switch on the ATV handlebar. The force gauge probe is held perpendicular to the bottom's surface.

2023; Fathallah et al., 2008).

The Extech Data Acquisition 407001A software was used for data collection. One research member collected all the data to ensure consistency in data collection. The force gauge was connected to a portable computer via an RS-232-to-USB serial link. Before data collection, the handheld force gauge was calibrated according to the manufacturer's guidelines to ensure reliable results.

2.1.2. Rollover scenarios

In a situation where the ATV is overturned, the net weight of the ATV was used to calculate the minimum force required to dislodge the overturned vehicle. Different post-rollover configurations are possible, necessitating the involvement of distinct limbs or muscle groups to push free of the ATV. In an effort to streamline the analysis and adopt a more conservative approach, we explored three distinct post-rollover scenarios.

Additionally, each scenario was analyzed as a static system. While we recognize that real life ATV operation may introduce dynamic factors that may decrease or increase the difficulty of a given scenario, the simplified analysis here allows for a baseline in evaluating youth capability to extricate themselves in each scenario.

First scenario: We model the ATV in an upside-down position with its center of gravity resting upon the rider's chest. In this configuration, the rider is able to utilize both hands for pushing the ATV off but is unable to use their legs. This particular configuration was regarded as the most challenging, constituting our worst-case scenario.

Second Scenario: We presumed the ATV's front rack/chassis to be situated on top of the rider's chest, enabling the use of both hands for pushing the AV off but still unable to use their legs.

Third scenario: The rider has the freedom to employ both hands and legs to displace the ATV, representing the best-case scenario. This third scenario served as a means to assess whether the initial worst-case scenario was overly conservative. As such, these three scenarios were formulated to account for the potential post-rollover configurations, with a visual summary provided in Fig. 3.

The methodology used to calculate the strength required for the rider to free themselves for each scenario was developed based on a previous study (Araujo et al., 2023). To summarize, for the first scenario, the rider's minimum corresponding strength was assumed to be the same as the ATV's net weight. On the other hand, for the second and third scenarios, the rider's minimum corresponding strength was calculated according to equations (1) and (2).

$$R_{MCS} = ATV_{CW}*\frac{CG_y}{Hand's\,momentarm} \tag{1}$$

$$R_{AS}*Hand's\,momentarm + R_{LS}*Leg's\,momentarm \geq ATV_{CW}*CG_y \tag{2}$$

Where:

R_{MCS}: Rider's minimum corresponding strength.

ATV_{CW}: ATV's curb weight.

Hand's moment arm: Distance between the point where the rider's hands touch the ATV and the ATV's rear rack.

CG_y: Horizontal distance between the CG location and the end of the ATV's rear rack.

R_{AS}: Rider's arm strength.

R_{LS}: Rider's leg strength (maximum voluntary contraction force – MVC).

Feet's moment arm: The distance between the point where the rider's feet contact the ATV and the rear rack of the ATV.

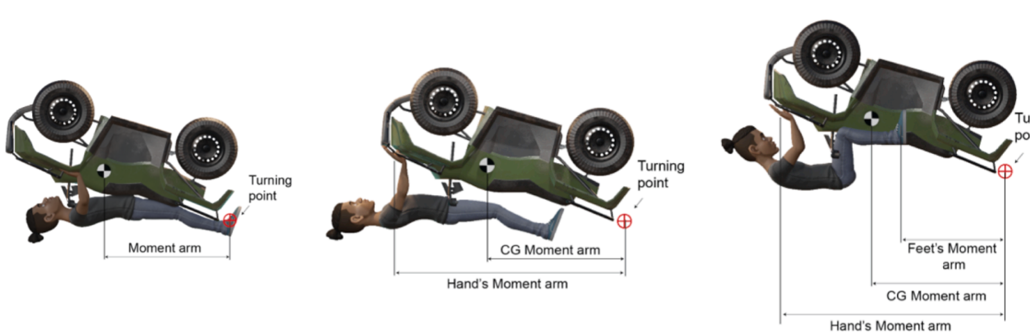
To simplify calculations, the hand's moment arm was assumed to be equivalent to the length of the ATV, while the feet's moment arm was taken as the same as the CGy. The ATV's center of gravity (CG) location was estimated based on information from a previous study (Heydinger et al., 2019).

2.1.3. Youth's strength

Information pertaining to the physical strength of youth in various body regions, such as the legs and hands, was drawn from a previous study by (Araujo et al., 2023), which obtained their strength data from a study done by the Department of Trade and Industry in the United Kingdom (Department of Trade and Industry, 2000, 2002). Data on the maximum voluntary contraction force (MVC) of the quadriceps in youth subjects was obtained from a previous study (Araujo et al., 2023). Table 2 summarizes the corresponding youth strength to ATV controls.

2.2. Reachability (Anthropometric dimension)

To determine the reachability, we used a four-step virtual simulation process. First, guidelines regarding the safe reachability of ATV controls



(a) (b) (c)

Fig. 3. Rollover scenarios. (a) Rollover scenario 1, (b) Rollover scenario 2, and (c) Rollover scenario 3.

Table 2
Corresponding youth strength to ATV controls (Araujo et al., 2023).

	Control	Corresponding youth strength
1	Foot brake	Pressing strength with the foot on a pedal
2	Hand brake	Pulling strength on a cylindrical bar with one hand
3	Handlebar	Pushing strength on a cylindrical bar with one hand
4	Throttle lever	Pushing with thumb
5	Ignition switch	Pushing with Index finger
6	Foot gearshift	Pressing strength with the foot
7	ATV resistance (worst-case rollover scenario 1)	Pushing strength on a cylindrical bar with two hands
8	ATV resistance (scenario 2)	Pushing strength on a cylindrical bar with two hands
9	ATV resistance (best-case rollover scenario 3)	Pushing strength on a cylindrical bar with two hands + MVC

were identified and listed in Table 3. These guidelines promote safety for all riders as well as ergonomics and comfortability. Second, anthropometric measurements of youth were taken from a database (Snyder et al., 1977) for youth of different genders (males and females), range of ages (8–16 years), and height percentiles (5th, 50th, and 95th). Next, five different youth-sized ATV measurements were collected using a virtual-reality setup. This setup consisted of instruments that scanned the vehicles to create 3D mockups for simulations. Lastly, the ability of youth to operate these vehicles was determined through anthropometric measurements in SAMMIECAD (SAMMIE CAD Inc., Leics., UK) and Matlab (Matlab, v2021a; Mathworks, Natick, MA). More details on each step are presented in the next sections.

2.2.1. ATV-rider fit guidelines

The main goal of this ATV-rider fit guideline is to assess the safety and comfort of ATV riders. These guidelines were retrieved from a study conducted by Khorsandi et al. (2022). This study based its recommendations on the fit criteria of various institutions such as the National 4-H Council (National 4-H Council, 2005), the CPSC (CPSC, 2006), Intermountain Primary Children's Hospital (IPCH) (IPCH, 2018), and Farm and Ranch eXtension in Safety and Health (FReSH) Community of Practice (FReSH, 2012). The guidelines consist of 11 anthropometric measures of fit, as presented in Table 3. The lack of personal protective equipment (PPE) on the model in the table is only for visualization purposes, and we do not endorse operating ATVs without wearing proper safety equipment such as helmets and riding gloves.

2.2.2. Human mockups

Fifty-four youth mock-ups were created for anthropometric evaluation. Anthropometric data for these models were taken from the Snyder et al. (1977) database, which contains measurements from 3,900 individuals aged 2 to 18 years across both genders. The total number of mock-ups used in creating youth-sized human mock-ups was determined by:

$$T = G \times A \times P$$

Where:
T = Total Number of mock-ups.
G = Number of genders (2 levels, Male and Female).
A = Number of ages (9 levels, from 8 to 16).
P = Number of body size percentile (3 levels, 5th, 50th' and 95th percentile).

In addition, two adult models, a male and a female representing the 50th percentile for body size (Snyder et al., 1977), were developed to serve as a baseline for comparison.

The data presented in Snyder et al. (1977) includes the majority of the required dimensions for making 3-D virtual youth-sized human mock-ups. Two required inputs for creating mock-ups in SAMMIECAD, arm length, and seated shoulder height, were not available in the database, but arm component measurements and seated height were available. The arm length and seated shoulder height were calculated by summing the individual components of the arm and subtracting the head and neck length from the seated height, respectively, as shown in Fig. 4.a and Fig. 4.b.

2.2.3. ATV mockups

This study selected five youth-sized ATVs from the most common ATV manufacturers, such as Yamaha Motorsports Corp, Kawasaki Motors Corp, and Tao Motor Inc. To create the ATV mock-ups in SAMMIE CAD, a Virtual Reality (VR) tracking system was used to measure the physical spatial coordinates of the required ATV features to investigate the reachability (Vive-HTC Corp., China). This system consists of Lighthouse tracking technology and Vive trackers to accurately capture spatial coordinates as shown in the schematic of measuring stations (Fig. 5).

The Lighthouse emits infrared laser beams, and the user employs a Vive headset and controllers to measure the spatial coordinate of interested ATV features in space by detecting the time differences in laser sweeps. All measurements were conducted in a dedicated space, a tent covered with a white rooftop, to minimize solar ray interference during collection. Vive sensors were mounted in fixed positions at the top corner of the tent to ensure accuracy. A total of 38 points were collected per ATV for representing selected ATV control parts and additional features, resulting in a total of 190 points being collected for youth-sized ATVs.

The reliability and accuracy of the Vive tracking system for measuring spatial coordinates have been validated in a previous study (Niehorster et al., 2017). The 3D ATV mock-ups were created in SolidWorks (SolidWorks Corp., Waltham, MA, USA) based on the measured spatial coordinates and then imported into SAMMIE CAD for evaluation (Fig. 6). A custom program was modified to calibrate, log, and manipulate data during measurement (Kreylos, 2016).

2.2.4. Virtual simulations

Two software applications were used to evaluate the mismatch between youth anthropometrics and requirements for effectively reaching different ATV controls: SAMMIE CAD and MATLAB. Each software serves specific purposes based on the nature of the evaluation criteria and characteristics of the software.

Fit criteria 4, 5, 6, 7, 8, 9, and 10 (as stated in Table 3) were evaluated using SAMMIE CAD, which has unique tools for assessing these interactions. To evaluate the criteria, the human mock-up limbs in SAMMIE CAD were adjusted to achieve the required posture for investigation. The model customization features on SAMMIE CAD allow the user to: (1) modify dimensions of the human models within certain constraints, preventing unrealistic proportions; (2) adjust body segments such as bending, cocking, and twisting limbs within specific joint constraints; and (3) conduct a simulation by integrating 3D human and ATV models into a virtual environment, were human limbs were adjusted to achieve the appropriate posture for each criterion such as a standing straddling posture for standing-seat clearance (Criterion 4) and a seated posture for knee angle (criterion 10).

To evaluate the ability of youth-sized human mock-ups to reach selected controls (Criteria 5, 7, 8, and 9), the "Reach" feature under the

Table 3
ATV-rider fits criteria. The operator is not equipped with appropriate personal protective equipment because we want to ensure that the body parts are visible (Khorsandi et al., 2022).

ID	Criterion		Institution(s)	"Fit success" and reasoning for each criterion
1	Handlebar-knee distance		National 4-H Council, CPSC	Handlebar–knee distance > 200 mm. This is necessary to ensure the rider can reach the handlebar and steer around obstacles.
2	Hand size compared to ATV handlebar reach		National 4-H Council, IPCH	With hand placed in the normal operating position and fingers straight out, the first joint from the tip of the middle finger extends beyond the brake lever. This is important to guarantee that the rider can activate the brake lever.
3	Brake-foot position		National 4-H Council	Distance from the "ball" of the foot (at its most rearward position in the ATV's foot well) to the brake pedal divided by the length of the foot < 105%. A disproportional rate indicates a risk for ineffective foot–brake operation.
4	Standing-seat clearance		National 4-H Council, CPSC, FReSH	Clearance zone between rider's crotch and ATV seat > 150 mm. This is important to guarantee that the rider can rise the torso up from the ATV seat to maintain balance and avoid distracting longitudinal torso impacts that occur while traversing rough terrains.
5	Elbow angle		National 4-H Council, IPCH	A narrow elbow angle (< 90°) indicates excessive arm flexion, while an angle too wide (> 135°) indicates the arms are excessively straight due to the grips being too far apart, which forces the rider to lean the torso to the outside of the turn to achieve an adequate range of handlebar turning
6	Upper leg		National 4-H Council	Upper leg within 10° of parallel to the ground. An upper leg too far off from parallel to the ground can compromise the rider's ability to activate the foot brake and keep balance.
7	Angle of lean from vertical		CPSC	Angle of lean from vertical < 30°. This is important to guarantee a correct posture while riding the ATV. Leaning forward significantly over the handlebars to steer when raised off the seat, can shift the system's center of gravity, increasing the likelihood of the ATV tipping forward.
8	Control reach		CPSC	Riders must be able to reach all ATV controls while seated upright.
9	Footrest reach		CPSC	Riders must keep their feet firmly on the footrests when not activating the foot-brakes. This is important to ensure the rider can maintain balance and not lose control of the ATV.
10	Knee angle		CPSC	Knee angle at least 45° while sitting and with the feet flat on the footrest. An angle wider than 45° indicates a risk for ineffective foot-brake operation.
11	Control grip		CPSC, FReSH	Riders must keep a grip on the handlebar and maintain throttle and brake control when turning the handlebar from lock to lock position. This is especially important while performing a sharp turn or a swerve.

"Human" menu in SAMMIE CAD was used. The "Reach" was set to "Absolute," and the "Object Point" was set to "Control." The reachability of the controls was simulated using different postures depending on their location and function. For example, the right hand and foot were used to simulate right-side controls, similar to the left, and both hands were used for controls that required both, such as turning handlebars (criterion 11).

MATLAB was employed to evaluate criteria 1, 2, 3, and 11 because it requires basic calculations such as determining the distance between ATV's handlebars and the rider's knee. MATLAB was selected for its ability to efficiently analyze data through automated calculations using conditional statements. Therefore, it was used to evaluate a rider's anthropometric measurement compliance with the design constraints. For example, Handlebar knee distance (criterion 1) was evaluated by inspecting the distance between the ATV footrests and handlebar minus the rider's knee height. It should be greater than 200 mm, as outlined in Table 3.

2.3. Field of vision

Field of vision is a critical factor in ensuring the safe operation of ATVs, as a limited visual range can increase the risk of collisions, roll-overs, and other accidents. This study quantified the field of vision for youth riders and compared it to adult riders. To visualize and quantify

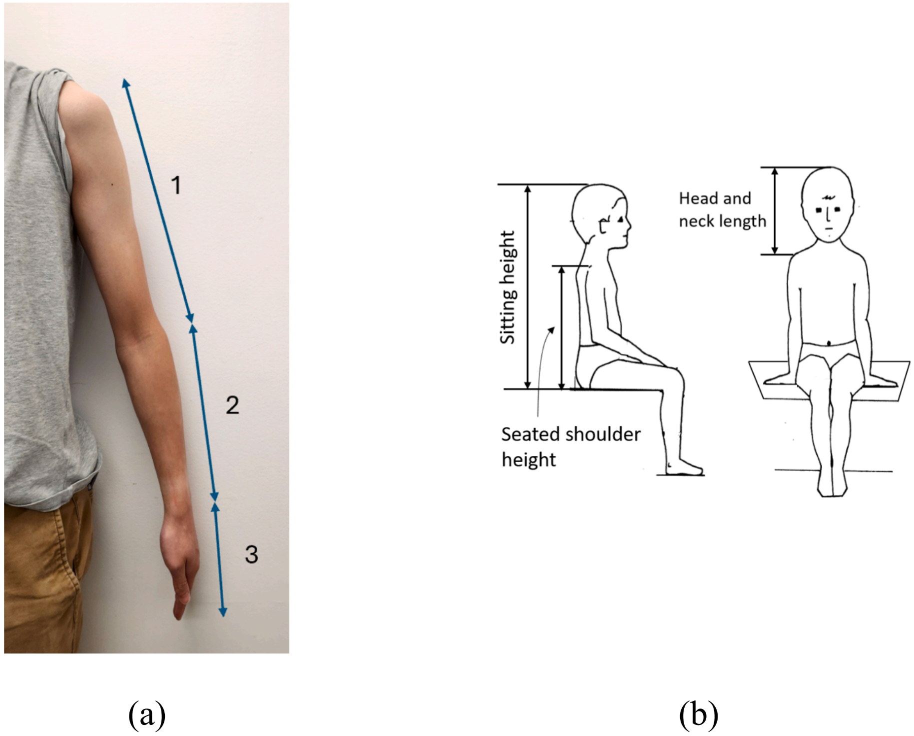


Fig. 4. Two examples of interpolation of missing variables: (a) Arm length calculated by summing (1) acromion-radiale length (2) radiale-stylion length and (3) hand length (from wrist to fingertip) (b) Seated shoulder height (Araujo et al., 2022).

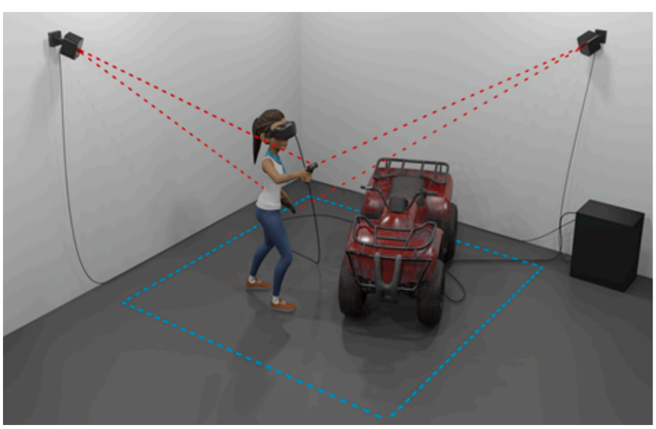


Fig. 5. The spatial coordinates collector was developed based on the Vive tracking system.

the field of vision, SAMMIECAD was used to simulate the vision to create 3D mockups of youth-sized ATVs to compare the field of vision of the youth to their adult counterparts.

2.3.1. Field of vision quantification

To quantify the field of vision of youth riders, we used the methodology developed by our research team from a previous study (Araujo et al., 2023). In SAMMIECAD, visual targets were placed concentrically around the rider on the ATV, including 21 targets represented as vertical grids (Fig. 7). Fig. 7a shows a view of the field of vision simulation in SAMMIE CAD, and Fig. 7b shows what the ATV riders can see. These targets were placed radially 1.0 m, 1.5 m, and 2 m from the rider at 10 cm at angles of 30°, 60°, and 90°, as shown in Fig. 7c. The vertical grids help researchers to quantify the operator's field of vision. The remaining parts of the vertical grid that weren't obstructed were then counted and summed using Equation (3).

$$FV = \sum_{r=1}^{2} \sum_{\theta=30}^{90} h_{r,\theta} \tag{3}$$

Where:

FV: Field of vision index for the subject in m;

r: Radius of the target (r = 1.0, 1.5, or 2.0 m);

θ: Angle at which the target was spanned (θ = 30°, 60°, or 90°);

$h_{r,\theta}$: Number of visible squares of the target located at (r,θ) (Araujo et al., 2024).

A computer vision algorithm was developed using Python for quantification of a rider's field of vision. A screenshot software tool, Greenshot, was used to capture screenshots of the simulated scenarios produced in SAMMIE CAD. The screenshots were then processed to find where the vertical poles were located and then occlude their nonvisible parts (e.g., parts blocked by the ATV body itself). The occlusion was performed under the assumption that nothing behind the ATV, from the operator's perspective, would be visible. This is shown in Fig. 8, where these areas are shaded solid red to block out the poles behind them. The occluded images were analyzed with our vision algorithm to quantify the number of squares that are fully visible. Notably, all squares beneath the front chassis were considered non-visible, as under real-life operating conditions, the operator would not be able to see this portion.

2.3.2. Field of vision assessment

To determine the field of vision for youth riders, we implemented an exposure ratio algorithm to determine the percentage of the ATVs that have a visual impedance on the subject To assess the percentage of youth-sized ATVs that have visual limitations for youth riders, we employed the exposure ratio method (Chang et al., 2010). This was done by calculating the ratio of the field of vision (FV) of the youth rider to an adult rider on the same ATV. The exposure ratio calculation is demonstrated in Equation (4).

$$E_r = \frac{FV_y}{FV_a} \tag{4}$$

Fig. 6. 3-D representation of ATV mock-ups. (a) Example of a 3-D ATV mock-up used for the virtual simulations in SAMMIE CAD (Araujo et al., 2022) (b) Fully assembled model – for visualization purposes only.

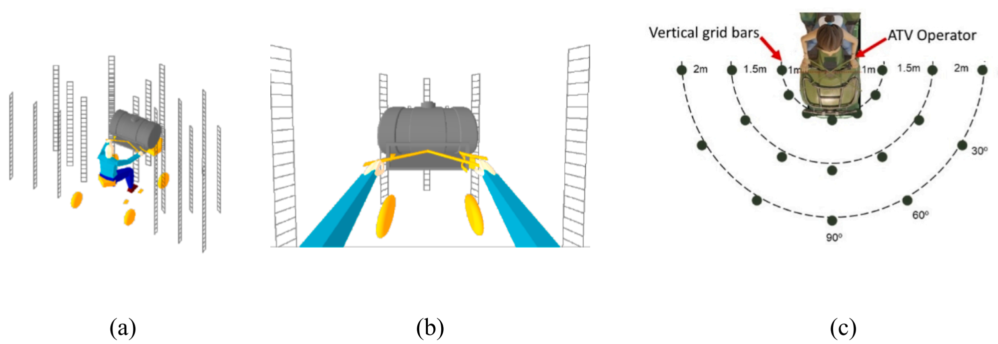


Fig. 7. Visual Fields (a) Computer simulation (SAMMIE CAD), (b) the view from the rider's eyepoint (G. Araujo et al., 2024), and (c) Visual target configuration.

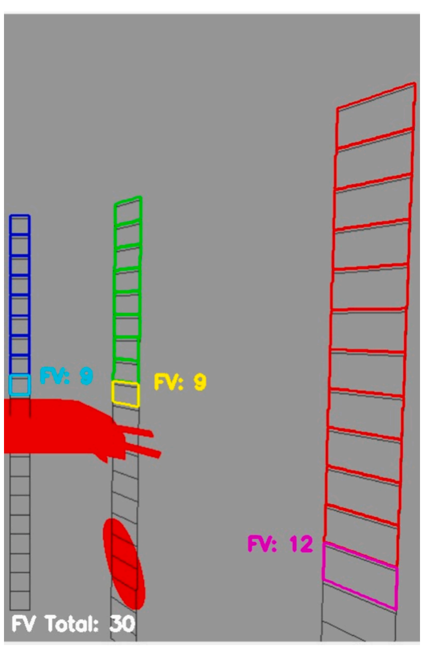


Fig. 8. Samples of quantified images with No implements. Visible parts of the ATV chassis and wheels are colored fully red to ensure total blockage of poles behind them. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Where:

E_r: Exposure ratio;

FV_y: Field of vision index of the young operator;

FV_a: Field of vision index of the adult counterpart.

ATVs with E_r smaller than 1.0 were considered to represent a visual limitation for youth, as recommended by Chang et al. (2010).

2.4. Data analysis

To determine if the ATV models are suitable for youth riders, our research team developed an Appropriateness Score (AS) to evaluate the vehicles. This score is based off of the fit of the ATVs to the youth rider's strength, anthropometry, and field of vision.

In order to maintain data granularity throughout the strength, anthropometry, and field of vision assessments, physical strength data needed to be deconstructed. As a result, the strength data was separated by age using linear interpolation to evaluate the fit of youth-sized ATVs for youth riders more proficiently.

Due to strength data only being available for age groups (e.g., 6–11, 12–15, and 16–20) rather than individual ages, linear interpolation of the data was implemented to estimate the strength of individual ages.

The Appropriateness Score (AS) for each age is calculated using Equation (5).

$$AS = S + A + V \tag{5}$$

Where:

- Strength Score (S): A comparison of the forces to operate the controls of the ATV to the strength of the youth operator. A score of 1 corresponds with the youth having more than sufficient strength to operate all controls of the ATV and overcome the third rollover scenario. A score of 0 indicates that the youth rider has insufficient strength to operate all controls and/or cannot overcome the third rollover scenario.
- Anthropometric Fit Score (A): An evaluation if the youth rider passes the anthropometric youth-fit guidelines. This test is conducted through SAMMIE CAD where a score of 1 indicates that the youth rider meets all 11 criteria and a score of 0 if the rider does not meet one or more criteria.
- Field of Vision Score (V): A score based off of the E_r from Equation (4). A score of 1 indicates an $E_r \geq 1$ for an equal or better field of vision compared to an adult rider. A score of 0 indicates an $E_r < 1$ for a reduced field of vision compared to an adult rider.

The Appropriateness Score (AS) ranges from 0 to 3 for each age for each ATV. A score of 3 represents excellent fit while a score of 0 indicates poor fit.

Additionally, several components of the AS score were adjusted in order to give ATVs a greater chance at attaining a higher AS score. For instance, the rollover scenario used for the strength score was the third rollover scenario, as that was considered the easiest scenario for youth operators to overcome.

3. Results and discussion

Five youth-sized ATV models by three different manufacturers were evaluated. Engine capacity ranged from 49-107 cc. Moreover, none of the ATVs evaluated included electric power steering (EPS) or 4-wheel-drive. On the other hand, they all had solid suspension and manual transmission.

3.1. Physical strength

The results for strength evaluation showed that youth of all ages, percentiles, and genders could activate all the youth-sized ATV controls, such as handlebar, throttle lever, hand brake, and foot brake. This indicates that youth-sized ATV controls appropriately match youths' strength capabilities. Results of our previous study showed that youths are not able to activate all utility ATV (adult size) controls, especially the foot brake (Araujo et al., 2023).

For the results of each rollover scenario, there was no significant performance difference between the three percentiles (5th, 50th, and 95th) among each age group, therefore only the average value for the three percentiles was presented in Table 4.

Table 4
Percent of ATVs with limitations for youth of different genders and ages for the rollover simulation scenarios.

Gender	Age	Scenario 1	Scenario 2	Scenario 3
Male	8	100	100	100
	9	100	100	100
	10	100	100	100
	11	100	100	83.3
	12	100	100	66.7
	13	100	100	16.7
	14	100	100	0.0
	15	100	100	0.0
	16	100	83.3	0.0
Female	8	100	100	100
	9	100	100	100
	10	100	100	100
	11	100	100	100
	12	100	100	83.3
	13	100	100	66.7
	14	100	100	66.7
	15	100	100	66.7
	16	100	100	33.3

Although youths are strong enough to activate all the youth-sized ATV controls, results showed that they cannot push the youth-sized ATVs off their bodies in most cases. In Scenarios 1 and 2, no youth participants aged 8 to 15 could push the ATV off their bodies. At age 16, males could push a small portion of ATVs in Scenario 2 (83.3% of ATVs could not be pushed), while all females at this age continued to fail. Scenario 3, which allowed participants to use both arms and legs, showed a higher success rate across genders. For males, success began at age 11, with 83.3% of ATVs failing to be pushed. By age 13, only 16.7% of ATVs failed to be push. At age 16, all males successfully passed Scenario 3. The higher success in Scenario 3 can be attributed to using both arms and legs, which provided additional leverage. The disparity in success rates between males and females across scenarios is likely due to gender differences in strength, which become more pronounced by age 16.

The results of this study show serious concern about youth being trapped under the ATV in rollover incidents. The ratio of the ATV's weight to the youth's weight during the youth and ATV fit process should be considered, as it is recommended that the ATV's weight be less than three times the operator's weight (CPSC, 2006). Also, parents should supervise youth during ATV operations to save youth in case of a rollover incident (National 4-H Council, 2005).

Several recommendations have been made to decrease the possibility of youth death due to entrapment under the ATV: use of crush protection devices (CPD), rollover detection, and notification devices (Khorsandi et al., 2024a,b). These options are explained below; some are currently not commercially available to youth-size ATVs.

A CPD is a safety structure that protects the operator during a rollover incident. CPD either creates a clearance zone during an ATV rollover, providing space for the rider to crawl out from underneath the vehicle or preventing the ATV from continuously rolling in an incident (Khorsandi et al., 2019). Unfortunately, CPDs are designed for larger, adult-sized ATVs. However, their adaptation for youth-sized ATVs could provide additional safety for young riders. The other option is to use a crush prediction, detection, and notification system that can notify parents if rollover incidents occur (Khorsandi et al., 2024a,b).

3.2. Anthropometry

The anthropometry evaluation results are presented in Tables 5, 6, and 7, which are based on ATV-rider fit guidelines (Table 3), the ATV engine size (Table 1), age, percentile, and gender of the riders. To simplify the presentation of results, the reachability values for each age group were averaged across the three percentiles (5th, 50th, and 95th), as the tables including all percentiles would be excessively long.

Results of reachability of ATV controls for ATVs with engine sizes less than 70 cc are presented in Table 5. According to CPSC, youths aged 6 to 11 should operate models with engines under 70 cc (CPSC, 2006). The results for this specific range (8–11) are highlighted in blue. Within this range, there is a greater percentage of ATVs that limit youth operation, especially in regard to upper leg angle (criterion 6), footrest reach (criterion 9), and knee angle (criterion 10). ATV compliance for an engine size under 70 ccs begins to increase between 11 and 12 years old, with the notable exception of elbow angle (criterion 5), which has the opposite trend. This is likely because older youth are too large for these vehicles, making it effective vehicle operation more difficult due to the smaller dimensions. Accordingly, ATV compliance drops sharply between 11- and 12-year-old males and females, with older youth failing to meet this requirement for any ATV. This failure in compliance can be justified, as longer arms force operators to position their elbows at a narrow angle to hold the controls comfortably, making it difficult to turn the vehicle properly.

Table 6 shows results for ATVs with engine sizes between 70 cc and 90 cc, which CPSC recommends for youths aged 12 to 15 (CPSC, 2006).

Table 5
Percent of ATVs engine size < 70 ccs (CPSC recommended for youth aged 6–11, highlighted) for which reach criteria limit youth-sized ATV usage by the youth of various ages. Criteria 1–11 refer to Table 3. All numbers in the table are (%).

Gender	Age (Year)	Criteria										
		1	2	3	4	5	6	7	8	9	10	11
Male	8	0	0	0	33	17	50	0	0	50	50	17
	9	0	0	0	17	17	50	0	0	50	50	17
	10	0	0	0	17	33	50	0	0	50	50	0
	11	0	0	0	0	33	50	0	0	50	50	0
	12	17	0	0	0	83	33	0	0	33	33	0
	13	33	0	0	0	100	33	0	0	33	33	0
	14	33	0	0	0	100	33	0	0	33	33	0
	15	50	0	0	0	100	17	0	0	17	17	0
	16	67	0	0	0	100	17	0	0	17	17	0
	Adult	100	0	0	0	100	0	0	0	0	0	0
Female	8	0	0	0	33	0	50	0	0	50	50	17
	9	0	0	0	33	0	50	0	0	50	50	0
	10	0	0	0	17	33	50	0	0	50	50	0
	11	0	0	0	17	33	50	0	0	50	50	0
	12	0	0	0	0	67	50	0	0	50	50	0
	13	0	0	0	0	83	33	0	0	33	33	0
	14	17	0	0	0	100	33	0	0	33	33	0
	15	33	0	0	0	100	33	0	0	33	33	0
	16	33	0	0	0	100	33	0	0	33	33	0
	Adult	0	0	0	0	100	50	0	0	50	50	0

Table 6
Percent of ATVs with engine size between 70 and 90 cc (CPSC recommended for youth aged 12–15, highlighted) for which reach criteria limit youth-sized ATV usage by youth of various ages. Criteria 1–11 refer to Table 3. All numbers in the table are (%).

Gender	Age (Year)	Criteria										
		1	2	3	4	5	6	7	8	9	10	11
Male	8	0	0	0	0	17	67	0	0	67	67	0
	9	0	0	0	0	33	50	0	0	50	50	0
	10	17	0	0	0	33	33	0	0	33	33	0
	11	17	0	0	0	50	17	0	0	17	17	0
	12	50	0	0	0	67	0	0	0	0	0	0
	13	67	0	0	0	83	0	0	0	0	0	0
	14	67	0	0	0	100	0	0	0	0	0	0
	15	83	0	0	0	100	0	0	0	0	0	0
	16	100	0	0	0	100	0	0	0	0	0	0
	Adult	100	0	0	0	100	0	0	0	0	0	0
Female	8	0	0	0	0	50	67	0	0	67	67	0
	9	0	0	0	0	33	50	0	0	50	50	0
	10	17	0	0	0	50	33	0	0	33	33	0
	11	33	0	0	0	50	0	0	0	0	0	0
	12	50	0	0	0	67	0	0	0	0	0	0
	13	50	0	0	0	67	0	0	0	0	0	0
	14	67	0	0	0	83	0	0	0	0	0	0
	15	67	0	0	0	100	0	0	0	0	0	0
	16	83	0	0	0	100	0	0	0	0	0	0
	Adult	50	0	0	0	100	0	0	0	0	0	0

ATV noncompliance generally peaks at the earliest ages (8–11), then quickly drops past age 11 as most youth are no longer failing most criteria.

Youths aged 12–15 failed to meet two necessary criteria: Handlebar-knee distance (criterion 1) and elbow angle (criterion 5). The elbow angle (criterion 5) is consistently challenging across all ATV engine sizes (as shown in Tables 5, 6, and 7) and in earlier research involving utility ATVs and engine sizes over 90 cc (Araujo et al., 2022). We propose revising the elbow angle criterion. Previous studies have shown that motorcycle riders often find elbow angles as wide as 168 degrees comfortable (Arunachalam et al., 2021). Therefore, we suggest that the rider's elbow angle should fall between 90 and 170 degrees, considering the rider's comfort while steering and continued ability to meet fit reach to controls (criterion 8) and grip on controls (criterion 11).

Based on the anthropometry analysis results for ATVs with engine sizes bigger than 70 cc (Tables 6 and 7), handlebar-knee distance (criterion 1) limits almost all ATV riders. The results of our previous study showed that a small portion of youth fails to meet this criterion for adult-sized ATV (Araujo et al., 2022). The handlebar-knee distance (criterion 1), is based on a CPSC recommendation (CPSC, 2003). The origin of this criteria is the ergonomic criteria for commercial bikes that recommend a minimum of 200 mm (or 8 in) distance from the operator's knee to the handlebar (Auxier et al; Muslim et al., 2011), despite the operator's posture and riding terrain for controlling and riding an ATV differs significantly from a bike. This study suggests evaluating and possibly reexamining handlebar-knee distance (criterion 1) for ATV riders, considering safety and functionality. If the criterion passes for ATV, then it is recommended that ATV designers consider this factor in future designs.

The results presented in Table 7 show the percentage of ATVs (with engine sizes over 90 cc) for which reach criteria limit youth-sized ATV usage across various age groups. None of the youths, regardless of age, could meet all performance criteria. Considering the issues with elbow angle (criterion 5) and proposed modifications to it, the results indicate

Table 7
Percent of ATVs with engine size > 90 cc (CPSC recommended for youth 16 and older, highlighted) for which reach criteria limit youth-sized ATV usage by youth of various ages. Criteria 1–11 refer to Table 3. All numbers in the table are (%).

Gender	Age (Year)	Criteria										
		1	2	3	4	5	6	7	8	9	10	11
Male	8	67	0	0	0	33	0	0	0	0	0	0
	9	67	0	0	0	67	0	0	0	0	0	0
	10	67	0	0	0	67	0	0	0	0	0	0
	11	100	0	0	0	100	0	0	0	0	0	0
	12	100	0	0	0	100	0	0	0	0	0	0
	13	100	0	0	0	100	0	0	0	0	0	0
	14	100	0	0	0	100	0	0	0	0	0	0
	15	100	0	0	0	100	0	0	0	0	0	0
	16	100	0	0	0	100	0	0	0	0	0	0
	Adult	100	0	0	0	100	0	0	0	0	0	0
Female	8	33	0	0	0	67	0	0	0	0	0	0
	9	67	0	0	0	67	0	0	0	0	0	0
	10	100	0	0	0	100	0	0	0	0	0	0
	11	100	0	0	0	100	0	0	0	0	0	0
	12	100	0	0	0	100	0	0	0	0	0	0
	13	100	0	0	0	100	0	0	0	0	0	0
	14	100	0	0	0	100	0	0	0	0	0	0
	15	100	0	0	0	100	0	0	0	0	0	0
	16	100	0	0	0	100	0	0	0	0	0	0
	Adult	100	0	0	0	100	0	0	0	0	0	0

that Handlebar-knee distance (criterion 1) remains the most problematic. This result is in good agreement with our previous study related to youth riding adult-size ATVs (engine size > 90 ccs), in which criteria 1 and 5 are shown to be more problematic compared to other criteria (Araujo et al., 2022).

Results (Tables 5, 6, and 7) showed that ATVs with engine sizes under 70 ccs are generally most suitable for younger youths, especially those younger than 11 years old. The results partially align with the CPSC's recommendations that youths aged 6 to 11 should operate models with engines under 70 cc (CPSC, 2006).

Table 8 was developed to summarize the results of the anthropometric analysis presented in Tables 5-7. Although the ATV industry follows CPSC recommendations regarding youth age and ATV engine size, the anthropometric evaluation results showed that none of the youths met all the requirements based on the 11 criteria. While there have been concerns regarding elbow angle (criterion 5), which was suggested for modification and change in ATV design, other criteria also present limitations, mainly Handlebar-knee distance (criterion 1).

3.3. Field of vision

This section presents the results of simulations and analysis related to the Field of Vision evaluation for two genders (Male and Female), Ages (8–16 and adults), ATVs with different engine size levels (less than 70 cc, between 70 and 90 cc, and higher than 90 cc). Table 9 shows the percentage of ATVs that present visual limitations to youth operators compared to adult counterparts. The visual limitations are evaluated at various angles (30°, 60°, and 90°) and distances (1.0 m, 1.5 m, and 2.0 m) from the operator's body.

It is important to remember that the results presented in the tables in this section are derived from the ratio between the fields of vision of youth and their adult counterparts. 0% ATV noncompliance does not imply that the youth are not limited at all, but rather that they are not performing worse than their adult counterparts for all ATVs for that particular combination of distance and angle. 100% means that youth are performing worse than their adult counterpart for all ATVs of that particular combination of distance and angle.

The results show that both male and female youths experience different degrees of visual obstruction, with notable differences based on age and distance. The presented results are the average based on different percentiles of youth and different ATV sizes. The results for each group of ATV size were conducted, showing that all ATV models exhibited high degrees of visual limitations for youth operators compared to their adult counterparts at all combinations of distances and angles. While exceptions exist, such as for 12-year-old males and females at 1.0 m, where at all angles, all five ATVs presented no limitations, we observe an overwhelming lack of fit for the field of vision. Consequently, this study recommends reevaluating the sightlines of youth-sized ATVs such that youth operators are able to have the maximal field of vision, especially if operating conditions are nonideal, such as in poor weather conditions or if implements are attached to the chassis.

We note that there was no significant difference in ATV compliance between males and females, a stark contrast to the results of a previous study where it was observed that females had significantly fewer visual limitations than their male counterparts (Gui-AUTHOR NEEDS TO PROVIDE YEAT AND REFERENCE). However, it should be noted that the ATVs sampled for that study were adult sized utility ATVs, whereas in this study youth ATVs are the focus. Therefore, we hypothesize that the differences in gender for field of vision performance are dampened when using youth ATVs, whereas they are more pronounced in adult sized ATVs.

An analysis of the field of vision for ATVs of different engine sizes was also performed, but the difference in the field of vision performance between different engine sizes was found to be insignificant; therefore, the results were not presented here.

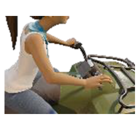
A notable limitation is that comparing an adult operator's performance to that of a youth operator may unfairly skew the results of the field-of-vision analysis. An adult operator may perform significantly better on a youth-sized ATV, creating a performance gap that youth operators cannot bridge. This discrepancy could result in the exposure ratio being overly conservative, potentially overestimating the percentage of non-compliant ATVs.

3.4. Comprehensive evaluation

Each of the five ATVs used in this study was evaluated using the appropriateness score (AS) as described in Equation (5). Table 10 reports the percentage of ATVs with an AS score of 3 for each age group and gender." The results from the comprehensive evaluation demonstrate that of the five ATVs selected for the study, none of them were suitable for youth operation and failed to meet all the fitting criteria, given their capabilities.

Youth were strong enough to activate all the ATV controls, but the

Table 8
Summary of results for ATVs with different engine sizes, youth ages, genders, and percentile.

ID	Criterion		Results
1	Handlebar-knee distance		Older youth, higher percentiles, and smaller engine sizes* lower the chances of passing this criterion.*The results for the size of ATV were derived based on both this study and our previous study (Araujo et al., 2022)
2	Hand size compared to ATV handlebar reach		All ages, genders, and percentiles passed for all youth ATV models.
3	Brake-foot position		All ages, genders, and percentiles passed for all youth ATV models.
4	Standing-seat clearance		All ages, genders, and percentiles passed for all youth ATV models except females 11 years old and younger and males 10 years old and younger females for ATVs with less than 70 cc engines.
5	Elbow angle		Older youth, higher percentiles, and smaller engine sizes lower the chances of passing this criterion. Results of this study suggest changing this angle (90° < elbow angle > 135°) to (90° < elbow angle > 170°).
6	Upper leg		Younger youth, lower percentiles, and smaller engine sizes lower the chances of passing this criterion, along with slight variations in performance between genders. All objectives passed the criteria for ATVs with engine sizes higher than 90 cc.
7	Angle of lean from vertical		All ages, genders, and percentiles passed for all youth ATV models.
8	Control reach		All ages, genders, and percentiles passed for all youth ATV models.
9	Footrest reach		Younger youth, lower percentiles, and smaller engine sizes lower the chances of passing this criterion, along with slight variations in performance between genders. All subjects passed this criterion for ATVs with engine sizes higher than 90 cc.
10	Knee angle		All objectives passed the criteria for ATVs with engine sizes higher than 90 cc.
11	Control grip		All ages, genders, and percentiles passed for all youth ATV models except females nine and younger and 8-year-old males for ATVs with less than 70 cc engines.

majority of them failed to push the ATV off their body, especially in worst-case scenarios (Scenarios 1 and 2). Most of the ATVs were within the ability of older youth operators to overcome the third rollover scenario. Only two cases could pass all 11 reach criteria for only one of the five ATVs used: (1) a 15-year-old male on a youth ATV model with a 90 cc engine size and the other was a 10-year-old female on a youth ATV model with a 107 cc engine size. Furthermore, no age group attained an exposure ratio greater than or equal to one, indicating poor visual performance relative to their adult counterparts across youth with different genders, ages, or percentiles.

Based on the results of this study (Table 10), we do not recommend that youth under 16 operate ATVs, even those of youth size. If they persist in doing so, parents should take precautions by assessing the vehicle's fit to match their child's physical capabilities (strength, anthropometry, and field of vision), in addition to following the recommended size with CPSC.

3.5. Study limitations

This study has several limitations and conditions to consider when interpreting the results. The real-world riding factors, such as vibration, terrain condition, and active riding, were not considered in this study. All three sections of the study (strength, reachability, and field of vision) include a limited number of scenarios, which are picked based on a comprehensive study and extensive consultation with experts in the field of ATV safety (Khorsandi et al., 2022).

The youth strength and anthropometry are based on previous study results (Department of Trade and Industry, 2002; Snyder et al., 1977). These studies were not originally designed to assess youth's ability to engage ATV controls.

The study only focuses on physical capabilities, and there is a need for future studies to access the required mental abilities, skills, and safety training to ride ATVs safely.

The number of evaluated ATVs is limited. The evaluated ATVs are brand new and in good performance condition.

For all results presented, the performance of the three percentiles per age was averaged into a single outcome. This was done as the difference in performance between a specific percentile within a given age group was not significant enough to warrant reporting separately, as it would make tables very long.

4. Conclusions

The conclusion of the manuscript provides brief answers to the research questions mentioned in the introduction. The answers are based on the results of this study, considering the limitations.

Can youth effectively activate the controls on youth-sized ATVs? (Strength evaluation) Yes, Youth of all ages and percentiles can activate ATV controls (e.g., throttle lever, foot brake, handlebar).

Are youth strong enough to push an ATV off their body in case of a rollover? (Strength evaluation) The study showed that most youths were unable to push the ATV off their body for the most dangerous rollover scenarios. Older males and females were able to increase their chance of pushing the ATV off their bodies if they were able to use both their feet and arms. For example, all boys older than 14 can push the youth-size ATV off their bodies if they can use both feet and arms. It is recommended to ride ATVs that are not heavier than three times the youth weight (CPSC, 2003), use CPD (Khorsandi et al., 2019), learn techniques to prevent rollovers, and use rollover detection and notification systems to increase the chance of survival if rollover incidents happen (Khorsandi et al., 2024a), in addition to riding under the supervision of adults (National 4-H Council, 2005).

Can youth effectively reach the controls on ATVs? (Anthropometry evaluation) For most cases, youth fail to reach ATV controls based on the 11 criteria mentioned in Table 8. Two criteria, in particular, presented the most difficulty, including knee distance to the

Table 9
Percentage of ATVs with visual limitations to youth (i.e., Er < 1.0). Angles (30°, 60°, and 90°) and distances (1, 1.5, and 2 m) represent the location of the vertical bars relative to the operator body. Numbers show the ratio between the fields of vision of youth and their adult counterparts.

Gender	Age	Distance: 1.0 *m*			Distance: 1.5 *m*			Distance: 2.0 *m*		
		90°	60°	30°	90°	60°	30°	90°	60°	30°
Males	8	46.7	40.0	33.3	100.0	100.0	100.0	53.3	73.3	53.3
	9	40.0	46.7	0.0	46.7	53.3	33.3	86.7	93.3	86.7
	10	53.3	66.7	33.3	26.7	33.3	13.3	40.0	40.0	46.7
	11	100.0	100.0	100.0	60.0	66.7	93.3	20.0	20.0	40.0
	12	0.0	0.0	0.0	100.0	100.0	100.0	46.7	73.3	66.7
	13	26.7	33.3	0.0	0.0	13.3	0.0	100.0	100.0	100.0
	14	73.3	86.7	66.7	46.7	60.0	33.3	13.3	13.3	20.0
	15	73.3	66.7	66.7	100.0	100.0	66.7	53.3	60.0	33.3
	16	33.3	33.3	0.0	73.3	73.3	66.7	73.3	86.7	66.7
Mean		**49.6**	**52.6**	**33.3**	**61.5**	**66.7**	**56.3**	**54.1**	**62.2**	**57.0**
Females	8	40.0	40.0	33.3	100.0	100.0	100.0	60.0	66.7	60.0
	9	40.0	40.0	0.0	60.0	60.0	46.7	86.7	86.7	66.7
	10	53.3	40.0	33.3	46.7	33.3	33.3	46.7	33.3	33.3
	11	100.0	100.0	100.0	73.3	73.3	100.0	26.7	20.0	26.7
	12	0.0	0.0	0.0	100.0	100.0	100.0	53.3	60.0	66.7
	13	13.3	26.7	6.7	20.0	6.7	13.3	100.0	100.0	100.0
	14	80.0	73.3	66.7	66.7	66.7	46.7	33.3	6.7	0.0
	15	73.3	73.3	66.7	93.3	100.0	100.0	60.0	60.0	0.0
	16	33.3	33.3	0.0	80.0	80.0	73.3	73.3	86.7	60.0
Mean		**48.1**	**47.4**	**34.1**	**71.1**	**68.9**	**68.1**	**60.0**	**57.8**	**45.9**

Table 10
A comprehensive evaluation of selected ATVs with the percentage of passing ATVs for each criterion. All numbers in the table are in percentages.

Gender	Age	Strength Score (S)	Anthropometry Score(A)	Vision Score(V)	Percent of Fully Suitable ATVs (AS = 3)
Male	8	0	0	0	0
	9	0	0	0	0
	10	0	0	0	0
	11	20	0	0	0
	12	40	0	0	0
	13	80	0	0	0
	14	100	0	0	0
	15	100	20	0	0
	16	100	0	0	0
Female	8	0	0	0	0
	9	0	0	0	0
	10	0	20	0	0
	11	0	0	0	0
	12	20	0	0	0
	13	40	0	0	0
	14	40	0	0	0
	15	40	0	0	0
	16	60	0	0	0

handlebar (criterion 1) and elbow angle (criterion 5), which most youths were unable to meet for ATVs with an engine size larger than 70 cc. The knee distance to the handlebar (criterion 1) is problematic for most age groups and ATV sizes, signaling that either ATV designs need to be changed to address this design, or that the criteria need more investigation as it is based on bike fitting recommendations. The other notable failure is the elbow angle (criterion 5), which this study recommends be changed from (90° < elbow angle > 135°) to (90° < elbow angle > 170°).

Is the field of vision for youth more limited than that of adults when operating ATVs? (Field of vision evaluation) Yes, youth have a limited field of vision compared to their adult counterparts riding ATVs. However, comparing adult and youth operators on youth-sized ATVs may unfairly skew field-of-vision results. It should be considered that the relative size of adults-to-youth ATVs is higher than youth that youth operators to-youth ATVs. Adults often perform better, creating a gap that youth cannot bridge. This could make the exposure ratio overly conservative, overestimating non-compliant ATVs.

Can youth safely operate youth-sized ATVs, which are categorized based on CPSC recommendations (Table 3)? (Comprehensive evaluation) Although, based on this study, the majority of youths fail to meet all the physical requirements for safely operating ATVs, a trend suggests alignment between youth capabilities and the current CPSC size recommendations based on engine capacity (CPSC, 2006). There are some extreme evaluation criteria, such as rollover scenarios where the operator can only use their hand, and the position under the ATV is extensive for pushing the ATV off the operator's body. Also, the field of vision evaluation is a comparison between youth with adult counterparts that represent extreme situations. We strongly recommend restricting ATV use to youths 16 years old and older. If parents choose otherwise, our findings recommend selecting an appropriately sized ATV for the youth's age and assessing their physical compatibility with the specific vehicle. Our research team is developing a checklist to evaluate youth capabilities, considering individual body size and strength differences for riding a specific ATV functional and safely.

Other measures include providing proper personal protective equipment (PPE), safety training, parental supervision (adults older than 16), avoiding road use, and assessing the youth's mental and decision-making abilities to handle ATVs safely. Existing safety training materials and checklists can support these evaluations (National 4-H Council, 2005). Furthermore, our results highlight the need for ATV designs that better accommodate the diverse physical characteristics of younger riders.

CRediT authorship contribution statement

Farzaneh Khorsandi: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Jordan Wong:** Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Formal analysis, Data curation. **Guilherme de Moura Araujo:** Writing – original draft, Software, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work was supported by the National Children's Center for Rural and Agricultural Health and Safety (NCCRAHS) under grant No. NIOSH 5U54 OH009568. In addition, the Western Center for Agricultural Health and Safety provided a seed grant for conducting preliminary studies. We would like to thank (based on alphabetical order) Aliya Abla, Fraz Ahmad Khan, Bradley Childs, Fadi Fathallah, Fernando Ferreira Lima dos Santos, Sami Kabakibo, and Oliver Kreylos.

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