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Evaluation of Pediatric Fit and Safety Guidelines for All-Terrain Vehicles

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ABSTRACT

All-Terrain Vehicles (ATVs) are a leading cause of youth injury in the USA, resulting in over 170 deaths and 40,000 reported injuries per year; these figures have steadily increased over the last decade. To reduce injury risk and severity, small-frame, limited power vehicles are made available for youths. The ATV industry's Safety Institute recommends the following restrictions: engine volumes < 70cc for children < 12 years; engines < 90cc for children 12-15 years; no restrictions for children 16 years and older. However, little scientific evidence is available with regards to the anthropometric relationship between young riders and vehicle frame size in determining an appropriate fit, much less the ability to control the ATV.

The objective of this study was to quantify the biomechanical relationship between the size of young riders and ATV type in a static condition with the hypothesis that age alone is not a suitable measure of rider-vehicle frame fit.

Male children (6-11 years, n=8 and 12-15 years, n=11) were recruited to sit upon adult and youth-sized ATVs inclined and declined between 0º and 30º in 5º increments while anthropometric markers were recorded at 50 Hz using twelve digital motion capture cameras. Fit was categorized by five measures adapted from 4-H recommendations to improve rider fit: standing seat clearance, hand size, foot vs. foot-brake position, elbow angle, and handlebar-to-knee distance.

Results indicate the age 12-15 group fit the adult ATV better than the age-appropriate youth model (63% of subjects fit all categories on adult vs. 20% on youth). The age 6-11 group fit poorly on both bikes (0% on adult versus 12% on youth).

Despite prevailing rules, age alone is not a good predictor of vehicle fit; new recommendations for ATV size, redesign, or new intermediate ATV size categories may be needed.

INTRODUCTION

ATV crashes are a significant cause of morbidity and mortality in the United States. ATV crash-related deaths reported by the Consumer Product Safety Commission for all ages have risen steadily since 1998 (Figure 1) (Streeter, 2008). Data for children under 16 shows a similar steady increase since 1998 (Figure 2). The growing problem of ATV-related deaths in children is often attributed to incorrect usage: factors include incorrect terrain selection, lack of protective gear, riding tandem, uncontrolled speed, and inability to control an improperly-sized ATV (Brandenburg et al., 2007). Many reports suggest that children lack the physical and/or mental ability to safely operate ATVs (Helmkamp et al., 2008; Graham et al., 2006).

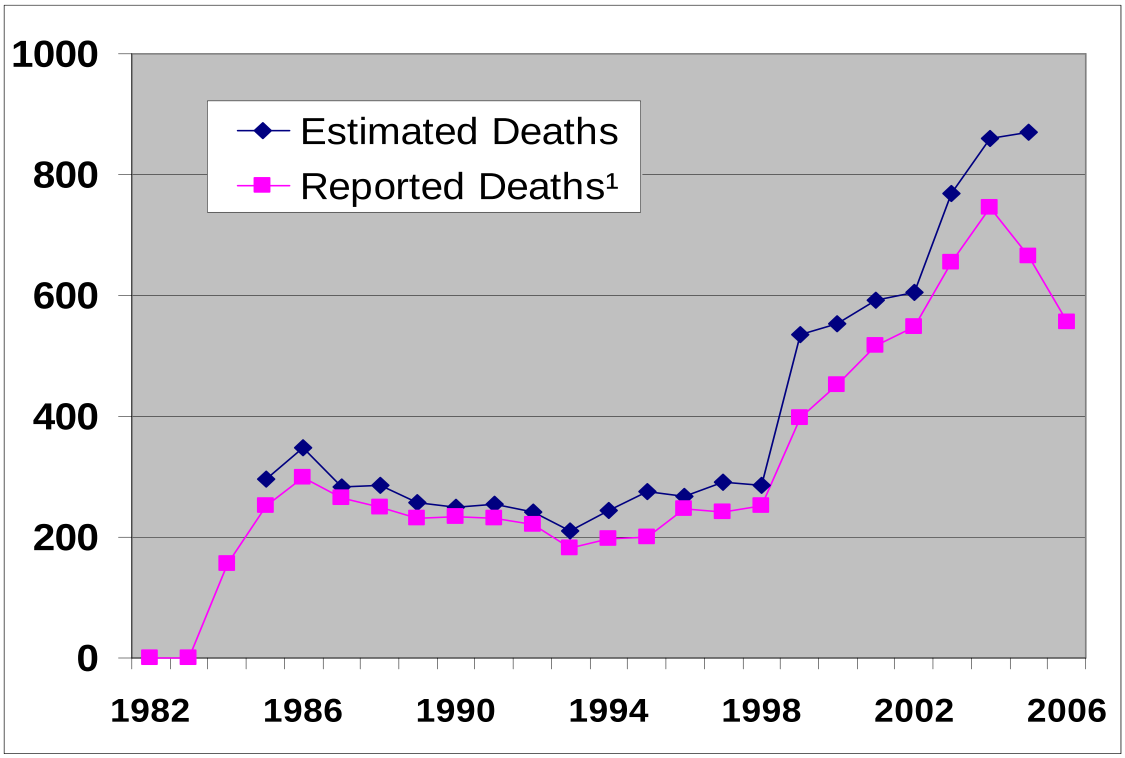

Figure 1: U.S. ATV deaths, 1982 to 2006. Data from Consumer Product Safety Commission (2008). Disparity between estimated and reported deaths is due to incomplete data collection methods.

Unfortunately, much of what is known about how ATV injuries occur is derived from incomplete or inadequate reconstructions and reports in the lay media. Little published data have established the causes specifically contributing to ATV crashes in children (Brandenburg et al., 2007; Graham et al., 2006). Though it seems intuitive that a significant vehicle / rider size mismatch would markedly reduce the ability to control an ATV, optimal fit relationships have not been scientifically determined.

Fit upon an ATV is a multifaceted quantity. 4-H Club has made recommendations aimed at achieving total body fit based upon guidelines from the Consumer Product Safety Commission and the ATV Safety Institute (Table 1). A complicating factor for child riders of ATVs is great variability in vehicle size. The ATV Safety Institute, an industry sponsored safety advocacy group, recognizes that vehicle-rider misfit contributes to injuries and has established size recommendations (Table 2), based upon rider age and engine displacement. State statutes have been based upon these recommendations. However, this guideline is limited by not equating directly with frame dimension. Furthermore, within the age ranges covered by the recommendations there is substantial variability in rider size. Neither the engine size nor any other frame fit guideline has ever been objectively validated. We hypothesize that age alone is not a satisfactory guide for determining rider-frame fit among children.

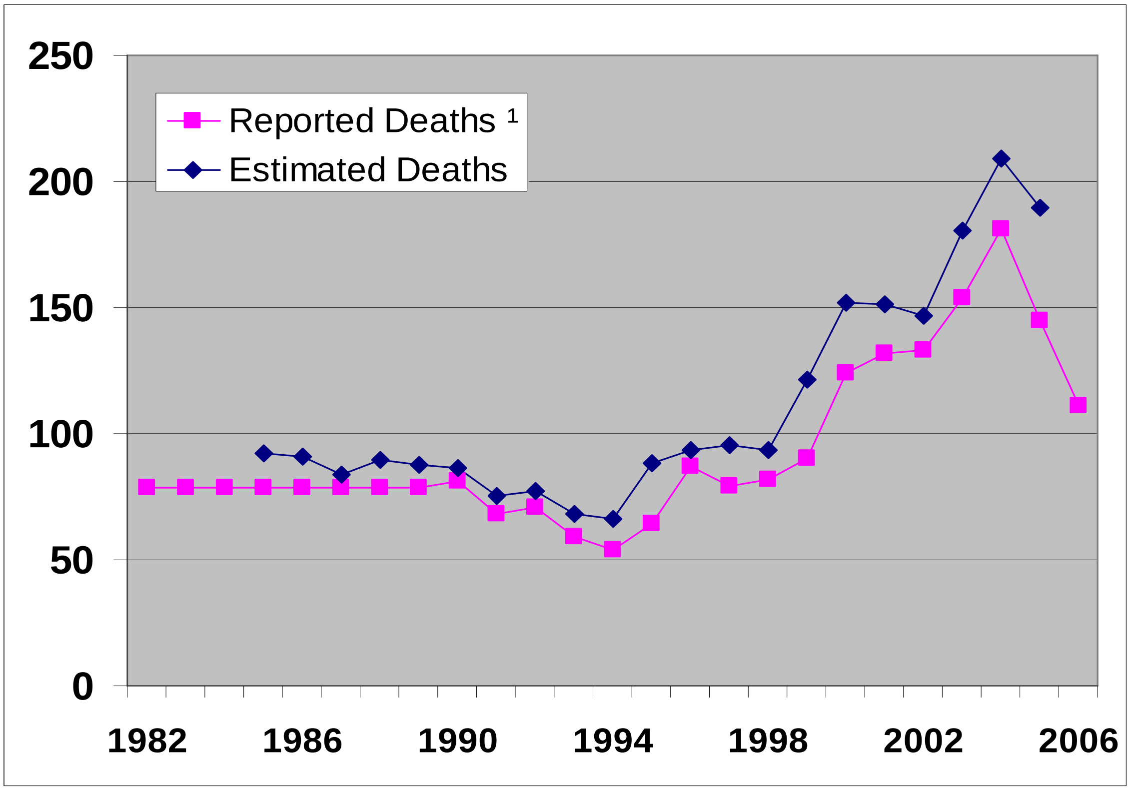

Figure 2: U.S. pediatric (age < 16) ATV deaths, 1982 to 2006. Data from Consumer Product Safety Commission (2008). Disparity between estimated and reported deaths is due to incomplete data collection methods.

Table 1. 4-H Community recommendations for ATV and rider fit. Recommendations are based upon guidelines from the Consumer Product Safety Commission and the ATV Safety Institute.

1. Clearance between seat and inseam (allowing posting) should be a minimum of 3-6 inches.
2. Thighs should be roughly horizontal while sitting.
3. The ball of the foot should fit comfortably on the footbrake.
4. Grip should enable proper throttle control.
5. The brake level should be securely gripped, and depressed with adequate force.
6. Elbows should make an angle of over 90 degrees, but should not be too straight.

Table 2. ATV Size Guidelines from the Consumer Product Safety Commission and ATV Safety Institute. Compliance by dealers is required at sale and some statutes are based upon the guidelines.

Age (years)	***Engine Displacement***
6-11	***< 70cc***
12-15	***70-90cc***
> 16	***> 90cc***

METHODS

In deriving the fit parameters to measure, a basic control system was constructed for an ATV (Figure 3) to visualize the interaction of anthropometry and vehicle dynamics. The key components within the control system are steering, braking, and positioning of the rider. These control inputs influence either the vehicle dynamics or the rider dynamics. The vehicle and rider dynamics interact with each other particularly through the terrain configuration. These dynamic systems feed back into the rider's decision to alter the control situation; these dynamics and the rider's decision are further enhanced by an anticipated or unanticipated event. The effectiveness of each control situation is directly influenced by the total body fit of the rider upon the ATV. Fit, in turn, is mediated by the anthropometry. The fit of the rider is affected by the vehicle and then the rider dynamics, meaning fit is not a constant.

Anthropometric measures were established relative to each of the control parameters outlined in Figure 3. For the control method of braking, we examined hand size compared to brake lever grip size and fit of the foot in the footwell as contributors to the ability to decelerate the vehicle. A hand strength dynamometer was used to determine whether any grip force was able to be produced at the grip sizes that matched the two ATVs. For the control method of steering, we examined the activity of turning the handlebars as directly affected by the handlebar to knee distance, as well as the elbow angle. For the control method of body control, we examined the activity of posting, naturally affected by the standing seat to pelvis distance. This factor was measured as the difference in position between the base of the pelvis were the subject standing vertically (calculated from limb length and foot position) and the crest of the seat in the coronal plane (calculated from a line drawn between markers at the front and rear of the seat). Elbow angle, measured before with respect to steering, also affects the ability to lean the center of mass to one side or the other, or shift backward or forward.

Criteria for judgment of fit were gathered both from published guidelines and from measurement of the ATVs themselves. The handlebar to knee distance recommendation was based upon a number of commercial bicycle fit guidelines, where 20 cm / 8 in was the minimum recommended distance between a handlebar in the neutral position and a knee in the maximum upward position that would allow ample room to operate the handlebars. The minimum standing seat to pelvis clearance criterion was established from the 4-H Community fit recommendation of 15 cm / 6 in, a measure that allows posting while the seat may move up and down in relation to the pelvis due to irregular terrain. Hand size versus grip size was based upon the ability of the rider to grip a variable-size hand strength dynamometer set to the average distance from the rear of the handlebar grip to the front of the brake lever. If the rider could not grip, he was scored as 0%; otherwise the rider was scored as 100%. The foot to foot-brake position criterion was measured as the ratio between the length of the foot and the distance from the foot pedal to the ball of the foot in a seated position; a score over 105% indicates an excessive distance between foot position and the foot brake and a risk for ineffective operation of the brake or clutch. Based on 4-H Community recommendations for ATVs in agreement with numerous bicycle fitment guidelines, the elbow angle criterion was set to between 90° and 135° (with locked elbows as 180°). Less than 90° indicates the arms are too angulated and the rider's torso is too close to the handlebar. Conversely, greater than 135° indicates the arms are too straight due to the torso being overly far from the handlebar and/or the handle grips being too far apart, where the rider may not be able to turn the handlebar effectively without leaning the torso.

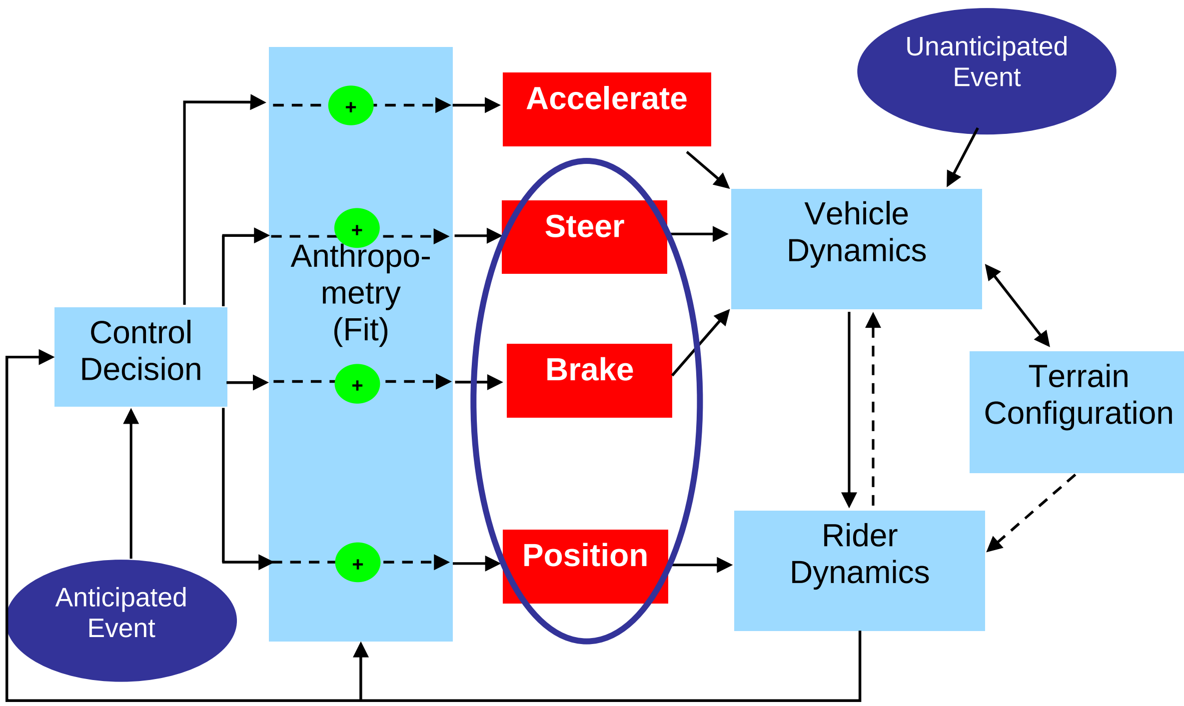

Figure 3: Basic control system diagram for an ATV. Control of an ATV is presented from an engineering perspective. The basic control parameter inputs to the system are acceleration, steering, braking, and rider positioning, each of which affect the vehicle dynamics or the rider dynamics. These two dynamic systems interact with each other, particularly through the terrain configuration. The rider dynamics and unanticipated/anticipated events feed back into the control decision whether to alter the control parameters, mediated by the total body fit (anthropometry) of the rider and the ATV.

No previous related studies were available from which to calculate sample size. We chose 8-10 subjects per group, and only males in this first phase to avoid gender variation. Riders in the two youth age groups delineated by the ASI engine size guidelines, 6-11 and 12-15 years, were placed upon age-appropriate (Kawasaki KFX90) and adult (Honda TRX500FM) ATVs. Height and body weight were also measured.

ATVs were inclined and declined with riders from 0° to 30° in 5° increments in a quasi-static approximation of likely hill angles. Thirty-six (36) reflective markers were placed upon important landmarks on the subject bodies and the ATVs themselves (Figure 4). These markers were recorded at each tilt angle using twelve digital motion cameras in order to derive the 3D spatial position of the landmarks, and through software analysis of these landmark locations the anthropometric parameters were produced. Shown in Figure 5 is a screenshot of one of our motion capture and spatial analyses.

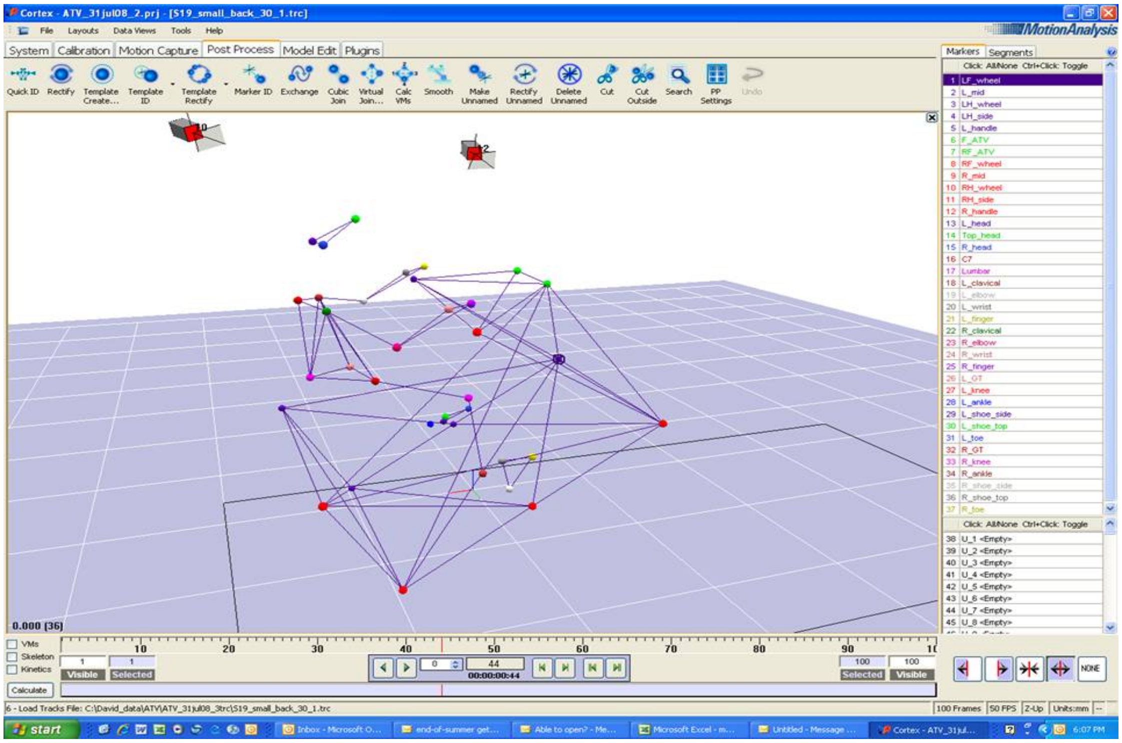

Figure 5: Example motion capture and spatial analysis of a study subject seated upon an ATV.

RESULTS

There was significant variability within the two age groups with respect to height and body mass. To describe the variability in the two age groups, box/whisker plots were assembled for the height and mass ranges. Figure 6 shows height range variability. The age 6-11 cohort shows the greatest variability across 40 cm in range, with the age 12-15 cohort varying across 30 cm in range. The mass of the study subjects was even more widely distributed, with nearly a 3-fold weight difference between the smallest and largest subjects in both cohorts (Figure 7).

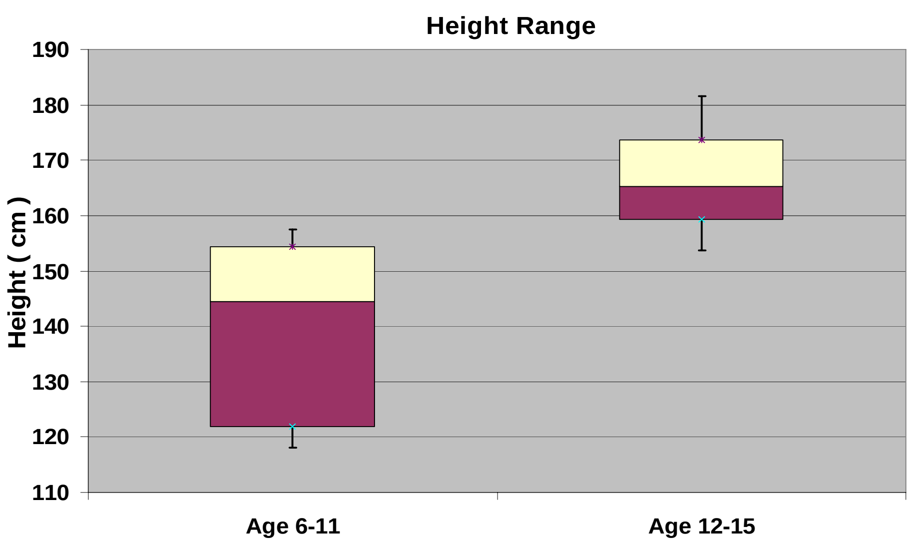

Figure 6: Height variability in the two age cohorts. Box and whisker plots show means (horizontal line), range (whiskers) and 25th percentile (boxes).

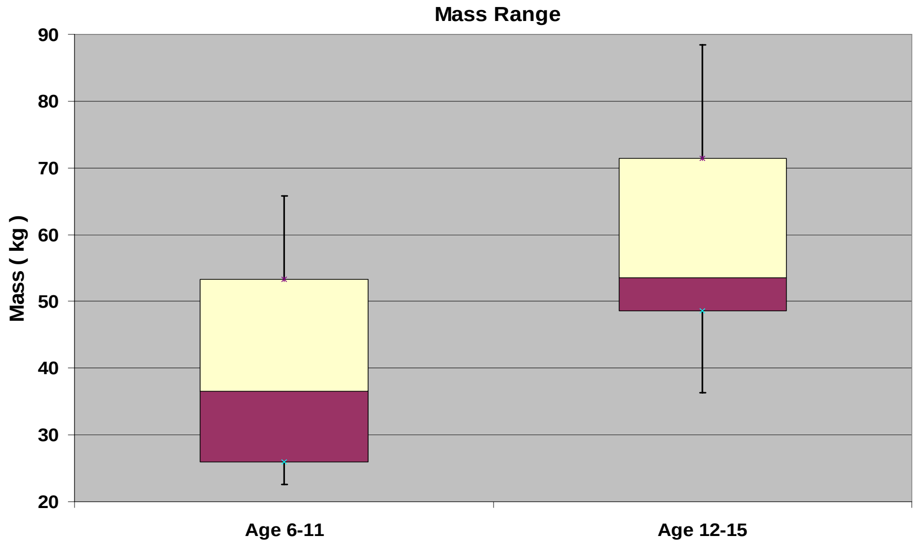

Figure 7: Mass variability in the two age cohorts. Box and whisker plots show means (horizontal line), range (whiskers) and 25th percentile (boxes).

Table 3 shows the 3 control methods of steering, braking, and body control, and the corresponding anthropometric parameters. On the (appropriate) youth ATV, the age 6-11 cohort had a mean hand size less than standard grip size for the hand brake (62.5% of subjects were able to exert a force on the grip dynamometer when sized to the handle grip size). Elbow angle was significantly larger than recommended (150° +/- 25° vs 90°-135°). For youth age 6-11 on the youth ATV, mean handlebar-knee distance, brake-foot position, and pelvic seat clearance fell within the recommended parameters.

Misfit of the age 6-11 cohort was accentuated on the adult ATV, with no criteria being met on the sample average basis except for the handlebar-knee distance. Low handlebar-knee distance was not expected to be a problem in the physically smaller 6-11 cohort on larger ATVs.

Table 3. Control methods (steering, braking, body control) and anthropometric measures of ability to execute those control methods (handlebar-knee distance, hand size, brake-foot position, pelvis clearance, elbow angle). Recommended criteria for anthropometric measures are shown above results for the age 6-11 cohort on the two test ATVs. Results show the mean and standard deviation across all subjects in the cohort (n=8). Red highlighted text indicates that the cohort on average did not meet the criterion.

Control Method	Steering	Braking		Body Control	
Anthropometric Measure	**Handlebar - Knee Distance**	**Hand Size**	**Brake-Foot Position**	**Pelvis Clearance**	**Elbow Angle**
Criteria	> 200 mm	100%	< 105%	> 150 mm	90º -135º
Youth ATV	224 ± 55 mm	**62.5%**	94 ± 20%	230 ± 102 mm	**150 ± 25º**
Adult ATV	377 ± 41 mm	**62.5%**	**116 ± 58%**	**133 ± 79 mm**	**149 ± 22º**

Subjects in the age 6-11 cohort were then analyzed with respect to each of the individual parameters to determine fit as a binary measure (Go / No-go, Figure 8). If a criterion was not met, the subject was scored as 0 for the criterion. If all parameters were not met, the subject was scored 0 for "overall fit". For the age 6-11 cohort as a whole, the fit upon the adult ATV was 0% (no subject fit all anthropometric measures). Go/No-go misfit was mostly due to excessive elbow angle in which no age 6-11 subjects met the fit measure. Low fitness figures were also noted in the foot position (2 of 8, 25%) and posting clearance (2 of 8, 25%). On the youth ATV, the elbow angle was again a limiting factor in the 6-11 age group where only 1 of the 8 subjects passed (12% fit). More subjects fit the foot position and posting clearance criteria on the youth ATV than on the adult ATV (75% on youth ATV vs 25% on adult ATV for each). Handlebar-knee distance, important for turning, was adequate for all subjects on the adult ATV and was the only category in which all subjects in the cohort met the criteria. The (appropriate) youth ATV was more restrictive, with 6 of 8 subjects (75%) meeting the criteria.

Subjects age 12-15 fit the youth ATV with respect to mean parameters in all anthropometric categories except handlebar-to-knee distance (Table 4). On average the age 12-15 cohort seated on the youth ATV found hand-size was adequate to depress the brake, the ratio between foot length and distance between ball of foot and brake pedal did not exceed 100%, pelvis clearance was adequate, and elbow angle was neither too straight nor too acute. Handlebar-knee distance was less than the set criterion for the age 12-15 cohort average. This restricted handlebar-knee distance was not unexpected. Although the vehicle used was within the recommended engine size for this age group, the frame was the same as for the 6-11 age group. In contrast to fit on the youth ATV, the 12-15 cohort fit the adult ATV frame in every category on a sample average basis. Better anthropometric fit of the 12-15 cohort on the adult ATV is in contrast to the engine size guideline.

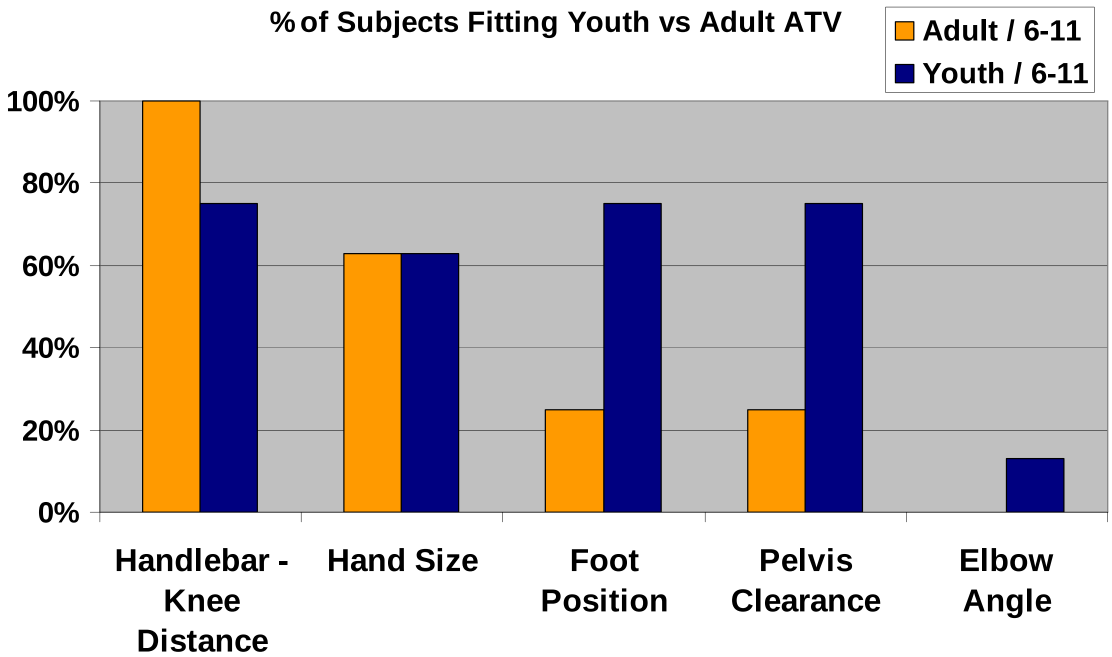

Figure 8: Per subject fit analysis for age 6-11 cohort, on the two test ATVs. Y-axis indicates percentage of subjects meeting fit criteria on each parameter and on each ATV (n=8). Criteria for anthropometric measures are listed in methods and shown in Table 3.

Table 4. Control methods (steering, braking, body control) and anthropometric measures of ability to execute those control methods (handlebar-knee distance, hand size, brake-foot position, pelvis clearance, elbow angle). Recommended criteria for anthropometric measures are shown above results for the age 12-15 cohort on the two test ATVs. Results show the mean and standard deviation across all subjects in the cohort (n=11). Red highlighted text indicates that the cohort on average did not meet the criterion.

Control Method	Steering	Braking		Body Control	
Anthropometric Measure	Handlebar - Knee Distance	Hand Size	Brake-Foot Position	Pelvis Clearance	Elbow Angle
Criteria	> 200 mm	100%	< 105%	> 150 mm	90º -135º
Youth ATV	197 ± 21 mm	100%	94 ± 7%	374 ± 64 mm	113 ± 34º
Adult ATV	343 ± 29 mm	100%	102 ± 24%	257 ± 84 mm	123 ± 26º

On a go/no-go analysis for the age 12-15 group, only 18% (2 in 11) fit the youth ATV on all parameters, mostly due to inadequate handlebar-knee distance (Figure 9). All subjects met the hand size and pelvis clearance guidelines for both ATVs. Only one subject out of eleven did not fit the elbow angle criterion and misfit for this subject occurred on both ATVs in a particularly small subject. Foot position was more consistently over the foot pedal on the youth ATV. In total the age 12-15 group fit the adult ATV better than the youth ATV.

To summarize, only 2 of 11 (18%) of age 12-15 riders fit the frame of the age-appropriate ATV (as determined by engine size). 63% (7 of 11) of subjects age 12-15 fit according to these criteria on the adult ATV. In the younger 6-11 cohort, 1 of 8 (12%) fit on the youth ATV in all parameters. No age 6-11 subjects fit the adult ATV on all criteria (Table 5).

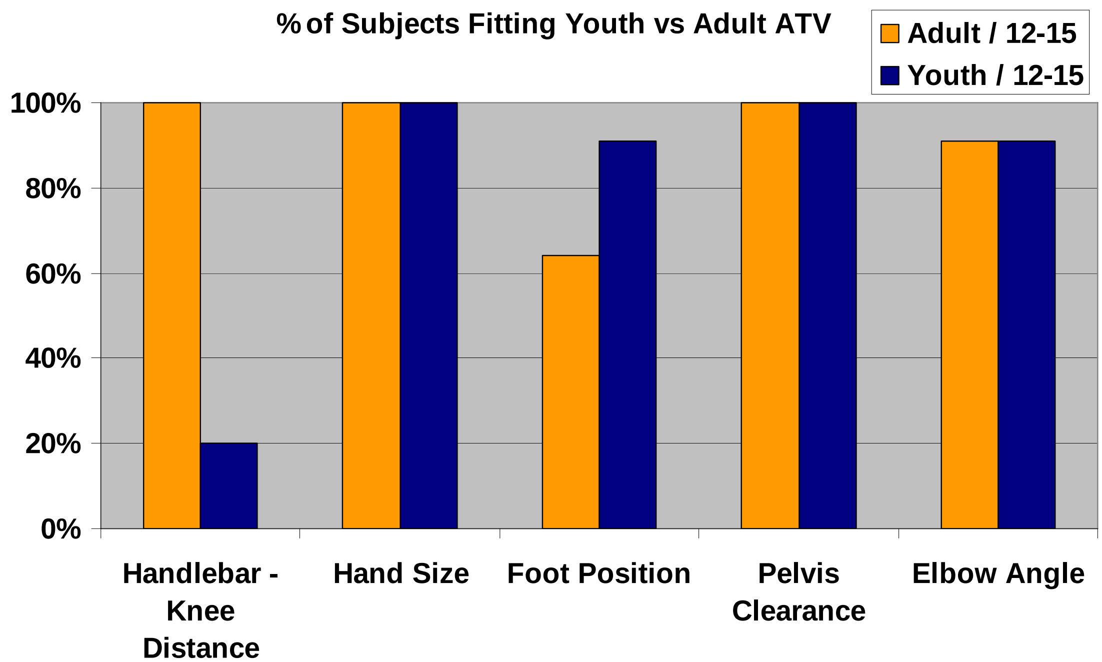

Figure 9: Per subject fit analysis for age 12-15 cohort, on the two test ATVs. Y-axis indicates percentage of subjects meeting fit criteria on each parameter and on each ATV (n=11). Criteria for anthropometric measures are listed in methods and shown in Table 4.

Table 5. Fit Summary. Subjects in each age cohort that fit all parameters on each ATV are shown.

Vehicle	*Age 6-11 (n=8)*	*Age 12-15 (n=11)*
Youth	12% (1/8)	18% (2/11)
Adult	0% (0/8)	63% (7/11)

DISCUSSION

Based on an actual sampling of human subject anthropometric data, we have shown that current guidelines based only upon age and engine size offer inadequate metrics for youth fit on all-terrain vehicles. ATV recreation is the fastest-growing motorsport in the United States, and youths regularly compete in sanctioned off-road racing events. Arguably, ATVs are here to stay, though some organizations and authors advocate a universal ban on ATV operation by youth (Curran and O'Leary, 2008; CAPS, 2008). Aitken et al. (2004) conducted focus group discussions to determine what prevention strategies might be effective and found that age limits were unlikely to be successful at reducing use. However, great caution must be exercised when purchasing an ATV for use by children.

Children suffer a disproportionately high mortality relative to adults in ATV crashes. Though this has been widely published in the medical literature, many children continue to be injured on ATV's, often while riding adult frames (Altizer, 2008; Su et al., 2006). Studies examining the causes of this discrepancy are only beginning to emerge (Moore and Sabella, 2007). Common mechanisms of injury in children are strike of stationary objects (trees, vehicles) and rolls. Brandenburg et al. described side rollovers as more common in children on both flat and uneven surfaces (Brandenburg et al., 2007; Helmkamp et al., 2008). Fractures are the most common injury pattern in youth, followed by head and trunk injuries (Kirkpatrick et al., 2007). Variability in rider size may affect injury pattern. Kellum et al. reported that older youth age 13-15 were more likely to sustain pelvic fractures while children 12 and younger sustained more lower extremity fractures (Kellum et al., 2008; Thompson et al., 2008).

Guidelines based only upon engine size have the advantage of being simple, but there is only a loose correlation between engine size and frame size. A relatively loose correlation between frame and engine size is further varied by manufacturer, model, and year. The ATV industry, through the ATV Safety Institute, has made engine size recommendations for the purpose of limiting power to young riders in gradations. However, as shown in the data presented here, wide variation exists in both height and body mass within the age groups specified by the engine size recommendations. The result is that within a given cohort, there are children that may fit all, some, or none of the investigated fit parameters. It is the opinion of the investigators that new restrictions must be established based on an alternate set of parameters.

Our data corroborate industry recommendations that children age 6-11 should never ride an adult ATV as they exist today. Based upon data shown, riders in the age 12-15 cohort may in some aspects feel more comfortable riding the Adult ATV. Unfortunately, the frame weight and engine size may be overwhelming, particularly if the rider is inexperienced. This fit finding is in contrast with what was expected. The popularly held belief that adult vehicle frame size is excessive may be false in older youth; rather, frame size may be acceptable while vehicle weight and power factor more into the propensity and severity of a crash. The cumulative effects of the control parameters measured here, vehicle weight, engine power, frame size, and terrain remain to be assessed.

Two unique and unexpected observations were made regarding ATV design. First, the handlebars on the youth and adult ATVs tested were nearly identical in size. This is evidenced by the fact that elbow angle was similar on the two ATV frames for the age 6-11 cohort. Though large elbow angle (straight arms) were accentuated by the more rearward seat position on the Adult ATV, handlebar length may impair turning ability for small children even on the youth ATV. Second, brake grip size was also approximately the same on both ATV frames. Wide brake lever variability is important to allow gradual depression and application of braking. However, wide brake levers may make reaching the brake lever, like reaching the handlebars, more of a problem for small youth even on the appropriate vehicle.

There are a number of limitations to this study. Anthopometric parameters were developed from recommendations from the CPSC, 4-H Community, industry, and standards for bicycle use. Precise relationships between these parameters and vehicle control can only be inferred at this point because these are the first published data relating anthropometry to control. This was a static test because capabilities to assess anthropometric parameters arising from realistic dynamic ATV motion were not present at the time of research. Reported fit measures may have been confounded by an observer's paradox, where the subjects may behave differently when in the lab versus on the trail. Only one ATV per frame class was assessed and for this particular manufacturer, the ATV frame size was the same between the Y6 and Y12 ATVs despite different engine displacements. Sample size was small for this exploratory study. A larger sample size and greater variability among ATVs could make the result more broadly applicable and may enable the creation of a universal fit metric. Only males were sampled. We have shown objective measures only and have not yet considered the perception of the reader as to what constitutes fit.

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DISCUSSION

PAPER: **Evaluation of Pediatric Fit and Safety Guidelines for All-Terrain Vehicles**

PRESENTER: ***James Auxier, University of Kentucky***

QUESTION: *Guy Nusholtz, Daimler Chrysler*
You fit geometric parameters to the size and positions for the ATVs. How are you going to determine what it means in terms of real-world or in terms of some sort of foundational characteristic response?

ANSWER: Are you asking how we've established the criteria for judgment of each of these parameters?

Q: Yes, it's the fit. You opened up with showing all these accidents that could happen.

A: Yes.

Q: How are you going to know that if you come up with the metric, what is that going to do either as far as reducing injuries? Or if you can't collect enough data, at least addressing the response characteristics that you could probably obtain from experimental procedures?

A: It's hard to know for sure and that does require a lot more thought on our part to assess the effect, and perhaps, an establishment of such a metric. I can always state that it would probably increase the safety of these ATVs, by and large, especially amongst children.

Q: Okay. So the hope is that if you get the fit right, then you'll have less of a problem in the field.

A: Exactly.

Q: Okay.

A: That's all we can hope to do.

Q: *Erik Takhounts, NHTSA*
I have a question. I am curious if there is some sort of consistent data set that would look into the types of injuries that occur in the field with the kids versus the death?

A: You're right. There's not really a consistent data source right now for assessing the types of accidents that occur and the situations surrounding them, especially even going as far as saying what types of injuries occur in each of these accidents. There's no consistent data source right now. This is, again, measured a lot from death reports, a lot from some trauma registry reports, but mostly from the lay media. So the establishment of such a database would definitely help in both establishing parameters for better control of who gets on the ATV or deciding who gets on what ATV, and also for deciding, kind of after-the-fact, what's going on in the most injuries.

Q: That's a totally unregulated area or--?

A: It's very loosely regulated. Some states have regulations according to wearing helmets; some states have regulations that follow the ASI guidelines according to the engine size; and, some states have no regulations whatsoever. So there's nothing on a consistent national level.

Q: Now the helmets are specific ATV helmets or they're motorcycle-type helmets?

A: They prescribe mostly according to motorcycle-like, dirt bike-type helmets.

Q: Okay.