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RESEARCH ARTICLE

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A method to evaluate the perceived ease of use of human-machine interface in agricultural tractors equipped with Continuously Variable Transmission (CVT)

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Abstract

At the end of the 20th century the adoption of the Continuously Variable Transmission (CVT) was one of the disruptive technological advances in agricultural tractors. Several changes in the Human Machine Interface (HMI) of the tractor cab have been introduced to accommodate this technology. HMIs are known to raise issues about their ease of use; however, this topic has been under-investigated in the agricultural sector. The present study introduces a method to investigate the perceived ease of use of the HMI of agricultural tractors equipped with technological innovations. The HMI required to manage a CVT tractor was evaluated by sixteen tractor drivers (8 novices and 8 experts). During the first contact with the machine and after having performed two targeted tasks with the tractor, participants filled in a questionnaire about the ease of use of the controls and of the touch-screen display, and evaluated the general perception of ease of use, safety, quality and solidity of the machine. The trial pointed out some significant differences between novices and experts, thus confirming the validity of the proposed method. In particular, novice users showed some difficulties when interacting for the first time with the HMI of the CVT tractor working station, whereas experts did not report similar difficulties. Thus, expertise seems to play a role in determining the quality of the interaction with the HMI. Training interventions should be designed to help novices in increasing their expertise effectively, avoiding effort and errors and improving user's comfort and system performance.

Additional keywords: tractor cab; ergonomics; expert; novice; questionnaire; user trial.

Abbreviations used: CAN bus (Common Area Network bus); CVT (Continuously Variable Transmission); HMI (Human Machine Interface); PTO (Power Take-Off).

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Introduction

The massive introduction of technology in agriculture led to a revolution in farming, in terms of a huge increase in productivity and energy savings (Arnó *et al.*, 2009), but also as a reduction of the environmental impact and an improvement of working conditions (Amiama-Ares *et al.*, 2011). Technological innovation particularly concerns machinery, and especially tractors, which are the most important and widespread machines in agriculture (Iftikhar & Pedersen, 2011).

Since the 80s, much attention has been paid to design safer and more comfortable tractor driving stations; at the same time, electronics has become more and more popular to control many of the systems embedded on the vehicle, such as technological features in transmission and engine management systems (Cavallo *et al.*, 2015). One of the technological advances that have marked a discontinuity in the development of tractors is the introduction of the Continuously Variable Transmission (CVT) (Cavallo *et al.*, 2014a). The CVT, in contrast with the traditional mechanical transmission having a fixed number of gear ratios, can change steplessly through an infinite number of effective gear ratios. The CVT designed for agricultural tractors are characterised by the combination of a traditional (discontinuous) mechanical transmission with a hydrostatic (continuously variable) transmission. Power-split hydrostatic CVT is operated by dedicated electronic control units (ECU) controlling and managing the hydraulic and the mechanic components of the transmission.

The introduction of CVT has deeply affected the layout of the controls in the tractor cabs. According to ISO 6682 (1986) standard, controls can be classified in primary controls, that are frequently and/or continuously used by the operator, and secondary controls, such as lights, windscreen wiper, starter, and heating and air-conditioning system, less frequently used. Figure 1 shows the different layouts of the controls in a tractor with mechanical gearbox and in one with CVT. Hand-acted levers in mechanical transmissions have been replaced in CVT by on/off buttons and potentiometers for pre-setting or regulation acting on electro-hydraulic actuators, and monitors.

Both primary and secondary controls have therefore been re-designed to accommodate and integrate the new technologies, with many advancements and changes as regards the Human Machine Interface (HMI) of the tractor working station (Yadav & Tewari, 1998).

The European Agency for Safety and Health at Work (EU-OSHA) defines the HMI as *"the part of an electronic machine or device which serves for the information exchange between the operator/user and the machine/device."*(p. 9). According to the same definition, HMI consists of three different parts: (1) operating elements (to transfer information from the operator to the machine, by adjusting knobs, pushing buttons, etc.), (2) displays (to show and transfer information about the machine to the user), and (3) an inner structure (hardware and software) (EU-OSHA, 2009). The HMI of a technological system brings new challenges and risks for workers (EU-OSHA, 2009); indeed, it provides the operator with a large amount of information and functionalities which may exceed user's cognitive resources and therefore it might be difficult for the user to retrieve and interpret the relevant information. This may lead to operating errors, increased mental strain and user frustration, and resulting in occupational diseases as stress (Nachreiner *et al.*, 2006). As to prevent these issues, a critical variable is represented by the perceived ease of use - defined as *"…the degree to which a person believes that using a particular system would be free of effort"* (Davis, 1989, p. 82)- of the HMI of a computerised system (Adams *et al.*, 1992; Davis, 1993; Henderson & Divett, 2003). HMIs and their ease of use have been investigated as regards Human-Computer Interaction in previous researches performed within the field of ergonomics (Norman & Draper, 1986; Carroll, 1991). The evaluation of the HMI of a system is typically performed by means of the direct involvement of the users, who are asked to perform some targeted tasks with the system and to express their evaluations about the quality of the interaction (Karwowski, 2006). Nielsen's studies (1995, 2000) showed that the first three users are likely to encounter all of the most significant problems related to the tested tasks; Kingman *et al.* (2005) concluded that three to five experts would be the optimal. The consultation of experts can be useful to provide a more complete list of problems, whereas novice users are helpful in identifying the most severe issues in an interface (Sauer *et al.*, 2010). Experience plays a major role in determining the ease of use of the system; novices usually have fewer resources to address

Figure 1. Controls layout in tractors working stations: completely mechanical gearbox with hand lever to select gears and ranges (a), and CVT (b).

critical issues compared to experts thus reporting more difficulties in interacting with the system (Chen *et al.*, 2006). According to Spires & Donley (1998) the contrast between experts and novices lies in the different organization of their conceptual structures. Experts have a mental representation (*i.e.*, a hierarchical structure) of the concepts in the domain, whereas a novice's structure is more chaotic and disorganized.

Different aspects define the perceived ease of use of an HMI: the ease with which the user thinks he/she can transfer information to the machine and control it (*i.e.* by operating the commands), the clearness and understandability of the information given by the system to the user, and the easiness to move between the different functionalities of the system (Davis, 1989, 1993). To collect this subjective and qualitative evaluation (Carroll, 1991), different questionnaires and scales have been developed for different Information Technologies (*e.g.* Henderson & Divett, 2003; Calisir & Calisir, 2004). As regards data analysis, since the samples involved in these trials are usually small, data gathered by means of the questionnaires are typically analyzed through descriptive and non-parametric statistics (Howell, 2010).

The ergonomic principles have been introduced in the occupational safety and health regulations of most of the developed countries, such the OSHA standards in the USA and the European Directives in European Union countries. In European countries, the European Regulation 167/2013 (European Parliament, 2013), recently enforced for the approval and market surveillance of agricultural and forestry vehicle including tractors, introduces *" …detailed technical requirements…. taking into account ergonomics [….]"* (art. 18) in the requirements for occupational safety.

Despite these regulations, the perceived ease of use of the HMI in highly technological tractors has been under-investigated in the ergonomic literature. A few studies investigated how the rural population perceives technological innovation in agriculture, often reporting low levels of technology acceptance and adoption (Cavallo *et al.*, 2014a,b). However, these studies were interested in gathering information about the general attitudes and beliefs of the farming population, without considering any specific human-machine interaction. Other studies addressed mainly the physical interaction between the user and the tractor cab interface, evaluating the potential mismatch between people's strength capabilities and forces required in operating farm tractors (Fathallah *et al.*, 2009). Ferrari & Cavallo (2013) investigated the operators' perception of comfort in two tractor cabs. Among the factors contributing to the perception of comfort, the authors reported the significant role played by the ease of locating controls during the first approach with the machine, and the ease of operating controls when performing different activities. However, the tractors considered in the study were not highly technological vehicles. Therefore, there is a lack of studies concerning operators' perceptions of the ease of use of this kind of tractor cab interfaces.

Bearing these considerations in mind, the present study introduces an ergonomic method to investigate the perceived ease of use of the HMI in agricultural tractors equipped with technological innovations. The technological innovation identified for this study was the HMI required to manage a CVT tractor. The investigation aimed, specifically, at collecting the subjective responses of a group of novice and expert users as regards the perceived ease of use of the HMI of the tractor cab, in terms of location, interpretation and operation of some controls and the accuracy of the information given by the displays, during both the first interaction with the machine and after performing a series of targeted tasks with it. The ultimate goal of the present investigation is to identify possible critical issues in the interaction between the driver and the HMI of the cab of a highly technological tractor, which can undermine the benefits related to technological development and which should be taken into account during the design process or targeted training actions.

Material and methods

In the present study, the ergonomic assessment of the HMI followed all the steps recommended by Norman & Draper (1986) and Carroll (1991), namely: 1) selection of the HMI to be investigated; 2) selection of the participants for the trial; 3) definition of the targeted tasks; 4) selection/creation of instruments to collect users' evaluations; 5) definition of the procedure of the trial; and 6) data analysis.

The tractor and its HMI

The study has been anticipated by a survey to investigate the layout of the primary and secondary controls on five models of CVT tractors from different manufacturers currently available. The clutch, brake and throttle pedals, and reverse lever close to the steering wheel have the same placing and function as in conventional mechanical transmission tractors. As it is depicted in Fig. 2 the remaining controls are placed on two main areas of the working station: the driver's seat armrest and the right side console.

The controls layout reflects the hierarchy suggested by usage frequency (ISO 6682, 1986). The armrest controls are the most frequently used or those intended for precision work, requiring the constant attention of the operator, such as the hand throttle, the gearbox, the rear 3-point hitch lift, and the auxiliary hydraulics. The setting and adjustment controls, less frequently used, are located on the right side console. Some models include displays of different size located on the right side console or on the front right pillar of the cab.

The model of CVT tractor involved in the present study follows the scheme that introduces controls on the seat armrest and on a console on the right side of the tractor cab, with a display located on the right side console.

Participants

Recruited participants were Italian, from the area of Bergamo, in the north-east of the country. Only male drivers were selected since the majority of Italian agricultural operators (71%) are males (Greco *et al.*, 2012). Sixteen drivers were involved in the study. Eight of them were considered experts, having at least 5 years driving experience (cutoff for experts as in Kumar *et al.*, 2001) on CVT tractors, even though not specifically on the model of tractor adopted for the study. The remaining eight participants did not have ever owned nor had operated a CVT tractor: they were considered novices.

Targeted tasks

The research team defined a number of tasks that the users would have to perform with the technological system under investigation. The tasks were chosen as representative of a fieldwork environment and on the basis of their relevance for a typical interaction with the tractor cab interface. The investigation was carried out using the facilities of the CREA Laboratory of Treviglio, north-eastern Italy. Participants were asked to perform two tasks: 1) road driving; and 2) harrowing operation simulation with manouvring on farm road.

The road driving task consisted in driving the CVT tractor at a constant forward speed of 20 km/h on a 500 m track made of two 150 m stretch lines and two 100 m bends. The road driving task allowed the participants to become familiar with the vehicle and to achieve a baseline knowledge in operating the tractor before the more complex following task.

The harrowing simulation task required the operator to drive the tractor and to operate the Power Take-Off (PTO), the rear 3-point hitch lift, and the auxiliary hydraulic couplings controls. The specific sub-tasks (see Fig. 3) were to: 1) operate the auxiliary service coupling to open the harrow to be ready for working; 2) operate the rear 3-point hitch lift to lower the harrow (without touching the test track); 3) switching the PTO on; 4) forwarding the tractor at 10 km/h and following a fixed and bounded path; 5) arriving near the bumps (simulating stones), operating the rear 3-point hitch lift to raise the harrow; 6) slow down till 7 km/h; 7) avoid to pass over the bumps; 8) operating the rear 3-point hitch lift to lower the harrow; 9) increase the forwarding speed back at 10 km/h; 10) follow the path till the end; 11) stop the tractor; 12) operating the rear 3-point hitch lift to raise the harrow; 13) switching the PTO off; 14) operate the auxiliary service coupling to close the harrow as for road transfer; and 15) carry out a sharp turn as at the end of the field in a bounded space.

The task required to run on 100 m test track set with road bumps. Cones on the side of the track were used to indicate where the operator had to perform the different actions operating the appropriate controls. All the participants performed the simulation harrowing task 4 times, for a total time of about 10 min.

Figure 2. Controls' layout of some CVT tractors currently available in Italy.

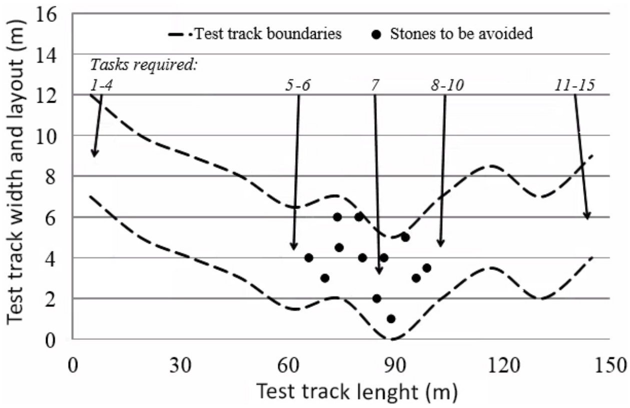

Figure 3. Trial layout for the harrowing simulation task.

The instrument to collect users' evaluations

The perceived ease of use of the HMI of the tractor cab was assessed using a paper-and-pencil questionnaire developed based on the aspects defining the ease of use of a technological interface (Davis, 1989, 1993), and the critical elements in tractors cab layout emerged in previous studies (Ferrari & Cavallo, 2013; Cavallo *et al.*, 2014b). The questionnaire has been pilot-tested before being used in the present study. In more detail, the questionnaire was organized as follows:

1) The first part gathered socio-demographic data about the participants, their experience with agricultural machinery and their familiarity with technology in everyday life (use of computer and smartphone, based on Loera & Parisi, 2009) and on tractors (Common Area Network bus (CAN bus), GPS, Power-boost, Virtual Terminal, based on Cavallo *et al.*, 2014a, b).

2) In the second part of the questionnaire the participants were asked to evaluate the ease of use of the HMI during the first contact with the cab (pre-tasks assessment), in terms of ease of recognizing and locating the different controls (*e.g.* PTO, Hydraulic system, Lighting), using a six-point Likert scale (1932) without a central anchor (1 refers to "I do not agree at all", 6 refers to "I strongly agree").

3) In the third part of the questionnaire the participants were asked to evaluate the ease of use of the HMI of the cab after having performed the tasks (post-tasks assessment), in terms of the ease of operating the control devices, understandability of the levers/knobs and buttons, and clearness of warning lights and accuracy of the information given by the displays, using a six-point Likert scale without a central anchor (1 refers to "I do not agree at all", 6 refers to "I strongly agree"). At the end of this section, the participants were also asked to give a general evaluation of the ease of use of the tractor, together with its safety, quality, and solidity (as in Ferrari & Cavallo, 2013), on the six-point Likert scale.

For both the second and the third part of the questionnaire, besides the rating scales, the questionnaire contained also some open-ended questions aimed at pointing out any difficulty found in approaching the cab and in accomplishing the tasks, and at soliciting additional feedback on the arrangement and operation of the control devices in the cab.

Trial procedure

The participants in the study were invited to the CREA Laboratory facilities in Treviglio, near Bergamo, northeastern Italy. After they were explained the aims of the study, the operation they were asked to perform and the safety rules to adopt, they signed an informed consent and filled in the first part of the questionnaire. In any part of the tests the participants were followed and instructed by a research assistant.

The participants were asked to access the cabin of the tractor and sit. Here, before receiving any information about the function of the controls and operation of the tractor, they were interviewed about the ease of locating the different controls (second section of the questionnaire, pre-tasks assessment). After that, the operators were trained by the research assistant about how to perform the two targeted tasks and, then, drove the tractor on the testing area. The third section of the questionnaire (post-tasks assessment) was administered after the driving and harrowing simulation tasks have been completed.

Data analysis

Data collected during the trial underwent a Shapiro-Wilk test and resulted in a not normally distributed sample. Therefore, the median values (*Mdn*) for all the considered variables were compared between experts and novices using a series of non-parametric Mann-Whitney *U* tests. Statistical Package for Social Science v. 22 was used for statistical analysis.

Answers given by participants to the open-ended questions underwent a content analysis (Weber, 1990); the content of the answers was categorised by two independent judges to identify the more recurrent themes for each of the investigated topics.

Results

In this section, results from the first section of the questionnaire (characteristics of the participants) are presented first. Then, for the pre- and post- tasks assessment, the results from the rating scales and the open-ended questions are presented together for each aspect considered in the questionnaire, as it is usually done in the ergonomic assessment of an HMI (Carroll, 1991).

Characteristics of the participants

The experts had a mean age of 35.25 years (SD=11.65) and a mean driving experience of 20 years (SD=10.35). The novices had a mean age of 38.75 years (SD=13.91) and a mean driving experience of 26.13 years (SD=13.92). Preliminary analyses showed no differences between the experts and the novices as concerns age ($t(14)=-0.546$, $p=0.594$) and years of driving experience ($t(14)=-0.999$, $p=0.335$). The same held true as concerns the familiarity with technology in everyday life and on tractors (Chi square tests, all $p>0.05$).

Pre- tasks assessment

Ease of recognizing and locating controls

With regard to the perceived ease of locating controls during the first contact with the machine, descriptive statistics and comparison between experts and novices are reported in Table 1.

The Mann-Whitney *U* tests showed that locating the PTO control (U=13.50, $p=0.047$), and the lighting control (U=13.00, $p=0.041$) was significantly more difficult for novices compared to experts. Open-ended questions revealed that these difficulties were mainly due to the fact that, according to the novices, these controls were placed in an unexpected area of the working station and, thus, more time was requested to make them out.

Post- tasks assessment

Ease of operating controls

With regard to the tasks performed, all the participants managed to accomplish the tasks, even though the open-ended question of the questionnaire revealed that three novices reported some difficulties in operating the PTO and the 3-point hitch lift controls when operating with the harrow because there were too many functions and similar buttons among which to discriminate, instead of levers, each serving a different aim, commonly adopted in conventional mechanical transmission tractors. Table 2 shows the descriptive statistics and the results of the analyses comparing experts and novices about the perceived ease of operating the different controls. As it can be seen, novices found significantly more difficult to operate the 3-point hitch lift ($U=1.00$, $p=0.001$), the hydraulic system ($U=8.50$, $p=0.014$), the transmission ($U=12.50$, $p=0.023$), and the driving ($U=10.00$, $p=0.011$) controls.

Table 1. Medians, ranges (in brackets) and Mann-Whitney tests results (*U* and *p*-values) for the ratings of ease in locating controls.

Controls	Experts	Novices	*U*	*p*-value
Ignition	6.00 (4-6)	6.00 (2-6)	32.00	0.626
3-point hitch lift	6.00 (2-6)	5.50 (4-6)	22.00	0.200
Hydraulic system	6.00 (2-6)	4.00 (1-6)	17.00	0.094
PTO	5.50 (2-6)	3.50 (1-6)	13.50	0.047*
Lighting	6.00 (1-6)	2.50 (1-5)	13.00	0.041*
Transmission	5.00 (1-6)	5.00 (2-6)	30.50	0.868
Reverser	6.00 (5-6)	6.00 (5-6)	32.00	0.264
Driving	6.00 (3-6)	5.00 (5-6)	29.00	0.729

*significant at the 0.05 level (two-tailed)

Understandability of levers/knobs and buttons

As far as levers/knobs and buttons are concerned, results regarding participants' ratings about their ease of use are shown in Table 3. The data discloses that, in general, novices expressed lower ratings, especially with regard to the ease of understanding what action each button controls and how to operate it.

The Mann-Whitney *U* tests pointed out:

• A significant difference between experts and novices as regards the ratings of the placement of the levers/knobs (U=11.00, $p=0.023$), with novices finding levers/knobs to be in a quite odd place compared to what they expected, more than experts.

• No significant differences between novices and experts about either the placement of buttons-such as the ones for pre-setting or regulation placed on the joysticks-, or the ease to understand what they represent, or how to operate them, or the comprehensibility

Table 2. Medians, ranges (in brackets) and Mann -Whitney tests results (*U* and *p*-values) for the ratings of ease of operating controls.

Controls	Experts	Novices	*U*	*p*-value
Ignition	6.00 (3-6)	5.00 (3-6)	25.50	0.471
3-point hitch lift	6.00 (5-6)	3.00 (1-5)	1.00	0.001**
Hydraulic system	6.00 (3-6)	4.00 (1-6)	8.50	0.014*
PTO	6.00 (5-6)	5.00 (2-6)	12.00	0.082
Lighting	6.00 (4-6)	5.00 (2-6)	14.00	0.172
Transmission	6.00 (4-6)	4.50 (3-6)	12.50	0.023*
Reverser	6.00 (3-6)	6.00 (4-6)	25.50	0.369
Driving	6.00 (5-6)	5.00 (4-6)	10.00	0.011*

*significant at the 0.05 level (two-tailed), ** significant at the 0.01 level (two-tailed)

Table 3. Medians, ranges (in brackets) and Mann-Whitney tests results (*U* and *p*-values) for the ratings of ease of use of levers/knobs and buttons.

	Issue	Experts	Novices	*U*	*p*-value
Levers/knobs	Placed as expected	6 (3-6)	4 (1-5)	11.00	0.023*
	Easy to understand what they represent	5.50 (2-6)	4 (1-5)	17.00	0.105
	Easy to understand how to operate	6 (1-6)	4 (1-5)	20.50	0.215
	Colors help in understanding the function	5.50 (1-6)	5 (2-5)	22.50	0.301
Buttons	Placed as expected	6 (3-6)	5 (3-6)	19.50	0.295
	Easy to understand what they represent	6 (2-6)	3 (2-5)	12.00	0.054
	Easy to understand how to operate	6 (2-6)	3.50 (1-6)	14.50	0.199
	Colors help in understanding the function	6 (3-6)	4 (2-6)	13.00	0.070

*significant at the 0.05 level (two-tailed)

of their colors. However, the comparison about the understanding of what the buttons represented was slightly above the level of significance (p=0.054), with the understanding being easier for experts than for novices (experts: *Median*=6, *n*ovices: *Median*=3).

The content analysis of the open-ended questions revealed some critical aspects regarding the size of the buttons and their icons, since they were considered by all the participants to be too small to be immediately visible and recognisable. Furthermore, the icons referring to these controls were also considered unclear.

Clearness of warning lights and displays

With regard to warning lights (Table 4), the Mann-Whitney tests showed a significant difference between novices and experts in understanding what warning lights referred to (U=10.00, p=0.030), with more difficulties for the novices.

As regards displays (see Table 5), the Mann-Whitney *U* tests showed that:

• The layout of the information on the screen was reported as significantly better (U=9.50, p=0.026) for experts than novices.

• The priority given to essential information shown on the display was reported as significantly higher (U=5.00, p=0.003) for experts than novices.

Interestingly, the analysis of the open-ended questions pointed out that not only many novices but also one expert reported that there was too much information to be monitored on the screen, as a critical aspect.

Global evaluation of the tractor

Finally, with regard to the overall assessment of the vehicle, as it can be seen in Table 6, the tractor received lower ratings by the novices compared to experts for all the four aspects considered, and in particular for safety and durability. The Mann-Whitney tests showed that the differences between the ratings of the experts and those of the novices were statistically significant for all the four aspects.

Content analysis confirmed that the high level of technological development of the vehicle was perceived by most the participants as useful in reducing physical efforts and saving time in performing fieldwork. However, the tractor was not considered particularly safe nor solid, by the novices. A main issue was the poor sense of control on the activity and the vehicle when dealing with such a highly technological tractor, because too many tasks were delegated to the machine itself. Moreover, if a maintenance problem raises on the tractor, novice participants reported being worried about the fact that they would have not known exactly how to intervene on the vehicle.

Discussion

The present study reported the method developed to apply the ergonomic principles of users involvement to the investigation of the ease of use of the HMI of a tractor equipped with technological innovations (Continuously Variable Transmission, CVT). A group

Table 4. Medians, ranges (in brackets) and Mann-Whitney tests results (*U* and *p*-values) for the ratings of ease of understanding of warning lights.

Issue	Experts	Novices	*U*	*p*-value
Clearly visible	6 (4-6)	5 (3-6)	13.50	0.067
Easily understood what they represent	6 (4-6)	5 (3-5)	10.00	0.030*

*significant at the 0.05 level (two-tailed)

Table 5. Medians, ranges (in brackets) and Mann-Whitney tests results (*U* and *p*-values) for the ratings of ease of use of the displays.

Issue	Experts	Novices	*U*	*p*-value
Information was easily visible	6 (4-6)	4 (3-6)	14.50	0.095
Information was complete	6 (1-6)	5 (3-6)	16.50	0.146
Information was well-organised	6 (4-6)	4 (2-5)	9.50	0.026*
Essential information was prioritised	6 (5-6)	4 (4-6)	5.00	0.003**

*significant at the 0.05 level (two-tailed), ** significant at the 0.01 level (two-tailed)

of novices and a group of experts were involved in the assessment. The investigation highlighted significant differences between the two groups of users, confirming the suitability of the method, and allows to draw some important considerations on the topic. In particular, the study showed that novice users experienced some difficulties when interacting for the first time with the HMI of the cab of the CVT tractor, consistently with previous studies performed in the field of human-computer interaction (Chen *et al.*, 2006). Data about familiarity with technology in everyday life and on tractors showed that novices and experts of the present study shared a similar technological background; thus, the present results seem not to be related to some kind of 'digital-divide' (van Dijk & Hacker, 2003) between the two groups of participants but to the interaction with the specific HMI characterising the CVT technology.

Some critical issues emerged since the first contact with the machine, with some difficulties reported by the novices in locating the PTO and lighting controls. The difficult regarding the PTO may be carefully considered, since most of the tractor operations are powered by the PTO and its misuse may lead to serious risks for operators' safety (PennState Extension, 2016). In the investigated tractor, the PTO speed setting control was isolated from the PTO engaging/disengaging control: this can arise some considerations about the need of alternative design solutions and training interventions to make this control more outstanding, self-explanatory and immediately noticeable.

As regards the ease of operating controls, the transmission control was, together with the 3-point hitch lift and the hydraulic system controls, one of the devices found to be more difficult to operate for the novices. The difficulties in operating transmission controls could be easily interpreted by considering that the transmission of the CVT tractor is very different from that of a traditional mechanical one: it requires to choose between a manual or an automatic management system of the driveline; it gives also the possibility to 1) set the maximum speed, 2) use a constant speed (cruise control), 3) work at constant PTO speed, 4) work in "Eco" or "power" mode, and 5) select the sensitivity of the throttle pedal. Because of this, the same control could assume different functions.

In relation to the 3-point hitch lift, novices resulted accustomed to use hand levers and, as they weren't familiar with the practice of pre-setting the 3-point hitch lift, they found some difficulties in operating controls, such as small wheels and potentiometers. Similar considerations may be done about the ease of operating the hydraulic auxiliaries, requiring hydraulic valves to be set before the use. Moreover the same parameter could be set both on the display and on the dashboard at the right side of the operator's seat. This double source of information could have required a more complex cognitive processing (Wickens, 2008), hindering operators' actions.

Some critical aspects were reported by the novices also with regard to the buttons. They were considered to be placed in quite an unexpected position, and having unclear icons to explain their function. These results may be interpreted by considering that the buttons in the CVT tractor used in the study were all placed very near to each other on the dashboard on the right side of the operator's seat, with nothing apart from the color to

Table 6. Medians, ranges (in brackets) and Mann-Whitney tests results (*U* and *p*-values) for the subjective ratings about overall assessment of the vehicle.

Issue	Experts	Novices	*U*	*p*-value
Ease of use	6 (5-6)	5 (4-6)	7.00	0.004**
Safety	6 (5-6)	4.5 (3-6)	6.00	0.003**
Quality	6 (5-6)	5 (3-6)	6.50	0.004**
Durability	6 (4-6)	4.5 (3-5)	9.00	0.011*

*significant at the 0.05 level (two-tailed), ** significant at the 0.01 level (two-tailed) distinguish between them. As mentioned previously in this paragraph, for instance, the button for setting the PTO speed was close to the controls of other functions, but aside from the button for the PTO engagement/disengagement. Also in this case, the procedure of a preliminary setting of the PTO speed before switching it on was not immediate for the novices.

The described difficulties in interpreting icons and signals on or near the controls is in line with some previous studies reporting low comprehension scores of safety pictograms affixed to agricultural machinery (Caffaro & Cavallo, 2015; Caffaro *et al.*, 2017a). This outcome should be examined more in depth since icons, signals and pictograms are supposed to be self-explanatory and able to quickly communicate concepts and instructions, compared to a written language (Edworthy & Adams, 1996). A critical aspect emerged also as regards the physical interaction with buttons, specifically, participants reported that buttons and icons or signals were not immediately seen due to their reduced size. These comments should be further investigated, especially with regard to particular groups of users like the elderly, whose rate is increasing in the agricultural population (Ilmarinen, 2006) and who are characterised by physical and cognitive impairments which may make it difficult to interact effectively with small devices.

Overall, it should be highlighted that the participants declared that highly technological machinery could help them in performing farm activities by reducing efforts and saving time. They matched the 'innovative-owner' profile defined by Cavallo *et al.* (2015) as regards the adoption of technological innovations, however they seemed neither to completely and correctly manage this technology, nor to take full advantage of all its benefits. This result may find an explanation in the construct of *mental model*, described by Norman (1988) as a user's internal representation of how he/she believes a system works, developed by interacting with the system. A mental model is a knowledge about the system, which allows the user to anticipate the behaviour of the system and to explain the system responses. When a system is developed in a way which does not fit the users' mental model, ease of use and learnability become at stake, errors increase and performance decreases (Norman, 1988). This might be the case of the novice users of this study: their mental models about how an HMI of a typical tractor should work, contrasted with the mental model of the designers of the HMI investigated in the study, making the system less intuitive and more difficult to use. To improve the quality of the HMIs and the human-machine interaction, it is therefore fundamental to consider the operators and their needs (Nachreiner *et al.*, 2006) in the design process of technological systems, adopting an ergonomic approach which takes account of both physical (such as perceptual processes) and psychological aspects (such as cognitive processes), to reinforce human factor potentials and reduce limitations (Nam *et al.*, 2009).

It should be also considered that operators of agricultural tractors often find out the different functions of the controls in the tractor cab by a 'trials and errors' procedure (DeRoo & Rautiainen, 2000): focused training sessions adopting behavioral modeling techniques -as hands-on demonstrations and behavioral simulations (Burke *et al.*, 2006)- could be provided when buying a new machine, with some periodical refreshes in case of new technological releases. Particular attention should be also paid to how these training activities are organised, since perceived benefits are important incentives for the use of technology (Davis, 1989; Venkatesh *et al.*, 2003): farmers should know how they can use new technologies equipping their tractors, in order to reduce the physical workload, increase economic benefits, and save time.

Some limitations of the present study should be taken into account. One aspect to be considered is that data about ease of use was exclusively self-reported. Further objective indicators of performance, such as the number of trials and errors, time spent to accomplish different tasks, and observations of human behavior when interacting with the system, have to be collected, in accordance with ISO 9241-11 (1998) standard. Finally, data was collected on one model of CVT tractor only. In depth investigations should be addressed to study the specific design of HMIs adopted by different manufacturers.

Technological innovation in agriculture should result in better working conditions. However, it can sometimes results in control systems that are more complicated to operate than mechanical ones, due to the great amount of information available for the users at the same time. An ergonomic method to assess the interaction between the HMI of a CVT tractor and novice/expert drivers was developed. The trials pointed out some significant differences between novices and experts, raising some considerations about the fact that the HMI may not be sufficiently self-explanatory, making the provision of proper information and training by manufacturers, and the involvement of workers in the development and evaluation of HMIs, an essential element for an effective improvement of the system.

The present method can be adopted for further investigating the aspects considered in this paper, *i.e.* with other tractor's layouts, or among the elderly, which represent a significant part of the agricultural population (Ilmarinen, 2006). Older users are known to have more troubles operating technological systems (Lavie & Meier, 2010) and they are often characterised by the so called 'digital divide' from the rest of the population (van Dijk & Hacker, 2003). Agricultural elderly population in particular is mainly used to mechanically controlled machines, thus they may represent a good sample on which to investigate the possible discrepancies between a consolidated mental model of a tractor cab HMI and the new HMI of hyper-technological machines, and their effects on ease of use and safety at work (Caffaro *et al.*, 2017b).

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