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Limitations in fields of vision for simulated young farm tractor operators

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Farm tractors account for the majority of deaths and injuries among youths working on North American farms. A vehicle operator's field of vision is an important operational aspect for safe driving. However, very little is known about visual limitations of young tractor operators compared to adult operators. The main purpose of this study was to quantify limitations in fields of vision of children with different anthropometry. The study was based on assessment of 42 farm tractors in popular use in the USA. The results showed that youth operators typically had diminished fields of vision compared to the average adult operator. The degree of visual limitation is greatest for objects at close distances and when objects are straight in front of the operator/tractor. This has serious implications in terms of risks for runovers, rollovers and collisions. Study findings may help illuminate the development of policies and guidelines in tractor-related jobs for children.

Statement of Relevance: This study provides an ergonomic approach for evaluation of children's visual limitations in tractor operations. This approach could be used in other related cases, where children are allowed to operate vehicles.

Keywords: agriculture; children; field of vision; safety; tractor

1. Introduction

There is a strong association between agricultural injury experiences among children and children's ages and stages of development (Hendricks *et al*. 2005, Brison *et al*. 2006, Hard and Myers 2006). Several groups, including the American Academy of Pediatrics (2001), the National Research Council and Institute of Medicine (1998) and the North American Guidelines for Children's Agricultural Tasks primary advisors (Lee and Marlenga 1999) have advocated for children's farm work exposures to be consistent with developmental abilities and norms.

Farm tractors require both physical and cognitive abilities to operate them safely. Compelling data exist that demonstrate the very young ages when substantial portions of the child farm population begin to operate tractors (Aherin and Todd 1989, Hawk *et al*. 1994, Freeman *et al*. 1998, Browning *et al*. 2001, Marlenga *et al*. 2001, 2004). Additional data exist that illustrate the major burden of death and injury that result from children operating tractors (Pickett and Brison 1995, Centers for Disease Control 2003, Hard and Myers 2006). However, there is not a complete evidence base for the establishment of minimum ages for tractor operation based on child development norms.

Recent studies have examined the physical abilities of youth at different ages and stages of development and compared them to the physical demands associated with the operation of common tractors in the USA (Fathallah *et al*. 2008, 2009). These studies have determined the forces required to operate sentinel controls on these tractors, as well as the distances required to reach these same controls from a standard sitting position. The results of these studies demonstrated that a large number of youth are expected to have difficulties reaching and activating key tractor controls and levers.

From the physical development perspective, additional scientific evidence that would assist in establishing minimum age requirements for tractor operation pertains to restrictions to fields of vision that children may have due to their anthropometric characteristics (e.g. eye height and stature). Operating a farm tractor requires continuous visual feedback to keep the vehicle on its path, to access controls, to identify the shape and location of obstacles around the vehicle and to make decisions about driving strategies. Thus, restrictions to field of vision can have serious consequences and can ultimately result in tractor rollovers, runovers of bystanders and collisions.

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This study had a unique opportunity to explore the static field of vision for simulated children operating 42 tractors in frequent use in the USA. These fields of vision were summarised for both genders and three ages, 12, 14 and 16, consistent with the ages that children commonly begin to operate tractors in North America.

2. Methods

2.1. *Overview of the study design*

The eye position of tractor operators determines the field of vision available for various tractor operations. The fields of vision of simulated tractor operators between 12 and 16 years of age with 5th, 50th, 95th percentile body sizes were compared to the field of vision of a 50th percentile (average-sized)/same-gender adult. The field of vision was simulated with the 42 most common agricultural tractors in the USA. Digital mock-ups of those tractors were created from tractors owned by individual farmers and tractor dealers in the states of California and Wisconsin. Digital human mock-ups representing the simulated young tractor operators were created from one of the few available comprehensive anthropometric databases (Snyder *et al*. 1977). Anthropometric data used to create digital adult mock-ups for both genders were provided in the simulation software, SAMMIE (SAMMIE CAD Inc., Loughborough, UK).

2.2. *Models of tractor under study*

A total of 42 tractor models out of the 50 most commonly used tractors in US farms (Myers 2003) were accessible and available to the study team. The selection of the tractors is detailed in an earlier publication (Fathallah *et al*. 2008).

2.3. *Field measurement procedure*

Details about the field procedure are outlined elsewhere (Fathallah *et al*. 2008, 2009). Briefly, dealers and individual farmers in the states of California and Wisconsin in the USA generously provided access to their tractors during the field data collection. General specifications and other information were documented for each tractor. Reflective markers were placed throughout the tractor body and cab and several digital images of each tractor were then captured under specific conditions (Fathallah *et al*. 2009). These images were used to create a 3-D digital mock-up of the tractor.

2.4. *Simulation apparatus*

The simulation apparatus consisted of three sub-categories; namely, photogrammetry for digital tractor mock-up creation, an anthropometric database for creation of digital human mock-ups of simulated youth tractor operators and ergonomic computer-aided design (CAD) software for the field of vision simulation.

2.4.1. *Photogrammetry*

Photogrammetry software (PhotoModeler; Eos Systems Inc., Vancouver, Canada) was used to create 3-D digital mock-ups of the 42 tractors considered in this study. The procedure for creating digital tractor mock-ups is described elsewhere (Chang and Fathallah 2006). Briefly, a number of digital images of the tractor were taken at various angles and imported into PhotoModeler in order to obtain meaningful geometrical information. Stickers placed on various parts of the tractor provided a 'referencing' process across images. A circular code was used for identification purposes and a centre marker constituted a coded target (see Figure 1). The coordinates of each point, where the stickers were placed, were computed allowing creations of lines, curves and surfaces. From

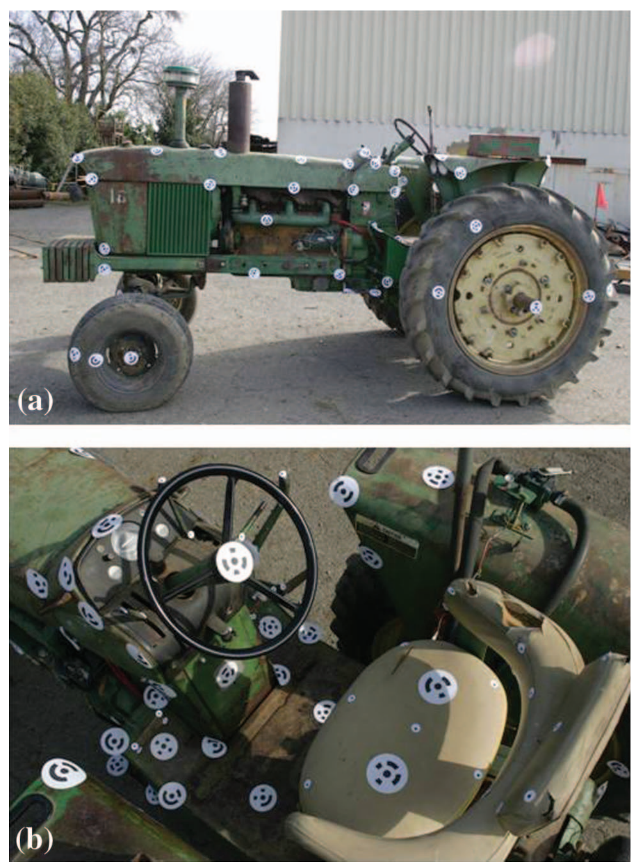

Figure 1. Images used in digital tractor mock-up creation with 'coded targets' around the tractor cab (a) and around the tractor body (b).

this information a properly scaled 3-D digital tractor mock-up was accurately produced (see Figure 2 for an example). Cylindrical components, such as exhaust pipes, were difficult to automatically create using this coded-target approach and were manually added to the digital mock-up (see Figure 3).

2.4.2. *Digital mock-ups for simulated tractor operators*

Data from a comprehensive study of children's anthropometry (Snyder *et al*. 1977) were used in order to create digital human mock-ups representing simulated young tractor operators with 5th, 50th and 95th percentiles of body size. Mock-ups were created for both genders. Details about the steps taken to create the human mock-ups are provided in an earlier publication (Fathallah *et al*. 2008). The process involved incorporating the data from the original child dataset (Snyder *et al*. 1977) into an ergonomic CAD system, SAMMIE (SAMMIE CAD Inc.), to create an appropriately scaled 3-D digital human mock-up.

2.4.3. *Field of vision evaluation*

To facilitate the field of vision evaluation, the tractor 3-D digital mock-ups and the appropriate 3-D human mock-ups were combined in SAMMIE. Figure 3 shows an example of what a 5th percentile 12-year old boy operating the tractor is expected to see when looking straight ahead. SAMMIE CAD provided a monocular field of vision with three options for the eye position (right, left and mean eye) and two options for the angle of field (wide and narrow). The mean eye position and wide angle were chosen throughout the simulations. Although the binocular field of vision was not tested, as suggested by the International Organization for Standardization, mean eye position was a logical option since the field of vision of young tractor operators would be compared to the average-sized adult operator's field of vision. The wide angle allows the collection of visual information at close range without changing the operator's posture.

The operator's field of vision is the visible area from the seated operator's eye position. ISO 5721 provides details pertaining to equipment, method and procedures. Briefly, the area of shadows cast by the light source on a cylindrical wall and the floor in a larger darkroom is recorded (International Organization for Standardization 1981). This is a complicated procedure and it is not feasible for a large sample of situations or vehicles such as tractors. This has led researchers to advocate alternative approaches (Hella *et al*. 1991, Barron *et al*. 2005). Therefore, due to the technical and procedural difficulties involving the large number of tractors, an alternative practical simulation method was introduced.

Virtual 2-m vertical bars, with a series of 5 cm grids (40 grids), were placed around the digital tractor mock-ups (Figure 4). The hypothetical vertical bars were located every 30°, forming a semicircle in front of the operator. Seven bars brought the first semicircular layer of bars to completion at a distance of 1 m from the centre of the digital operator mock-up. The semicircular layer of bars was expanded up to 5 m from the operator in 1 m increments. An additional set of five bars was located at 6, 7, 8, 9 and 10 m in the sagittal plane of the operator (i.e. straight in front of the operator). Digital tractor and human mock-ups were placed at the centre of the grid bars system. Field of vision was simulated using Human's View mode in SAMMIE, which provided what the field of vision would be, based on the digital human mock-up's anthropometry and posture. Figure 5 depicts an example of how much a 5th percentile 12-year old boy tractor operator could see out of the 2-m vertical bars on his right side (0, 30, 60 and 90° or in front of him) placed at 2 m (Figure 5a) and 3 m (Figure 5b) away from the operator. To illustrate, when the 2-m vertical bars are placed at 2 m away from the operator, the 12-year old boy is expected to see only the top 120 cm of the 2-m vertical bar placed at his far right or at 0° (i.e. child can see about 24 out of the 40 5-cm grids that make up the 2-m vertical bar). When the bars are placed 3 m away from the operator (Figure 5b), the

Figure 2. Example of a 3-D digital tractor mock-up (a) of a non-roll over protection structures (ROPS) tractor (b).

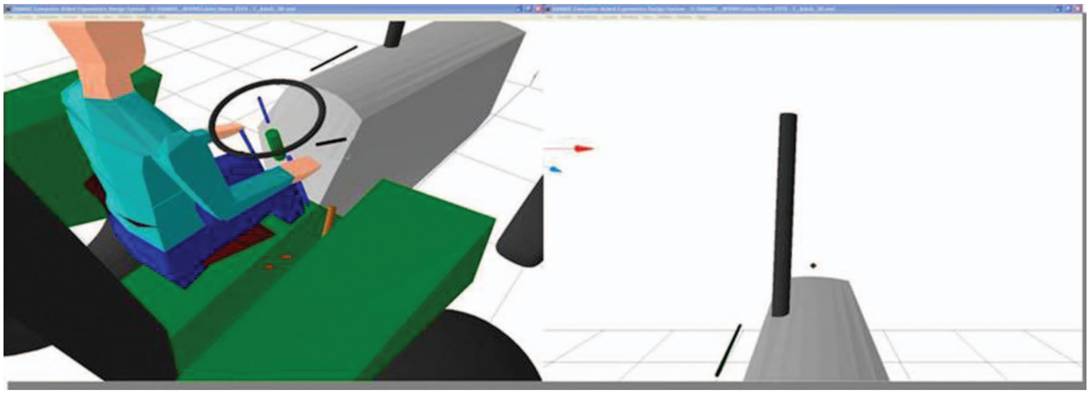

Figure 3. Example of what a 5th percentile 12-year old boy operating a tractor (left side of figure), and his field of vision or what he is expected to see when looking straight ahead (right side of figure).

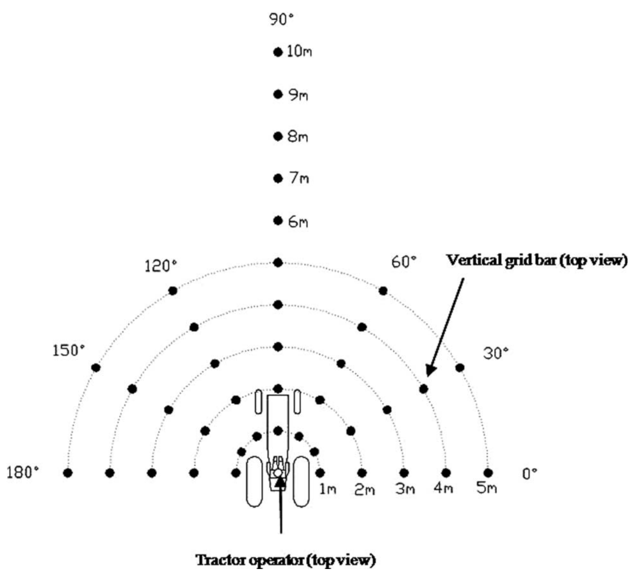

Figure 4. Layout of 2-m vertical grid bars around the digital tractor and operator mock-ups (top view).

child is expected to see the entire 2-m vertical bar placed at his far right (i.e. he can see all 40 5-cm grids that make up the 2-m vertical bar).

2.5. Data analysis

The number of tractors for which the simulated young tractor operator had a limited field of vision compared to the same-gender adult was determined for each position of the vertical grid bars. These statistics were summarised by gender, age and anthropometric percentiles.

Exposure elevation (visible vertical length from the top of a given 2-m bar) was measured by counting the number of the 5-cm grids from each digital child mock-up's viewpoint. For example, if the child simulation could detect only the top eight grids of the 2-m bar, then the child is expected to see up to 0.4 m from the top of the bar. Bars located in the projection of the digital tractor mock-up were not considered during the simulation due to lack of reality (e.g. vertical bar in front of operator shown in Figure 5a). The exposure elevation of each bar for the digital child mock-ups was compared to the exposure elevation of the same bar by gender-matched average (50th percentile) adults by creating an exposure ratio (Equation (1)):

$$E_{c/a} = \frac{E_c}{E_a} \qquad (1)$$

where $E_{c/a}$ = exposure ratio of a given vertical grid bar; E_c = exposure elevation of a given grid bar (visible vertical length of a given bar from the top) for digital child mock-up; E_a = exposure elevation of a given grid bar (visible vertical length of a given bar from the top) for a digital adult mock-up.

3. Results

Characteristics of the 42 tractors used in this study are presented in Table 1. Tractors under study were manufactured by five major tractor companies. Approximately 60% of tractors were older than 30 years, 62% of the tractors had 70 or less horsepower and the majority of them were not equipped with roll over protection structures (ROPS).

As an illustration, the percentage of tractors with visual limitation for a simulated 12-year old 5th percentile male is given in Figure 6. The focus was on the operator's right side with sagittal views only (0, 30, 60 and 90°) at 3 m or more away from the operator (the 1 and 2 m distances created many unrealistic conditions). Due to potential structural obstacles, the problem views are the zero and 90°, followed by the 60°. The 30° view did not have any tractor with visual limitation for the small 12-year old boy. Hence, the remaining analysis will focus on the 0, 60 and 90° views at 3 m or more away from the operator.

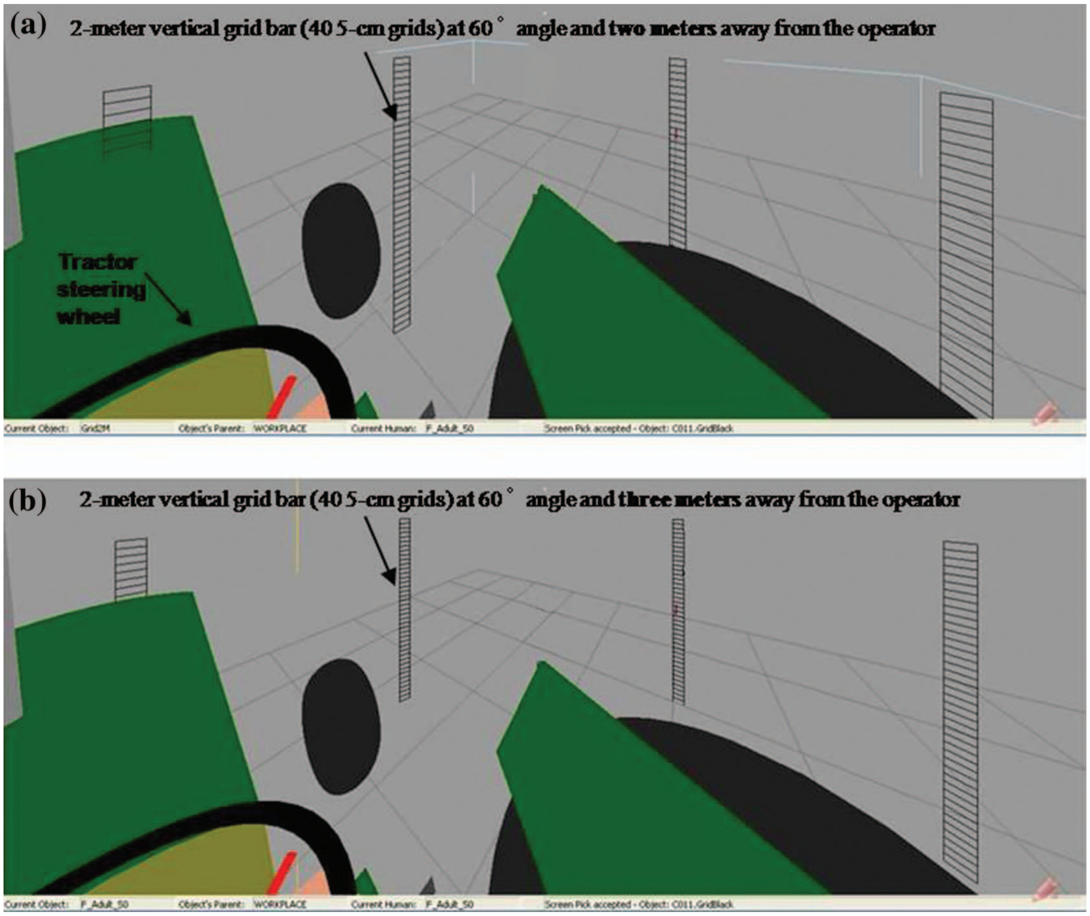

Figure 5. Examples of how much a 5th percentile 12-year old boy could see out of the 2-m vertical bars on his right side (0, 30, 60 and 90° or in front of him) placed at 2 m (a) and 3 m (b) away from him.

Table 1. Description of tractors under study.

	ROPS tractors* (n = 13)		Non-ROPS tractors† (n = 29)		Total (n = 42)	
	n	%	n	%	n	%
Manufacturer						
Allis-Chalmer	0	0.0	1	2.4	1	2.4
International Harvester	4	9.5	8	19.1	12	28.6
Ford (New Holland)	1	2.4	8	19.1	9	21.4
John Deere	8	19.1	8	19.1	16	38.1
Massey Ferguson	0	0.0	4	9.5	4	9.5
Age						
Up to 30	9	21.4	8	19.1	17	40.5
31 to 40	4	9.5	8	19.1	12	28.6
40 and over	0	0.0	13	31.0	13	31.0
Horsepower						
Under 70	3	7.1	23	54.8	26	61.9
70 and over	10	23.8	6	14.3	16	38.1

*Rollover protection structures (ROPS) tractors: Ford 3930; International Harvester 966, 1066, 1086, 1486; John Deere 4240, 4320, 4430, 4450, 4630, 4640, 5300, 5400.

†Non-ROPS tractors: Allis-Chalmers D-17; International Harvester 140, 560, 656, 706, C, Super C, H, M; Ford 8N, 641, 2000, 3000, 3600, 5000, 5610; John Deere 60, 2440, 2555, 2940, 3010, 3020, 4020, 4230; Massey Ferguson 35, 135, 165, 245; New Holland 4630.

Table 2 summarises the percentage of tractors in which the simulated young tractor operators have reduced exposure elevation by 2-m vertical bar locations in these important directions, 0°, 60° and 90°. Visual limitations in those sentinel directions are more noticeable than visual limitations in other directions (see Figure 6). Note that the number of tractors, in which the simulated young tractor operators have visual limitations, varies by the angular location of the 2-m vertical bar; for example, 24 tractors (57.1%) at 3m-0° and four tractors (10.0%) at 3m-60°. Very similar tendencies are observed for young female operators (Table 2).

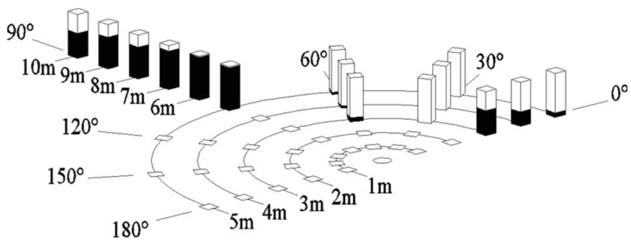

Figure 6. Example of percentage of tractors with visual limitation for a 12-year old 5th percentile male.

As expected, in a given direction, the number of tractors that yielded reduced exposure elevation upon children against an adult decreased as the location of the vertical bar became further away from the operator. For instance, in the 0° direction (far right of the operator), 24 tractors (57.1%) yielded reduced exposure elevation at the 3 m location for a 12-year-old male operator with a 5th percentile anthropometry; whereas, 14 tractors (33.3%) and four tractors (10%) yielded reduced exposure elevations at 4 m and 5 m, respectively, in that same far right of the operator or 0° direction (Table 2).

Table 2. Percentage of tractors in which young male and female tractor operators have visual limitations (i.e. less than 1.0 of exposure ratio).

		Age and anthropometric percentile of children								
		12			14			16		
Grid bar locations	Sample size	5th	50th	95th	5th	50th	95th	5th	50th	95th
Male										
0°										
3 m	42	57	45	38	48	46	19	38	29	0
4 m	42	33	19	7	21	14	0	14	2	0
5 m	42	10	2	2	2	2	0	2	0	0
60°										
3 m	40	10	8	7	10	8	5	7	8	0
4 m	40	5	5	5	5	5	5	5	5	0
5 m	40	5	5	7	5	5	8	5	8	0
90°										
5 m	42	98	98	91	98	98	21	95	62	0
6 m	42	98	93	81	95	83	33	83	71	0
7 m	42	88	81	71	86	74	29	74	67	0
8 m	42	74	71	64	71	64	21	64	55	0
9 m	42	71	57	48	60	48	19	48	38	0
10 m	42	57	48	36	52	36	12	36	29	0
Female										
0°										
3 m	42	52	43	12	45	41	0	43	0	0
4 m	42	31	17	0	19	7	0	14	0	0
5 m	42	5	2	0	2	2	0	2	0	0
60°										
3 m	40	10	8	5	8	0	0	8	0	0
4 m	40	5	5	5	5	0	0	5	0	0
5 m	40	5	5	5	5	0	0	5	0	0
90°										
5 m	42	98	93	2	98	55	0	93	0	0
6 m	42	98	93	7	93	71	0	93	0	0
7 m	42	86	76	12	81	57	0	76	0	0
8 m	42	74	71	12	71	52	0	71	0	0
9 m	42	71	55	14	57	48	0	55	0	0
10 m	42	57	38	7	48	36	0	43	0	0

4. Discussion

This study examined limitations in the field of vision of simulated youth tractor operators when operating commonly used farm tractors. Using a combination of actual field measurements and a novel digital simulation approach, simulated young tractor operators' simulated fields of vision were compared with a simulated average adult's field of vision. The major finding of this unique study was that, compared to an adult operator, youth farm tractor operators, especially those who are younger than 14 years and/or smaller in size, have compromised fields of vision. Specifically, a high percentage of the tractors evaluated had many visual obstacles to young operators, particularly if objects are at less than 9 m in the direction straight ahead of the youth operator (90°), followed by objects at less than 4 m in the far right direction (and the far left since tractor symmetry can be assumed) (0° and 180°). This finding infers that youth tractor operators will likely not see a bystander or an obstacle that is in the vicinity of the tractor, especially in the dangerous region in front of the tractor, even at several meters away. This very likely explains one determinant of the high incidence of bystander runovers and collisions involving tractors on North American farms (Pickett *et al.* 1999, 2001).

In general, female youth had slightly fewer limitations in their visual fields among the evaluated tractors when compared to their male counterparts. This is especially true for females aged 14 or 16 years who are 50th or 95th percentile body size. This is due to the differential rates of growth between male and female youth, where females tend to reach their full anthropometric growth at an earlier age than males.

The establishment of a minimum age for tractor operation is a major focus for researchers concerned with rural children's safety and health. However, there has been a lack of objective data on children's physical capabilities and limitations when operating farm tractors (Fathallah *et al.* 2008, 2009). Exceptions that allow youth of any age to operate tractors on family farms, or those who are 14–15 years old and receive special training (US Department of Labor 2004), clash with the 16-year age limit recommended by American Academy of Pediatrics for farm vehicle operation, without exceptions (Committee on Injury and Poison Prevention and Committee on Community Health Services 2001). The North American Guidelines for Children's Agricultural Tasks includes recommendations for tractor-related tasks based on the age of the operator and job complexity (Lee and Marlenga 1999). Nonetheless, these consensus-based guidelines could benefit from objective data regarding the type of physical limitations that youth operators may face when operating farm tractors. Combined with previous efforts detailing strength and reach limitations among youth tractor operators (Fathallah *et al.* 2008, 2009), this current study provides complementary data about the visual limitations that can be expected by youth tractor operators. These comprehensive quantitative data on the physical and visual limitations of youth tractor operators emphasise the need to revisit minimum age limits for youth tractor operation.

4.1. *Strengths and limitations*

Strengths of this study include its novelty, the introduction of a new approach to evaluate the impairments to young tractor operators' field of vision and its possible contribution to the establishment of guidelines for tractor-related tasks based on objective evidence. The newly introduced practical field of vision evaluation approach could be used in other situations in addition to farm tractors, such as operating cars, buses or other vehicles. Together with the effort described in this study, sentinel forces required in tractor operations (Fathallah *et al.* 2008) and anthropometric mismatches in reach distance to the major controls (Fathallah *et al.* 2009) were studied. Each study demonstrates physical mismatches between children's capabilities to operate tractors and operational demands. Collectively, these efforts should inform revised guidelines for children's tractor-related tasks in order to reduce injury events caused by physical mismatches.

Several limitations warrant discussion. First, the sampling of tractors was not random, although the approach was systematic and logical. Hence, although it targeted the most common tractors in the USA, it may not necessarily represent all the tractors operated by children in the USA. Second, the digital human mock-ups were generated based on an anthropometry study completed in the 1970s. Although the anthropometry study was very comprehensive and unique, there may be anthropometric discrepancies between children in the 1970s and current US children. No adjustment has been made to identify these potential anthropometric differences. Furthermore, evaluation with actual youth and adult operators representing various anthropometric percentiles under actual or simulated driving conditions, though very difficult, may yield different results than those reported in this study. Third, the posterior field of vision is as important as the anterior field of vision in actual tractor operation; however, tractors, in general, especially non-ROPS ones, have a wide-open posterior view when no implements are used. It was not feasible to introduce implements mounted on the tractor due to their variety in size and shape. Frequent viewing of implement operation raises greater safety and ergonomic concerns. Note that the field of vision analysis was not separated into ROPS and non-ROPS; however, in cases where ROPS were present, the tractor mock-ups included these structures. Hence, the field of vision comparisons would reflect their presence. Finally, due to feasibility issues, the operator's seat was fixed at its most forward horizontal location regardless of the anthropometry of the digital human mock-up. It is clear that taller adult operators are expected to adjust the seat backwards to provide additional leg room; yielding an increased field of vision. Hence, the difference in field of vision between a shorter child and a taller adult would be even greater than what is reported in this study for the average male adult.

5. Conclusion

It is common for youths 16 years old and younger to operate tractors on North American farms. This study focused on the evaluation of visual limitations in tractor operations among children of various gender, age and anthropometric size. The main finding of this study was that simulated youth operators typically had diminished field of vision compared to a simulated average adult operator. The degree of diminished visual field is greatest for objects at close distances and when objects are straight in front of the operator/tractor. This has serious implications in terms of risks for tractor runovers and collisions. When considering these results with those developed for strength and reach deficits, serious consideration should be given to modify the age exemptions for tractor driving on North American farms.

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