An ergonomic analysis of the controls present in a tractor workstation

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Drakopoulos, D. and Mann, D.D. 2007. **An ergonomic analysis of the controls present in a tractor workstation**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **49**: 2.15-2.21. In the cab of a tractor, the driver communicates information to the tractor using various types of controls (i.e., rotary switches, toggle switches, rocker switches, knobs, push buttons, hand–levers, and steering wheels). The published literature documents numerous design and ergonomic considerations that should be followed to maximize the operator's interaction with machine controls. This paper reviews the published literature and identifies guidelines related to seven types of controls, control placement, control labeling, and functional reach. Six agricultural tractor workstations, with manufacturing dates between 2003 and 2005, were analyzed to determine the degree to which tractor manufacturers comply with these published recommendations. Published design recommendations are being followed, however, some dimension values being used are less conservative than others. Separation distance is the most notable case; small separation distances are being used, perhaps to fit more controls into the limited space available within tractor cabs. Analysis revealed that 89% of controls are situated on the right-hand side of the workstation, but only 75% of controls fall within the functional reach envelope. Ninety-five percent of controls are labelled using either a symbol or text, with symbols being used most frequently. **Keywords:** tractor controls, design guidelines, ergonomic analysis.

Lorsqu'il est à son poste de conduite, l'opérateur d'un tracteur agricole transmet des commandes à la machine en utilisant différents types de commandes (i.e., interrupteurs rotatifs, interrupteurs à bascule, interrupteurs culbuteurs, manivelles, boutons à enfoncer, leviers et volants). La littérature fait état de plusieurs considérations ergonomiques et de conception pouvant être utilisées dans le but de maximiser l'efficacité des interactions de l'opérateur avec les contrôles du tracteur. Cet article fait la revue des articles publiés et identifie les recommandations pour sept types de commandes, l'emplacement optimal pour ces commandes, l'identification visuelle et l'accessibilité des commandes. Six postes de conduite de tracteurs agricoles fabriqués entre 2003 et 2005 ont été analysées pour déterminer jusqu'à quel niveau les manufacturiers de tracteurs suivent les recommandations publiées. Bien que les recommandations de design publiées soient généralement suivies, quelques dimensions utilisées sont moins conservatrices que d'autres. La distance séparatrice est l'élément le plus remarquable; de petites distances séparatrices sont utilisées, probablement pour pouvoir placer le plus de commandes possibles dans l'espace limité disponible dans les postes de conduite de tracteurs. Une analyse montre que 89% des contrôles sont situés sur le côté droit de la station de travail mais que seulement 75% des contrôles sont à l'intérieur de la zone fonctionnelle de portée de l'opérateur. Quatre-vingt-quinze pourcent des contrôles sont identifiés, que ce soit par un symbole ou par du texte, et les symboles constituent le mode d'identification le plus répandu. **Mots clés**: contrôles de tracteurs, recommandations de design, analyse ergonomique.

INTRODUCTION

In the environment of the tractor cab, a control is the device that allows the tractor operator to 'communicate' with the tractor and the attached implement by transmitting information to them (Purcell 1980). The functionality of a control panel in a tractor comprised of various individual controls depends upon the human operator's ability to interact with it. It must be remembered that the controls are part of a larger system consisting of the tractor, one or more implements attached to the tractor, and the human operator (Langle et al. 1997). Casey and Kiso (1990) found that there are preferred locations for certain types of tractor controls. At the other extreme, Hsiao et al. (2005) found that the placement of controls in some tractors actually creates an impediment to body movement. Thus, it is critical that human factors be considered when designing both individual controls and the entire control panel. Information on control design exists in the published literature, however, it is not known whether the published design recommendations are followed by designers of agricultural tractors.

In this paper the published literature is reviewed to identify the recommended dimensions of seven types of controls (i.e., rotary switches, toggle switches, rocker switches, knobs, push buttons, hand levers, and steering wheels) and suggestions for labelling and placement of such controls. The reader is directed to Wagner et al. (1996) for schematic diagrams of these control types illustrating the relevant dimensions. The objective of this research was to determine the degree to which manufacturers of modern tractors comply with these published recommendations. To achieve this objective, six tractor workstations, representing six distinct tractor manufacturers with manufacturing dates between 2003 and 2005 were analyzed.

LITERATURE REVIEW

Recommended dimensions for rotary switches

Pheasant (1986) noted that the rotary switch is the preferred control in situations where multiple settings (i.e., up to 24) are required. The efficiency of using a rotary switch is most influenced by its length, width, height, and its separation from other controls (Department of Defense 1999). The majority of sources (Table 1) suggested a minimum length of 25 mm, but there was some discrepancy in the maximum length. Pheasant (1986) suggested an optimum length of approximately 30 mm, but others suggested the length may be up to 100 mm. There is good agreement that the width should be less than 25 mm and

Table 1. Recommended dimensions for rotary switches.

Source	Length (mm)	Width (mm)	Height (mm)	Separation (mm)
Van Cott and Kinkade (1972)	25-76	≤ 25	12-76	50*
Pheasant (1986)	25-30*	≤ 25	15-25*	50*
Granjean (1988)	≥ 25	≤ 25	12-70	N/A
Konz (1990)	N/A	N/A	N/A	25*
Weimer (1993)	25-100	13-25	12-75	N/A
Sanders and McCormick (1993)	25-76	12-25	≥ 12	N/A
NASA (1995)	N/A	N/A	N/A	40*
Corlett and Clark (1995)	12-70	≤ 25	12-70	25-50
Wagner et al. (1996)	25-100	≤ 25	16-75	50*
Department of Defense (1999)	25-100	≤ 25	16-76	50*

* Presented as being the optimum value

Table 2. Recommended dimensions for toggle switches.

Source	Arm length (mm)	Horizontal separation (mm)	Vertical separation (mm)
Van Cott and Kinkade (1972)	13-50	25*	50*
Pheasant (1986)	15-50	50*	50*
Granjean (1988)	12-50	50*	50*
Konz (1990)	N/A	19*	N/A
Weimer (1993)	12-50	50*	50*
Sanders and McCormick (1993)	12-50	50*	≥ 50
NASA (1995)	13-50	50*	50*
Corlett and Clark (1995)	13-50	≥ 12	75*
Wagner et al. (1996)	13-50	50*	50*
Department of Defense (1999)	13-50	50*	50*

* Presented as being the optimum value

Table 3. Recommended dimensions for rocker switches.

Source	Width (mm)	Length (mm)	Separation (mm)
Van Cott and Kinkade (1972)	N/A	N/A	N/A
Pheasant (1986)	12-15*	25-30*	50*
Granjean (1988)	N/A	N/A	N/A
Konz (1990)	N/A	N/A	25*
Weimer (1993)	≥ 6	≥ 13	N/A
Sanders and McCormick (1993)	N/A	N/A	N/A
NASA (1995)	≥ 6	≥ 12	≥ 19
Corlett and Clark (1995)	25*	15*	N/A
Wagner et al. (1996)	≥ 6	≥ 13	≥ 32
Department of Defense (1999)	≥ 6	≥ 12	≥ 19

* Presented as being the optimum value

that the height should range between 15 and 75 mm. Several of the sources suggested 50 mm as the optimum separation distance between rotary switches for one-hand operation. According to these sources, acceptable dimensions for rotary switches are:

- Length: 25-100 mm
- Width: ≤ 25 mm
- Height: 12-75 mm
- Separation: 50 mm

Recommended dimensions for toggle switches

Grandjean (1988) demonstrated that the toggle switch is the preferred control for on/off or other two–state selection. He also states that it may be used in three positions (e.g., on/standby/off), but the rotary switch is preferable in such cases. Similar findings have been presented by Pheasant (1986) and Weimer (1993). A further study from NASA (1995) regarding the operation efficiency of toggle switches showed that there are three important dimensions: 1) arm length, 2) horizontal separation distance, and 3) vertical separation distance. From the sources reviewed (Table 2), there is good agreement for all three dimensions. Acceptable dimensions for toggle switches are:

- Arm Length: 12-50 mm
- Separation (horizontal and vertical): ≥50 mm

Recommended dimensions for rocker switches

The Department of Defense (1999) conducted laboratory studies regarding the usefulness of rocker switches. They found that rocker switches may be used in lieu of toggle switches for functions requiring two discrete positions. Rocker switches may also be used for applications where toggle switch handle protrusions might snag the operator's sleeve or where there is insufficient panel space for separate labelling of switch positions. The critical dimensions for a rocker switch are width, length, and the separation between centres. A small number of sources contained information regarding rocker switches, although there was good agreement among those sources containing relevant information (Table 3). Wagner et al. (1996) suggested that the separation distance should be increased to 32 mm if the operator is likely to be wearing gloves. Acceptable dimensions for rocker switches are:

- Width: ≥ 6 mm
- Length: ≥ 12 mm
- Separation: ≥ 19 mm

Recommended dimensions for knobs

Grandjean (1988) noted that knobs should be used when low activation forces or precise adjustments of a continuous variable are required. In tractors, there are a variety of operations that require precise adjustments (Purcell 1980). The need for precise adjustments is expected to continue for the foreseeable future given the current emphasis on precision agriculture. For most tasks, a moving knob with fixed scale is preferred over a moving scale with fixed index (Department of Defense 1999). Most sources suggested that the height of a knob should range between 12 and 25 mm; only one source suggested a maximum height greater than 25 mm (Table 4). Another critical dimension is knob diameter. Recommended diameters range from 10 to 100 mm. One possible explanation for the

Table 4. Recommended dimensions for knobs.

Source	Height (mm)	Diameter (mm)	Separation (mm)
Van Cott and Kinkade (1972)	12-25	50*	50*
Pheasant (1986)	15-25	15-30*	50*
Granjean (1988)	15-25	35-75	50*
Konz (1990)	N/A	N/A	25*
Weimer (1993)	12-25	10-100	50*
Sanders and McCormick (1993)	12-25	50*	50*
NASA (1995)	N/A	N/A	N/A
Corlett and Clark (1995)	12-70	25-100	25-50
Wagner et al. (1996)	13-25	10-100	50*
Department of Defense (1999)	12-25	10-100	50*

* Presented as being the optimum value

Table 5. Recommended dimensions for push buttons.

Source	Diameter (mm)	Separation (mm)
Van Cott and Kinkade (1972)	≥ 12	12-50
Pheasant (1986)	12-15	50*
Granjean (1988)	12-15	50*
Konz (1990)	N/A	50*
Weimer (1993)	10-19	50*
Sanders and McCormick (1993)	≥ 12	50*
NASA (1995)	≤ 40	N/A
Corlett and Clark (1995)	12-25	15-22
Wagner et al. (1996)	9.5-25	50*
Department of Defense (1999)	10-25	50*

* Presented as being the optimum value

Table 6. Recommended dimensions for hand levers.

Source	Displacement (mm)	Separation (mm)	Activation force (N)
Van Cott and Kinkade (1972)	≤ 355	50-100	≤135-225
Pheasant (1986)	100-200*	100*	N/A
Granjean (1988)	≤ 350	N/A	≤ 125
Konz (1990)	N/A	N/A	N/A
Weimer (1993)	≤ 355	100*	≤ 125
Sanders and McCormick (1993)	≤ 355	100*	90-440
NASA (1995)	N/A	N/A	≤ 215
Corlett and Clark (1995)	≤ 355	50-100	≤ 155
Wagner et al. (1996)	≤ 360	100*	≤ 125
Department of Defense (1999)	≤ 355	100*	9-135

* Presented as being the optimum value

wide range of recommended diameters for knobs is that an operator may employ a fingertip grasp, a thumb-and-finger-encircled grasp, or a palm grasp (Wagner et al. 1996). The smallest diameter is appropriate if a fingertip grasp is expected to be used; the largest diameter should be chosen if the palm grasp is anticipated. Most of the sources suggested a separation distance of 50 mm, although Wagner et al. (1996) suggested that the separation distance may need to be increased to 125 mm if two hands are being used simultaneously. Based on the sources reviewed, acceptable dimensions for knobs are:

- Height: 12-25 mm
- Diameter: 10-100 mm
- Separation: ≥ 50 mm

Recommended dimensions for push buttons

Van Cott and Kinkade (1972) showed the benefits of using push buttons. They mentioned that, in most cases, push buttons require only a small amount of panel space. In addition, they can be operated quickly and simultaneously with other push buttons in an array and they can be identified easily by their position within an array or by their associated display signal. The main disadvantage is that push button control setting is not easily identified, visually or tactually. As a solution, Van Cott and Kinkade (1972) suggested the use of a concave surface to deal with tactual problems and the use of a positive indication of control activation to deal with visual problems.

Two critical dimensions for push buttons are button diameter and separation distance. Button diameter may be expected to vary depending upon whether the button is to be activated using a fingertip or the thumb (Wagner et al. 1996). Recommended diameters ranged between 10 and 25 mm (Table 5). The majority of sources suggested that a separation distance of 50 mm is optimum. Acceptable dimensions for push buttons are:

- Diameter: 10-25 mm
- Separation: ≥ 50 mm

Recommended dimensions for hand levers

The hand lever is a very important control in the agricultural industry and for many years was the primary control that was used in tractors. Although its use today has been partly replaced by other types of controls, it still remains an easy and simple method to make a number of adjustments in tractors. Corlett and Clark (1995) and Weimer (1993) demonstrated the use of hand levers. Their main conclusion was that hand levers may be used when high forces or large displacement are involved or when multidimensional movements of controls are required. Furthermore, they categorized hand levers as being either rigid or spring–loaded and reached the conclusion that spring–loaded levers are preferred because their control positions can be determined visually. On the other hand, they showed that due to the fact that hand–levers have a limited range of movement, they are usually unsatisfactory for precise positioning over a wide range of adjustments. The disadvantage mentioned can explain the partial, or in some cases the total, replacement of hand levers as a primary control from old to modern tractors.

Table 7. Recommended dimensions for steering wheels.

Source	Diameter (mm)	Rim thickness (mm)	Angle to horizontal (°)
Van Cott and Kinkade (1972)	381-457	19-50	30-60
Pheasant (1986)	380-440*	20-40*	50-60*
Granjean (1988)	180-500	N/A	N/A
Konz (1990)	400-510	20-32	45*
Weimer (1993)	180-530	20-50	30-60
Sanders and McCormick (1993)	180-533	19-50	N/A
NASA (1995)	N/A	N/A	N/A
Corlett and Clark (1995)	100-500	20-50	N/A
Department of Defense (1999)	400-510	19-32	45*

* Presented as being the optimum value

A comprehensive guide regarding hand lever design was given by Corlett and Clark (1995). In this guide, three factors are presented as important when operating a hand lever: displacement, separation distance, and activation force. Weimer (1993) suggested a maximum displacement of 355 mm (Table 6). Early work by Van Cott and Kinkade (1972) defined the minimum separation of hand levers at the value of 50 mm. Most sources suggested a separation distance of 100 mm. Maximum recommended activation force varies from 125 to 440 N, although five of the ten sources suggested maximum values between 125 and 155 N. As illustrated by Wagner et al. (1996), humans have more strength when moving a lever forward and backward compared with moving a lever side-to-side. Therefore, the orientation of the lever must also be considered. Acceptable values for the displacement, separation, and activation force for hand levers are:

- Displacement: ≤ 355 mm
- Separation: ≥ 100 mm
- Activation Force: ≤ 155 N

Recommended dimensions for a steering wheel

Purcell (1980) describes the steering wheel as the most important control in the tractor cab. He mentions that the driver's left hand must be available for steering at all times. Special consideration is given to the following three dimensions of a steering wheel: diameter, rim thickness, and angle to the horizontal plane.

According to Pheasant (1986), a 380-mm diameter is at the lower limits of acceptability and 400-440 mm would probably be better, giving additional torque to the weaker driver. In addition, an ideal rim thickness is 20 to 35 mm for heavy machines such as tractors. Studies conducted by Howe et al. (1992) proved that a vertical wheel might be more easily accommodated. However, at the same time, he showed that the maximum force (torque) was exerted on a horizontal wheel, although paradoxically the speed of rotation was greatest when the wheel was vertical. Howe et al. (1992), therefore, recommended that the axis of the wheel (i.e., the steering column) should be 40-60° to the horizontal plane, in which position 70% of the maximum force can be exerted. This concept is also supported by other design specialists (Van Cott and Kinkade 1972; Konz 1990; Weimer 1993).

Table 7 lists different design recommendations for the diameter, rim thickness, and angle to the horizontal plane for a steering wheel. A reasonably large range (i.e., 180 to > 500 mm) is suggested by several sources suggesting that steering wheel diameter is not critical. A reasonable summary of the recommendations is:

- Diameter: 180-533 mm
- Rim Thickness: 19-50 mm
- Angle to the Horizontal Plane: 30–60°

Placement of controls

According to the literature, the placement of controls seems to be the most important ergonomic factor which ensures safe and efficient operation. As Van Cott and Kinkade (1972) noted, controls should be arranged in such a way as to minimize the requirement for operators to change their position solely to operate a control. A further study by Woodson et al. (1992) confirmed this suggestion. Specifically, they showed that all controls should be positioned so that, in manipulating them, operators do not appreciably move their nominal eye reference and possibly miss seeing important events occurring outside or on the principal internal display.

Many authors emphasized the contribution of control placement to tractor safety (Purcell 1980; Grandjean 1988). This issue is one of the most serious challenges that designers must face as many accidents in the United States were caused due to the bad placement of controls (National Safety Council 1978). Hsiao et al. (2005), as part of an investigation of anthropometric criteria for the design of tractor cabs, found that the steering wheel sometimes impedes the operator's legs, thighs, hips, or stomach. The gear handle sometimes impedes the operator's ability to move around on the tractor. It can be assumed that a control impeding the operator in any way is a potential hazard. In an earlier study, Casey and Kiso (1990) presented models showing the optimal placement zones for transmission controls, throttle controls, and hydraulic controls. Rather than placing a control where it can cause interference, the designer should ensure that controls are placed optimally.

In 1980, Purcell developed a guide for the consideration of human factors in farm equipment design. In this guide, he suggested that all controls in the tractor cab which required accurate manipulation should be grouped on the right hand side of the operator, leaving the left hand available for steering at all times. A standard entitled "Operator Controls on Agricultural Equipment" (ASABE 2006a) makes specific reference to the engine speed control saying "the engine speed hand-operated control on agricultural field equipment shall be located to operate with the right hand."

Control labelling

Control labelling is an important issue for operators working with any control layout. Studies conducted by Sanders and McCormick (1993) showed that the identification of controls is essentially a coding problem. Making controls easy to identify decreases the number of times a wrong control is used and reduces the time required to find the correct control (Van Cott and Kinkade 1972). Labels and symbols (or icons) are common methods of identifying controls.

Table 8. Measurement details related to the specific dimension of controls.

Dimension	Control type	Definition
Length	Rotary switch	Distance of the switch from the top to the edge
	Rocker switch	Half the distance of the total length
Width	Rotary and rocker switches	Thickness of the switch based on the front surface
Height	Rotary switch	Depth of the switch based on the inside surface
	Knob	Vertical length of the knob
Separation	Rocker switch	Distance between the centers
	All other types	Minimum distance between two controls of the same type
Arm length	Toggle switch	Vertical length from the base to the top of the switch
Diameter	Knob and push button	Outside diameter of the control
	Steering wheel	Diameter from the inside of the rim
Displacement	Hand-lever	Maximum travel distance through the range of motion
Activation force	Hand-lever	Maximum force recorded by the dynamometer during movement of the lever through its range of motion
Rim thickness	Steering wheel	Maximum vertical thickness
Tilt angle	Steering wheel	Taken from specifications for the tractor

Labels are probably the most common method of identifying controls and should be considered the minimum coding required for any control. Early work by Chapanis et al. (1949) showed that adequate space, visibility, and lighting are the prerequisites for using this method. Generally, a large number of controls can be coded with labels and, if properly chosen, the operator does not require much training to comprehend the intended meaning. Extensive use of labels as the only means of coding controls is not desirable (Sanders and McCormick 1993; Van Cott and Kinkade 1972). A disadvantage is that labels take time to read and thus should not be the only coding method where speed of operation is important.

Corlett and Clark (1995) defined the proper location of labels. They demonstrated that labels should be placed above the control so that the hand will not cover them when the operator is reaching for the control. Also, the label should be visible to the operator before reaching for the control. Van Cott and Kinkade (1972) concluded that readability is affected by the size of the letters in the label. Specifically, they noticed that the optimal height of characters varies with distance of the viewer from the label.

To enhance a text label, the designer should add symbols that are meaningful and familiar to the operator. For agricultural vehicles, ASABE (2006b) has established a guide which presents different standardized graphical symbols that can be used on operator controls. The specific standard is entitled "Graphical symbols for operator controls and displays on agricultural equipment."

Functional reach

Important components must be placed in convenient locations so that they can be reached without undue arm exertion (i.e., without shoulder stretching). Pheasant (1986) defines the term 'functional reach grip' as the horizontal distance from the operator's shoulder to the tip of the thumb, measured with the subject's shoulders against the seat, the arm extended forward, and the index finger touching the tip of the thumb.

Purcell (1980) combined a graphical layout and anthropometric data published by McFarland et al. (1953) and NASA (1978) to develop a graphic solution for optimum seating placement and location of controls in tractors. According to this solution, the maximum reach zone (i.e., finger grip) of a 2.5th percentile male was defined at 750 mm covering a 180° envelope in front of the operator's shoulders.

MATERIALS and METHODS

Determination of the control dimensions

In this study, data were collected from six tractor workstations (i.e., John Deere 8220, Case IH MX 230, Buhler–Versatile 2210, New Holland TG 285, Fendt 920 Vario, and Caterpillar Challenger MT665B) with manufacturing dates between 2003 and 2005. Dimensions of the controls were determined using a common measuring tape. Activation force was determined using a dynamometer. Measurement details related to the specific dimensions of controls are described below (Table 8).

Determination of the control panel characteristics

The following criteria were used to evaluate three human factors characteristics of the control panels present in the tractors. For placement of controls, each tractor cab was reviewed to determine the number of controls that were located on the right-hand side of the operator. The right-hand side was identified using a line joining the midpoint of the seat and the centre of the steering wheel. For control labelling, each tractor cab was

Table 9. Mean and standard deviation dimension values for seven types of controls. For reference, the range of values recommended in the literature is included in parentheses.

Dimension	Rotary switch	Toggle switch	Rocker switch	Knob	Push button	Hand lever	Steering wheel
Length (mm)	47±0 (25-76)	N/A	20±5 (≥ 12)	N/A	N/A	N/A	N/A
Width (mm)	11±0 (≤ 25)	N/A	18±3 (≥ 6)	N/A	N/A	N/A	N/A
Height (mm)	10±0 (12-75)	N/A	N/A	15±5 (12-25)	N/A	N/A	N/A
Separation (mm)	42±0 (≥ 50)	35±22 (≥ 50)	41±47 (≥19)	34±17 (≥ 50)	18±45 (≥ 50)	104±91 (≥ 100)	N/A
Arm length (mm)	N/A	23±9 (12-50)	N/A	N/A	N/A	N/A	N/A
Diameter (mm)	N/A	N/A	N/A	31±14 (10-100)	19±5 (10-25)	N/A	398±8 (180-533)
Displacement (mm)	N/A	N/A	N/A	N/A	N/A	76±38 (≤ 355)	N/A
Activation force (N)	N/A	N/A	N/A	N/A	N/A	10±20 (≤ 155)	N/A
Rim thickness (mm)	N/A	N/A	N/A	N/A	N/A	N/A	29±2 (19-50)
Tilt angle (°)	N/A	N/A	N/A	N/A	N/A	N/A	63±21 (30-60)

reviewed to determine the number of controls that had an associated label or symbol. Labels or symbols that were located beneath the control were considered to not exist. For labels, the text height had to be at least 2.5 mm to be counted. For symbols to be counted, they had to be consistent with standard symbols for agricultural equipment described in ASABE (2006b). Finally, each tractor cab was reviewed to determine the number of controls located within 750 mm (covering a 180° reach envelope) from the seat reference point (Department of Defense 1976). This measure was used to evaluate the functional reach.

RESULTS and DISCUSSION

Control dimensions

Mean and standard deviations were calculated for the relevant dimensions for the seven control types based on measurements from the six agricultural tractors (Table 9). For ease of comparison, Table 9 also shows the range of values identified through a review of the published literature. In general, the measured dimensions agree with the recommended values. Separation distance was the one notable exception for several of the control types.

Although it may be tempting to conclude that tractor designers do not follow the published recommendation for separation distance between controls, such a conclusion would be difficult to prove. For example, Tables 1, 3, 4, and 5 all show that some authors recommended separation distances much less than 50 mm. Recommended values, as presented in this paper, represent the view of the majority of sources surveyed. However, the observed separation distances are consistent with the less conservative values recommended by a small number of the sources. Thus, there is sufficient evidence to conclude that the controls being used in tractors are consistent with the published design recommendations for controls.

It is important to note that control panel space is quite limited inside tractors. It is possible that designers have specifically chosen to use the less conservative separation distances so that more controls can be placed in the limited space available. Care must be taken to avoid the crowding of controls that could contribute to accidental activation and potential harm to the machine or operator (Sanders and McCormick 1993). The use of control types that combine more than one operation (i.e., multifunction controls) in an effective manner is one potential solution to saving space because the total number of controls will be reduced.

Control panel characteristics

Of the 355 controls present in the six tractors, 316 (89%) were placed on the right-hand side of the control panel to be operated by the driver's right hand. Unfortunately, we did not record the function of the 39 controls that were placed to the left of the operator's seat (i.e., we do not know whether these controls are expected to be operated while the tractor is being driven or whether it is expected that they will be operated while the tractor is stationary). If they are not relevant to operation of the tractor during driving, their placement on the left-hand side of the control panel may be irrelevant.

Of the 355 controls, 337 (95%) were labelled with either a text label with a minimum text height of 2.5 mm or a symbol consistent with ASABE (2006b). Designers of agricultural tractors tend to rely on symbols rather than text labels.

For the final characteristic, 265 of 355 controls (75%) were located within 750 mm of the seat reference point. We did not record the function of the 90 controls that were situated outside the functional reach envelope, but it is safe to assume that some of these controls would need to be operated during operation of the tractor. Therefore, the operator would have to assume less comfortable positions during the long working hours which could increase the risk of pain and injury to the back and shoulders (National Safety Council 1978). Manufacturers should be more aware of the arrangement of control issues if they want to achieve not only easier control accessibility for all the potential operators but also a user–friendly workstation environment.

CONCLUSIONS

There is sufficient evidence to conclude that the controls being used in modern tractors are consistent with the design recommendations found in the literature. Of the recommended dimensions, the least conservative values were chosen for separation distance. Perhaps this is an indication that space is a premium inside a tractor cab. The majority of controls (95%) are labelled using either a symbol or text, but there is a tendency to use symbols rather than text. Most controls (89%) are located so that they can be operated by the driver's right hand, however, only 75% of controls were located within the functional reach envelope (i.e., 750 mm from the seat reference point). It is speculated that space may be a limiting factor due to the large number of controls required to operate modern agricultural equipment.

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