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Evaluation of the NAGCAT Tractor Guidelines

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Abstract. This study aims to build upon the North American Guidelines for Children's Agricultural Tasks (NAGCAT) project by providing a field test of the NAGCAT tractor guidelines. Several tractor dealers and farmers offered their tractors for the study in California and Wisconsin; for a total of 86 tractors. A unique photographic technique provided 3-D digital mock-ups of the tractors, which facilitated the evaluation of reach and visual abilities of adolescents using anthropometric data. Force requirements were captured using a digital force gauge and compared to existing force requirements and databases. The results indicate, in general, that hand-operated controls tend to be out of reach for both genders with the exception of steering wheels. The worst controls were hand throttle levers. On the other hand, foot-operated controls yielded higher reachable percentages for both genders, while steering wheels showed a medium range of reachable percentages. In general, youth operators showed relatively restricted fields of vision compared to the adults, and their fields of vision decreased as obstacles were closer to the tractor. The results also showed that foot-operated controls require more strength than the recommended levels. In the meantime, the recommended physical strengths of children surpassed the activation forces for hand-operated controls. This result suggests that youth operators would be very likely exposed to muscle fatigue in the leg due to the frequent use of foot clutches and brakes during tractor operation. The study showed that the demarcation of the NAGCAT by the size of the tractor is not significant for the majority of controls.

Keywords. ergonomics; safety; adolescents; children

Introduction

Agriculture is one of the most dangerous work environments in the United States. According to the National Safety Council (NSC), 5,100 workplace fatalities were due to unintentional injuries in 1998 in the United States. Fifteen percent of all fatalities occurred among agriculture workers and an additional 140,000 workers became disabled temporarily and permanently. The death rate of agriculture workers was the second highest compared to the other major industry sectors (NSC, 1998). In 1999, the fatality rate of agriculture workers was 22.5 fatalities per 100,000 workers, while the average rate for all industries was 3.8 fatalities per 100,000. Although the non-fatal injuries in agriculture are not well documented, the NSC estimated 150,000 disabling injuries, translating into 4.5 injuries per 100 workers (Rautiainen and Reynolds, 2002).

Agriculture is a dangerous environment not only for adult workers but also for children and adolescents. Unlike other industrial sectors, the workplace and home are commonly not separated in agriculture. A large portion of agricultural workers live with their families where they work. Because of this uniqueness in agriculture, childhood farm safety has received many researchers' attention in North America (Adekoya and Pratt, 2001; Bartels et al., 2000; Castillo et al., 1999; CDC, 1998; Cogbill et al., 1985; Lee, 2002; Marlenga et al., 2001; McCurdy et al., 2002; Reed and Claunch, 2000). In addition, children in agriculture are exposed to certain levels of legislative disadvantages. Family-operated farms or small farms with ten or fewer employees are not protected by the Occupational Safety and Health Act (OSHA). The other protection from unfair labor for children, the Fair Labor Standards Act (FLSA) of 1938, allows children to be hired in agriculture to work full-time as young as 12, which is 2 years earlier than in other industries. Furthermore, children hired by their family members are not subject to regulation by the FLSA (McCurdy et al., 2002). More than 90% of farms in the United States are categorized into family-operated or small farms with fewer than 11 employees (Schulman et al., 1997).

A large number of children and adolescents are exposed to farm injuries. An average of 23,505 children and adolescents 0 to 19 years of age in the United States were treated in the emergency room involved with farm-related injuries for the years 1979 to 1983. From 1990 to 1993, 22,288 children and adolescents on the average were sent to the emergency room for treatment due to the farm-related injuries. Although the number of injuries treated in the emergency room decreased between these two periods, the non-fatal injury rate in farms increased by 10.7% due to a decrease of total population in agriculture (Committee on Injury and Poison Prevention and Committee on Community Health Services, 2001; Rivara, 1985; Rivara, 1997). Common causes of non-fatal injuries among children in agriculture have been examined through many efforts (Cogbill et al., 1985; Cogbill et al., 1991; Committee on Injury and Poison Prevention and Committee on Community Health Services, 2001; Kelsey et al., 1996; Pickett et al., 2001). Machinery-related injuries, including those from agricultural tractors, accounted for a large portion of overall injuries among children (Castillo et al., 1999; Cogbill et al., 1985; Cogbill et al., 1991; Committee on Injury and Poison Prevention and Committee on Community Health Services, 2001; Gerberich et al., 1998; Hard et al., 2002; Pickett et al., 2001; Rautiainen and Reynolds, 2002; Rivara, 1985; Rivara, 1997; Schulman et al., 1997).

Farm-related fatalities among children have been studied extensively (Adekoya and Pratt, 2001; Castillo et al., 1999; Cogbill et al., 1991; Committee on Injury and Poison Prevention and Committee on Community Health Services, 2001; Dunn and Runyan, 1993; Lee, 2002; Myers and Adekoya, 2001; NSC, 1998; Pickett et al., 1999; Rautiainen and Reynolds, 2002; Rivara, 1985; Rivara, 1997; Schenker et al., 1995). In the United States, 188 deaths were classified as work-related death among youth less than 20 years of age in agriculture from 1992 to 1996, 44% of which were involved with family business, while 51% had wage based status (Castillo et al., 1999). In California, 40 deaths under 15 years of age were classified as farm-related deaths from 1980 to 1989, from death certificates analysis (Schenker et al., 1995). In Canada from 1991 to 1995, 503 deaths have been reported as work-related farm fatalities for all age groups, indicating fatality rate of 11.6 per 100,000 farm workers (Pickett et al., 1999). On average, 810 deaths in the United States were classified as agricultural fatalities by the National Safety Council (NSC) from 1992 to 1999 (Rautiainen and Reynolds, 2002).

Machinery, especially agricultural tractors cause many injuries among children in agriculture. They might be the primary cause of injury among children in rural area for several reasons. First, the majority of agricultural work-related deaths caused by machinery is accounted for by tractors. However, tractors are classified as either vehicles or machinery depending on the database system used. Fatalities due to tractor operation account for 30%, 19%, and 6% of deaths in relation to crop production, live stock production, and service area, respectively. Second, tractors are dangerous not only for the operators but also for the passengers and bystanders accounting for certain amount of fatalities (Castillo et al., 1999). Third, tractor-related accidents cause severe injuries. It has been observed that tractor-related accidents induce multiple system traumas in most cases. Finally, the mortality rate and permanent disability rate due to tractor-related injury are higher than for most other causes (Cogbill et al., 1991).

Tractor-related accidents may occur on farms due to the work assignments for children that require more of their limited physical and mental capabilities. It is important to recognize the need for match a child's developmental capabilities with the work requirements in agriculture. This will help provide parents, guardians, and supervisors the knowledge about work assignments for the children. Also, the National Committee for Childhood Agricultural Injury Prevention (NCCAIP) recommended developing work guidelines for children in agriculture (National Committee for Childhood Agricultural Injury Prevention, 1996). To meet these demands for work assignment guidelines for children, the North American Guidelines for Children's Agricultural Tasks (NAGCAT) was established based on the consensus method. A few remarkable evaluations for the NAGCAT were introduced in accordance with the effort to reduce pediatric agricultural injuries. It was observed that the work-related pediatric injury rate was decreased by implementation of NAGCAT (Gadomski et al., 2006). However, evaluation of the validity of the NAGCAT

in terms of the age and horsepower restriction for the tractor operation has not been reported.

Another, even more distinctive, purpose of this research is to provide quantitative data about popular tractors in the US, such as the locations of controls and required activation forces for controls, among others. Many tractor-related standards have been developed to provide higher lever performance and safety (ISO, 1978; SAE, 1993); however, it is also true that control configurations vary depending on the manufacturers. For instance, some tractors have clutch levers instead of clutch pedals; some tractors have linear motion gear shifts instead of standard H-type gear shifts; and so on. In addition to the differences in control configurations, the activation forces vary. It seems reasonable to understand the diversity of tractors in terms of the location of the controls, the configuration of the controls, and the activation force for the controls. These types of information could contribute to not only the possible ergonomic research but also other purposes, such as legislation, quality improvement of older tractors, and so on.

Finally, control-related data collected from various tractors are to be used in comparison with children's physical capabilities. Many efforts have been made to evaluate man-tractor relationships in different areas (Yadav and Tewari, 1998). Some focused on individual controls (Dupuis, 1959; Liljedahl et al., 1959; Pheasant and Harris, 1982); some focused on seat characteristics (Keegan and Radke, 1964; Mehta and Tewari, 2000; Morrison and Harrington, 1962; Stikeleather, 1981), and some focused on ergonomic concerns related to the mechanical characteristics of tractors (Goglia et al., 2003; Huang and Suggs, 1967; Scarlett et al., 2002; Sorainen et al., 1998). This valuable research has provided a massive amount of knowledge in evaluation of man-tractor relationships; however, their primary concerns focused on farmers. Considering a significant number of children being exposed to tractor operations in the US, it became another concern to include them in this domain. Hence, the main objectives of this study are to identify potential mismatches between children's physical abilities and tractor-operating environments with respect to: a) Children's physical capability of reaching for major controls, b) strengths exerted to maneuver major controls, and c) reduced field of view compared to an adult operator.

Methods

Sampling

Tractor selection was based on the investigation of roll-over protective structure (ROPS) usage in the US (Myers, 2003) and tractor demographic data (NASS, 2002). The data contained the top 30 tractors with ROPS and the top 30 tractors without ROPS in four regions in the US: Northeast, Midwest, South, and West. Within each region, a rank number from 1 to 30 was assigned to each tractor; i.e., the smallest number for the highest ranking and the largest number for the lowest ranking. If a particular tractor was not listed in the top 30 tractor list for a particular region, it was ranked 31st, which might be the highest possible ranking for that particular tractor. An average ranking for each tractor across the four regions was computed. The tractor list was sorted in ascending order by the highest ranking tractor among the four regions and then by the average ranking across the four regions. The top 25 tractors from the sorted list were selected. Since original data included rankings of the tractors but not actual units of tractors, it was not possible to determine the true ranking of tractors in use in the US. Also, only the top 30 rankings were included in the data; assigning a ranking of 31 for out-of-list tractors in a particular region might have introduced some uncertainty since that particular tractor might be ranked much lower in that region.

Data Collection Procedure and Analysis

The data collection process for each tractor was completed in two steps: a photography session and a force measurement session. A photography session starts with positioning a tractor on a level surface that allows enough room to take photographs around the tractor. A large building with ceiling lights is the most preferable space since influence of weather, such as wind, humidity, and lighting, can be minimized. In positioning of the tractor in an appropriate spot, the wheels must be aligned parallel to the tractor body in order to minimize unnecessary effort in the mockup creation process. Dirt and grease are to be removed from the tractor surfaces prior to setting up the marker. The controls must also be placed in proper positions. Coded targets printed on the markers are placed on the points that can be used to create a frame of the tractor. The introduction of the coded target allows for higher productivity and accuracy with the model. Neither the location of the coded target nor the orientation of the control can be changed once an image is taken, so it is very important that each step be followed with care during preparation.

Photographs of the tractor can now be taken. The primary concern with respect to photography is to ensure enough light in order to reduce the amount of noise in each photograph. The secondary concern is to reduce the contrast in images, for higher accuracy in the black and white images, which are converted from the original images during photogrammetry. Images of the tractor are taken from different locations around the tractor, varying not only the horizontal angles but also the vertical angles. The aperture and the shutter speed are set to provide wide depth of field. A so-called "full shot", which shows the whole tractor from the front to the end and from the top to the bottom, is preferred; however, partial images of the tractor might be introduced, if necessary. All images are downloaded to the portable computer for the photogrammetry

process. The photogrammetry process produces three-dimensional mock-up of the tractor using specialized computer software (PhotoModeler; Eos Systems, Vancouver, Canada). Figure 1 shows an example of a 3-D tractor mockup obtained through PhotoModeler software.



Figure 1. Example of a 3-D tractor mockup (right) created from 2-D photographs of a non-ROPS tractor (left).

Force measurement and photography sessions alternate for a tractor based on feasibility; there are several factors to consider, such as the weather and tractor availability. Usually, the activation forces for pedals are measured primarily, then levers and the steering wheel for measuring convenience; however, the measurements are not specifically ordered. The most important instructions for the investigator with the force gauge are to maintain the force gauge perpendicular to the control and to maneuver the force gauge at a slow and constant pace. Custom-made attachments are used for different controls. Three trials are performed per control; the continuous data for each trial are recorded electronically, and the peak force reading from the gauge is recorded manually for each trial, in case of data contamination and loss. Data files are converted into a spreadsheet file format for analysis purposes and investigated thoroughly to extract meaningful data points and to identify contamination. The average of three meaningful data points from each trial is considered to be the activation force for the specific control on the tractor. Activation forces for controls are brought into the database constructed to record all the tractor-related information.

Along with the force measurements, descriptive information for the tractor is also collected. A Tractor Assessment Checklist is developed based on the contribution of another co-investigator of the research. The checklist includes 4 major sections: identification and characteristics of the tractor, characteristics of the tractor seat, characteristics of and activation forces for the tractor controls, and the characteristics of the entry and exit system. Identification and the characteristics of the tractor include general information about the tractor, including manufacturer, model, make year, serial number, tractor configuration, ROPS, and other mechanical characteristics. Characteristics of the operator seat include the adjustability, armrest, backrest, seatbelt, seat material, general condition, and so on. Descriptive information about and activation forces for the control are recorded in the characteristics and activation forces section. Descriptive information of entry/exit system, such as the number of steps and handrails, is recorded for the characteristics of the entry and exit system. A large amount of information describing the characteristics of the tractor is collected on the 11-page checklist.

The activation forces for and all descriptive information about the tractor, including an image of the tractor are constructed into a database, called "SimplyTractor", using Microsoft Access (Microsoft Co.). Basically, it is designed based on the Tractor Assessment Checklist and capable of including all remarks that are additionally recorded on the checklist. Also, it is able to input the gauge readings of the activation forces in the database. Database construction allows convenient data entry and expansion of records for further usage. An example is presented in Figure 2. The main purposes of database construction are preservation of all information in the archives and providing convenience for the further research.

Figure 2. Example of the tractor electronic database.

Reach analysis is one of the important parameters in workplace assessment and displays the dimensional characteristics of the operator and the workplace. Digital human figures for 12, 14, and 16 year old males and females were created using an anthropometry data set of US children, and the reach capabilities of youths on popular tractors were simulated using a CAD-based computer software (SAMMIE CAD Inc., Loughborough, UK) (see Figure 3 for an example). "Field of vision" implies the amount of visual information for the tractor operator. Visibilities for youths were simulated in accordance with the field of vision module in SAMMIE CAD and compared with the visibilities for same gender adults in order to display visual disadvantage of the youth operator. The visibility was evaluated based on a series of 200 cm bars placed at dispersed distances (1 through 10 meters, in 1-meter increments) at various angles with respect to the operator's eyes (0 to 180 degrees in 30-degree increments; 0 far right; 180 far left).

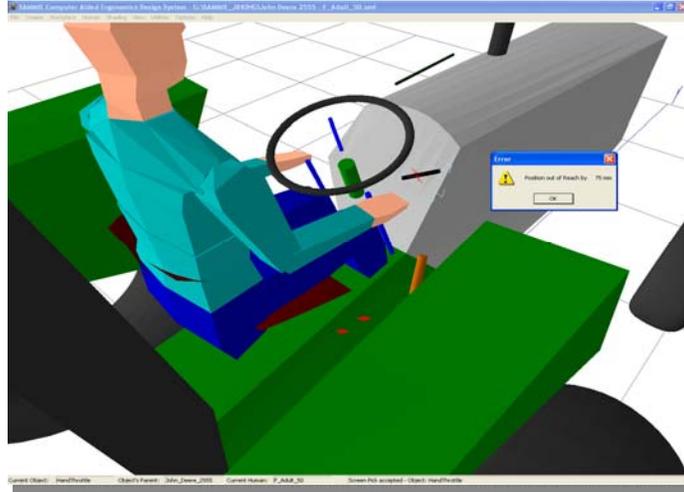


Figure 3. Example of reach evaluation using SAMMIE CAD, which combines the tractor digital 3-D mockup with digital anthropometrically-based 3-D human figure.

Results

Reach Evaluation

The number of observations and percentage of observations for which controls were located within reach distance are listed in Tables 1. Some controls yield a relatively high percentage for reach among children, for instance foot brakes and clutches. On the other hand, the majority of hand controls were out of reach, except for steering wheels. More than 90% of the gears were out of reach for male children at all age groups, while only 1 tractor had a gear within reach distance for all female children of all ages. Less than 10% of tractors had PTO levers within reach distance for all male and female age groups. Less than 15% of tractors had 3-point levers within reach distance for all male and female age groups. Up to 40% of tractors were equipped with hydraulic levers at reachable distance for male children; however, the value decreased to 24% for female children. Hand throttles were located at the farthest position, showing 0% of observations for all age groups in both genders.

It was also interesting to see the results of the simulation on adult mockups in the 50th percentile in anthropometry, although it was not a primary objective of the study. The 50th percentile male mockup showed a 100% of reach for foot brakes and clutches, while the female mockups showed 91% and 95% of reach for foot brakes and clutches, respectively. A relatively smaller percentage of reach was observed among hand controls for both genders. Power-takeoff (PTO) was the worst control for the adult population; a 50th percentile male adult could reach the PTO levers on 13 particular tractors (approximately 30%) and a 50th percentile female adult could reach the PTO levers on 8 particular tractors (approximately 18%). The hand throttle, which was the worst control for children, was located within reach distance of a 50th percentile male adult on 27 tractors and was located within reach distance of a 50th percentile female adult on 16 tractors.

Comparison between horsepower of the NAGCAT tractor guidelines was assessed for distinguishing among tractor reach requirements for various adolescents. The size of the tractor, i.e., horsepower, showed

significance with respect to steering wheels, 3-point levers, and remote hydraulic levers for limited numbers of human figures. The results indicate that horsepower-based guidelines are appropriate for certain types of controls among children of specific ages and with specific body size. Other factors, such as manufacturer and age of the tractor, were suggested; however, they also show significance for limited numbers of the test.

Table 1. Number of tractors (44 total tractors) for which controls were located within reach distance for selected controls for 12 and 16 male and female of varying anthropometric percentile as compared to 50th percentile adults.

Gender	Male						
Age	12			16			Adult
Percentile	5 th	50 th	95 th	5 th	50 th	95 th	50 th
Foot Brake Right	13	35	41	40	44	42	44
Foot Brake Left	17	37	40	41	42	39	42
Foot Clutch	21	38	38	39	37	27	40
Steering Wheel	12	17	26	17	25	31	45
Hand Throttle	0	0	0	0	0	0	27
Gear	0	3	3	3	3	4	24
3-point	3	4	6	4	4	6	25
PTO	2	2	2	2	2	2	13
Hydraulic	9	10	13	9	14	15	22
Gender	Female						
Age	12			16			Adult
Percentile	5 th	50 th	95 th	5 th	50 th	95 th	50 th
Foot Brake Right	10	32	40	35	40	44	41
Foot Brake Left	15	35	41	39	41	43	41
Foot Clutch	19	34	41	39	41	39	41
Steering Wheel	10	14	16	15	15	16	42
Hand Throttle	0	0	0	0	0	0	16
Gear	0	0	1	0	0	0	19
3-point	1	2	3	2	2	2	24
PTO	0	4	4	2	2	0	8
Hydraulic	6	8	9	8	9	9	23

Visibility Evaluation

The visible lengths of 200 cm grid bars at each location are summarized in Tables 2 for a 12 year boy with 5th percentile anthropometry. These were also obtained at different age, gender, and anthropometry. Naturally, visible length increased as the grid bar was located farther from the tractor. For an average adult, the visible lengths of the bars located at 0° and 180° increased from 89 centimeters to 200 centimeters and 83 centimeters to 200 centimeters on average, respectively. The same tendency was observed for bars located at 60° and 120°, showing an increase from 176 centimeters to approximately 190 centimeters for both angles. However, visible length at 60° and 120° increased gradually as the grid bars were located farther away, while it showed a dramatic increase at 0° and 180°. The differences in these tendencies indicate that the left and right fenders of tractors interfered with the operator's view. On the other hand, the operator had a clearer view at 60° and 120°, where the majority of tractors had entrances.

The horsepower partition of the NAGCAT tractor guidelines was effective with respect to most of the male mockups and some of female mockups tested in the visual evaluation.

Table 2. Average visible length of 200 cm grid bars upon 12-year-old boy with 5th percentile anthropometry (empty cells indicate the 200 cm is completely visible).

		Angle (degree)*						
		0	30	60	90	120	150	180
Bar Distance (meter)	1	83.00	160.00	169.19		169.82	164.12	78.33
	2	114.39	133.90	176.81	95.83	175.00	133.90	114.02
	3	164.88	161.34	186.46	60.28	182.32	166.71	164.76
	4	187.93	180.37	187.56	72.56	185.37	180.85	188.05
	5	197.80	190.98	187.32	91.95	185.37	190.12	196.59
	6				111.59			
	7				131.22			
	8				147.32			
	9				161.10			
	10				172.44			

* 90 degrees looking straight ahead; 0 degrees looking to the far right and 180 degrees looking to the far left

Force Evaluation

Descriptive statistics of the required activation forces for major controls in tractors are provided in Table 3. Most lever controls showed small differences between push and pull operations, except for the 3-point lever. Steering wheels also showed small differences between clockwise and counterclockwise operations; however, a greater difference was observed between power and non-power steering wheels. Braking forces showed greater differences between measurement conditions, i.e., with and without ramp. The method for the measurement of braking forces without ramp was similar to the method for the measurement of clutching forces in terms of full depression of the pedal. Braking forces for full depression, clutching forces for full depression, and steering forces for non-power steering wheels showed the greatest mean values compared to the other controls.

The mean of required activation force (Table 3) was compared to the mean of estimated strength (Table 4) in children at 12, 14, and 16 for both genders with a t-test (Table 5). Positive t-values indicate that the strengths of children are equal to or greater than the required activation forces. On the other hand, the negative t-values indicate that the strengths of children are smaller than the required activation forces, if significant. All negative t-values happened to be significant statistically ($p < 0.05$). In other words, it requires more than the allowable children's strengths (i.e., 30% of maximum strength) to fully depress brake pedals and clutch pedals for all age and gender groups. However, all lever type controls require less force than the allowable children's strength in push and pull operations.

The horsepower partition in the NAGCAT tractor guidelines was not effective in distinguishing among groups, especially for the foot-operated controls. Tractors from certain manufacturers required significantly less activation forces for brakes, and tractors between 21 and 40 years required significantly greater clutching force than tractors up to 20 years. Generally speaking, required activation forces for foot brakes, foot clutches, and non-hydraulic assisted steering wheels surpassed the allowable strength of children up to 16 years of age for both genders, while activation forces for standard lever-type controls remained within the range of the allowable strength of children.

Table 3. Descriptive statistics of required activation force in Newton.

Controls	Direction	Sample size	Mean	STD	Min	Max	Remarks
Brake	-	50	83.3	72.9	8.0	313.3	With Ramp
	-	31	203.6	44.4	129.0	325.8	Without Ramp
Clutch	-	85	282.0	85.0	113.3	487.7	
Steering wheel	CW	70	22.1	23.9	6.0	163.3	With hydraulic assistance
	CCW	71	20.5	23.1	6.7	155.3	
Steering wheel	CW	15	213.2	66.9	117.3	356.0	No hydraulic assistance
	CCW	14	208.9	62.8	101.5	315.0	
PTO	Push	80	71.0	51.3	8.7	233.0	
	Pull	78	69.9	65.3	4.7	375.5	
3-point	Push	76	56.3	37.0	7.8	190.0	
	Pull	75	71.1	42.7	9.3	205.7	
Remote hydraulic	Push	84	78.4	51.2	10.7	268.7	
	Pull	84	68.4	45.0	6.0	238.7	
Hand throttle	Push	68	47.0	21.6	16.0	136.0	
	Pull	70	43.4	19.3	16.2	109.2	
Gear system	Push	86	65.1	23.0	19.1	122.6	Gear/range shifts combined
	Pull	86	65.6	24.8	24.9	192.4	

Table 4. Estimated strengths of children

Gender	Age	Lever			Pedal		
		N	Mean	SD	N	Mean	SD
Male	12	50*	96.66	19.02	27	106	22.83
	14	50*	134.49	32.61	27	150.6	30.20
	16	50*	169.89	32.61	22	183.2	36.90
Female	12	50*	90.66	19.02	31	98.6	19.90
	14	50*	108.3	22.50	20	110.5	17.40
	16	50*	118.62	24.06	33	123.1	18.27

* Estimated sample size

Table 5. Results of t-test between required activation forces and estimated strengths of children

	Male			Female		
	12	14	16	12	14	16
Brake with ramp	2.03	5.69	7.71	1.41	2.47	3.69
Brake without ramp	-10.71	-5.37	-1.82	-12.00	-10.48	-9.37
Clutch	-17.23	-12.06	-8.15	-18.55	-17.14	-16.29
PTO push	4.05	8.63	13.44	3.10	5.69	7.14
PTO pull	3.40	7.41	11.47	2.64	4.77	5.99
3-point push	8.03	12.47	18.12	6.84	9.80	11.46
3-point pull	4.55	9.39	14.63	3.48	6.33	7.93
Hand throttle push	2.94	7.73	12.62	1.97	4.64	6.14
Hand throttle pull	5.05	9.81	15.06	3.98	6.82	8.41
Remote hydraulic push	13.21	16.49	23.16	11.61	14.86	16.67
Remote hydraulic pull	15.02	17.66	24.52	13.33	16.51	18.29

Discussion and Conclusion

Agriculture is essential to human life yet has been established as a hazardous work environment for those who work in it. Due to cultural and economic reasons, it is widely accepted to assign agricultural tasks to youths. Work assignments tend to be decided based on the experiences of supervisory adults rather than documented guidelines or legislative regulations. These disadvantages may cause overestimation of the capabilities of youth workforces and exposure to greater danger as a result. Tractors, one of the most common and frequently used pieces of equipment in agriculture, are no exception. The significance of young victims of tractor-related accidents has attracted the attention of epidemiologists and the public. Tractor operation depends on the operator's mental capabilities and physical capabilities; however, it is important to realize that superb mental capabilities do not compensate for the lack of physical capabilities and vice versa. This paper focused on the evaluation of physical mismatches between operational demands and the operator's capabilities in tractor operations.

The overall evaluation was simulated by an ergonomic CAD system in connection with photogrammetry software. Photogrammetry derives geometrical information of an object from digital images taken at various angles. The overall quality of the virtual 3-D models created by the photogrammetry software was satisfactory in indicating relatively higher accuracy – less than one pixel of residual error on the average. Using photogrammetry is advantageous, especially in connection with an ergonomic evaluation tool, graphic software, or CAD systems. An ergonomic evaluation tool called SAMMIE CAD was implemented for the dimensional evaluations and field of vision analysis.

Reach analysis is one of the important parameters in workplace assessment and displays the dimensional characteristics of the operator and the workplace. Human figures for 12, 14, and 16 year old males and females were created using an anthropometry data set of US children, and the reach capabilities of youths on popular tractors were simulated. The results indicate, in general, that hand-operated controls tend to be out of reach for both genders with the exception of steering wheels. The worst controls were hand throttle levers; literally no tractor had a hand throttle lever within reach for all age groups tested. Only 60% and 36% of all tractors had hand throttles within reach for average-sized mature males and females, respectively. On the other hand, foot-operated controls yielded higher reachable percentages for both genders, while steering wheels showed a medium range of reachable percentages. "Field of vision" implies the amount of visual information for the tractor operator. Visibilities for youths were simulated in accordance with the field of vision module in SAMMIE CAD and compared with the visibilities for same gender adults in order to display visual disadvantage of the youth operator. In general, youth operators showed relatively restricted fields of vision at 30, 90, and 150° compared to the adults, and their fields of vision decreased as obstacles were closer to the tractor. Differences in field of vision between an adult and a child may look small, i.e. more than 90% of the adult field in most cases; however, this small difference may determine detection of an object around the tractor, such as a simple obstacle, a ditch, or even a bystander.

The strength of a youth operator dictates his/her capability for maneuvering various controls on a tractor. The physical strengths of children were compared to the activation forces for various controls to verify their maneuvering capabilities. The activation forces for controls were collected based on the popularity and accessibility of tractors, while the physical strengths of children were estimated from alternative sources, due to the lack of exact data for US children. Their maximum strengths easily surpassed the activation forces for controls in general; however, it was not recommended to exert more than 30% of maximum strength for frequently used controls. The results of statistical analysis indicate that foot-operated controls require more strength than the recommendation. In the meantime, the recommended physical strengths of children surpassed the activation forces for hand-operated controls on the average. This result suggests that youth operators would be very likely exposed to muscle fatigue in the leg due to the frequent use of foot clutches and brakes during tractor operation.

Overall, the results of comparisons suggest that there are differences between operational demands and the physical/visual capabilities of youth operators, which do not necessarily indicate a need to ban on tractor operation by youth operators, but urges the necessity of awareness by supervisory adults and the public. The primary purpose of this study is to confirm the difference between operational demands of agricultural tractors and the physical/visual capabilities of youth operators. The study has also demonstrated that the horsepower division in the NGCAT guidelines may not be an effective way to assign tasks to adolescent operators. Furthermore, it is expected that the confirmation of those differences will be used in related research and the development of guidelines, ultimately to contribute to decrease in agricultural injuries and deaths of children.

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