Agricultural tractor cabin evaluation from users' perspective

Ester Ferrari and Eugenio Cavallo
IMAMOTER – CNR
Italy

Abstract

Several ergonomic studies have shown that operators are more productive when their work environment is designed for the best human performance. Ergonomic requirements are issued in various standards and EU directives and need to be met by tractor manufactures. Among those, ISO 9241 defines usability as the effectiveness, efficiency and satisfaction with which users achieve specified goals in a particular context. The aspect of satisfaction in use is the most difficult to investigate as it is based on the evaluation of comfort and acceptability of the system by its users. Indeed, comfort is a subjective construct, requiring operators' direct involvement. The objective of this study was to evaluate tractors cabin comfort focusing on operators' perspective. Twenty tractor operators completed a questionnaire and a semi-structured interview after performing a series of tasks on an agricultural medium power tractor. Operators' opinions on ease of accessing the seat and the cabin, ease of exiting the cabin, concentration required in tasks execution, ease of locating and operating the controls, noise and visibility were collected. Results showed the need of improvements in different design aspects. Indeed, elements of bad ergonomic design were identified (e.g. some controls of the control panel did not match operators' task mental model).

Introduction

The focus of the ergonomic approach is the interaction between humans and other elements of a system in order to improve efficiency, safety, and human well-being (Marras & Karwowski, 2006). Several studies have demonstrated that operators are more productive when their work environment is designed for the best human performance (Gibson et al., 2006; Stanton & Salmon, 2009). A comfortable machine can stimulate operator's optimal performance (Kuijt-Evers et al., 2003), reducing errors, and injuries (Liaoa & Drury, 2000).

Ergonomics can be described as an approach to design products in a user-centred way (ISO 9241-210, 2010). Ergonomic requirements are issued in various international standards and are also part of the comprehensive set of safety criteria for machinery stipulated in the European Machinery Directive (2006/42/EC), which states that machines must be designed reducing the discomfort, fatigue and physical

In D. de Waard, K. Brookhuis, F. Dehais, C. Weikert, S. Röttger, D. Manzey, S. Biede, F. Reuzeau, and P. Terrier (Eds.) (2012). Human Factors: a view from an integrative perspective. Proceedings HFES Europe Chapter Conference Toulouse. ISBN 978-0-945289-44-9. Available from http://hfes-europe.org

and psychological stress faced by the operator. Usability, defined as "*the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*" is one of the most important ergonomic aspects (ISO 9241-110, 2006).

Nevertheless, ergonomic criteria are not always prioritized by engineering designers (Wulff et al., 1999) and usability in particular has not played a central role in the design of agricultural machines (Haapala, 2006). Operator satisfaction is an essential aspect in the design of a human–machine interface and it is considered to be the most difficult usability element to examine, due to the fact that it is based on the evaluation of comfort and acceptability of the system by its users (ISO 9241-11, 1988). Maximizing comfort will increase tractor operators' satisfaction, as well as safety and productivity (Driessen et al., 2008). Despite its importance, the concept of comfort is missing of a clear operational definition, on the other hand it is widely accepted that comfort is a subjective construct and that needs to be evaluated by the users (Lueder, 1983; Looze et al., 2003; Vink, 2005). In view of that, a study investigating operator's satisfaction on an agricultural tractor cabin has been conducted and presented in this paper.

Agricultural tractor cabin evaluation

An agricultural tractor is a traction machine intended primarily for off-road usage and designed to supply power to agricultural implements (SAE, 2003). It provides a force in the direction of travel and it usually supplies mechanical, hydraulic and/or electrical power to implements, enabling them to perform their intended functions.

The study presented in this paper involved twenty users (i.e., operators), balanced in term of expertise (novices and experts), in a dynamic and low cost evaluation of an agricultural machine tractor workspaces (i.e., cabin). The purpose of the study was to evaluate operators' satisfaction with the workspace interaction and to identify the elements affecting it. In particular, the study aimed at identify the elements that positively affect the interaction - and should therefore be kept as they are - as well as those negatively affecting it, and that should be modified (bad ergonomics). Additionally, in consideration of future evaluations, it was investigated whether participants with different level of expertise contributed differently in the evaluation of those aspects.

The evaluation has been conducted on a medium-power utility tractor (four-wheel drive with smaller front wheels, equipped with an air suspended seat), constructed by one of the major worldwide agricultural machine manufactures and already available for purchase on the European market. The tractor complied with all relevant regulations concerning road traffic, safety at work, environmental protection and requirements for design of machinery workstations (ISO 4253:1993; ISO 14738:2002; Directive 2003/37/EC; ISO 15077:2008). In view of that, the operators' satisfaction level was expected to receive high scores. At the same time, elements that should be improved in order to increase operators' satisfaction, and ultimately the usability of the systems, were expected.

Material and methods

Tractor workspace has specific features affecting comfort. It involves a limited space with restrictions to posture, several control tasks, and noise and vibration from the vehicle and implements. Moreover, tractor operators are often required to work continuously for extended hours (often more than 8 hours a day), while performing various field operations. Tractor operators further differ from people working in non-vehicular workspaces as they are often required to leave the seat to get in and out of the cab several times (Andreoni et al., 2002). Arrangements and layout of seat, controls and displays were considered responsible for the operator's perceived level of comfort and acceptability of the system, and were analysed from the operator's point of view by the means of a questionnaire and a semi-structured interview.

Participants

The study sample consisted of an opportunity sample of twenty male recruited among the researcher's contacts. Their mean age was 28 years, ranging from 17 and 55 years old. Participants were familiar with tractors operations and half of them were experts (operated a tractor daily and have been working in the field for many years), while the other half was made of novices (operated a tractor only few times).

Tasks and procedures

The study was conducted at the IMAMOTER Institute facility test site in Piedmont (North-West of Italy). Participants were asked to perform a scenario, representative of fieldwork environment (approximately 30 minutes). During the scenario they had to accomplish the following tasks: starting the tractor and driving it on three different terrain conditions (i.e., artificial test track, asphalt road and cement road), locating and activating the 3-point linkage control, the hydraulic system control, and the PTO (power takeoff), and stopping the engine. To ensure consistent test conditions participants drove the tractors on the same path made out of the three different terrain conditions and the speed on each surface was kept consistent as much as possible.

Data collection and analysis

After the trial participants were asked to complete a questionnaire and to respond to a semi-structured interview, both reviewed before applying it in the study. The questionnaire consisted of demographic data and 40 close-ended questions on a 4-point Likert-type scale (1932) without a central anchor (1= highly disagree; 4= highly agree). A final question focused on the overall comfort, while the rest of the statements were grouped into 10 categories investigating operators' perspective in the following aspects: ease of accessing the cab and the seat, ease of exiting the cab, concentration required, visibility adequacy, vibration level, noise level, location and arrangement of displays, and the location and the ease of operating the PTO, the hydraulic system and the 3-point linkage control. Temperature and humidity were not investigated in the study in reason of the short trial time duration.

Once each participant completed the questionnaire, a one-to-one semi-structured interview was undertaken. The interview used the list of questionnaire statements and some tractor's pictures as a prompt to support and encourage the participant to talk about the interaction in more details. Participants were asked to judge the overall experience, describing positive and negative aspects of the interaction, as well as the reasons behind these opinions. Interviews lasted between 15 and 35 minutes and were recorded and transcribed, ensuring accuracy before they were coded.

Descriptive statistics were used to report the preliminary results of the questionnaire and non-parametric Mann-Whitney test was used for inferential statistics to compare participants with different level of experience in operating tractors. Descriptive content analysis was used to analyse the interview data (Weber, 1990; Hsieh & Shannon, 2005). It involved organizing data categorically, in order to identify the elements affecting the quality of the interaction. The coding framework was based on the questionnaire categories and sub-codes were assigned on questionnaire statements.

Results

Results showed that participants assigned high scores on almost all the aspects investigated (Table 1), indicating that the overall interaction resulted to be satisfactory for them. From the mean results emerged that the elements affecting the most the interaction were those related to the level of noise, the level of vibration, and the concentration required in executing tasks.

Table 1. Questionnaire categories mean, standard deviation, and minimum and maximum

Categories	Mean*	SD	Min	Max
Exiting the cabin	3.85	.37	3	4
Accessing the cabin	3.75	.44	3	4
Visibility	3.65	.59	2	4
Overall comfort	3.50	.51	3	4
PTO control	3.50	.61	2	4
Displays	3.00	.92	1	4
3-point linkage control	2.90	.70	2	4
Hydraulic system control	2.90	.91	1	4
Concentration	2.10	.85	1	4
Vibration	1.75	.91	1	3
Noise	1.75	.79	1	3

*Likert scale (1= highly disagree; 4= highly agree)

A Mann-Whitney U test was conducted to evaluate differences between study participants with different level of experience in operating tractors. Similarly, statistical significant differences were found only on the statements related to the level of noise (U=19.0, N_1=10, N_2=10, p=.019 two-tailed), the level of vibration (U=23.5, N_1=10, N_2=10, p=.043 two-tailed), and the concentration required in executing the tasks (U=6.8, N_1=10, N_2=10, p=.018 two-tailed). Novices evaluated

the level of vibration and the concentration required in executing the tasks higher compared to experts' opinions, while the level of noise was rated lower.

Content analysis was useful to interpret the quantitative results. Indeed, differences in the score assigned to the level of noise were related to the fact that novices considered the tractor engine noise an essential auditory feedback. Indeed, novices reported sentences like "*I listened to the engine* […] *it was useful*".

Differently, probably due to the fact that they are less used to operate agricultural machines, the level of vibration and the concentration required were negatively affecting more the quality of their interaction with the tractor compared to what happened with the expert participants. Considerations like: "*I'm used to drive smaller machines*", "*I'm not used to it, I had to be careful*", and "*I had to think about what I was doing*" were pronounced by novices.

Participants had an overall positive experience interacting with the tractor during the study. From the content analysis it was possible to distinguish among the aspects that deserved attention for their positive added value, such as ease of accessing the workspace, lateral visibility, and PTO control. Nevertheless, participants also identified elements which had a negative impact on the level of comfort experienced (elements of bad design that could be modified to improve user experience) related to the 3-point linkage and the hydraulic systems control.

The ease of getting out of the cab was the aspect that received the highest score in the questionnaire. Content analysis indicated that shape and dimensions of the doors were mentioned as important elements in the ease of exiting the cab (i.e., *"I like the big door, I can get out of it without difficulty", "I can get off looking around easily", "It's comfortable. I have a larger view on where I go"*). The tractor cab was equipped with wide doors (pivoting directly on the rear posts of the cab) and three steps and handrails to enhance operator safety when entering and when exiting the vehicle (Fig. 1). Participants were aware of the risks in getting in and out of a cab (e.g. wet or icy surfaces), yet they considered that the shape and size of the door was exclusively important for their comfort in exiting the cab. Also, working with a tractor typically requires the use of an implement making rear visibility essential during field operations. Participants appreciated the wide visibility of the tractor; the door pivoting directly on the rear posts of the cab allowed a larger field of lateral visibility. Considerations like: "*It's comfy* [...] *I control what's going on just by looking on the side"* were expressed by participants.

Figure 1. Tractor investigated

Results concerning the ease of locating and operating the controls have highlighted the importance of control layout in tractor workspace. The PTO speed can be selected by simply lifting the collar and moving the long lever to the desired speed. The PTO can then be engaged by pulling the yellow knob (Fig. 2). From the content analysis resulted that the ease of finding the PTO was linked to the intuitive yellow controls, while the ease of operating it was related to their positive perception of the mechanical interface. Indeed, the use of levers to control the operations was appreciated, especially by experts. Participants reported thoughts like: "[…] *no doubt, it's the yellow one",* and *"The lever is good. You look at it and you know what to do and* […] *you can relay on it, not like digital stuff".*

Figure 2. Lever (1) and knob (2) controlling the PTO

Differently, participants criticized the 3-point linkage control (Fig. 3). As shown in Figure 3, the system can be controlled by turning the wheel, depressing and holding the switch in the right-hand console (2), or by pressing the switch on the multi-controller unit (1). According to experts the type of control (i.e., the wheel) was not suitable to the task and a throttle control would have been a better solution. In support of experts' opinion, the wheel movement (turning clockwise or counter-clockwise) does not match the mental image of the 3-point linkage system movement, which raises and lowers the implement. Concerns like: "*If I have to raise it I don't know if I have to turn it to the right or to the left side"* were expressed by participants.

Figure 3. The 3-point linkage fast switch (1), the 3-point linkage control (2), and the hydraulic system (3)

At the same time, the 3-point linkage switch that enables the operator to rapidly raise or lower the implement to the previously set height was considered not easy to locate. Its position on the multi-controller unit was perceived as "*uncomfortable*", and criticized especially by experts. Complains were justified by referring that it was "*positioned too close*" to other switches. Indeed, it is grouped with the switch controlling speed, the remote valve and the automatic and manual playback. Experts reported that this switches configuration required them to "*pay attention*" to the control panel in order to single out the desired switch.

Also, participants negatively remarked the interaction with the hydraulic system. They reported that the system was not easy to operate because three out of four hydraulic valves were controlled by the joystick (Fig. 3). Altogether, experts reported that a group of levers would have made the task more intuitive to execute compared to the use of a joystick. This result was probably related to the different exposure to technologies and input devices. Indeed, novices were younger than experts and more exposed to a wide range of technological devices, such as video game console.

Conclusions

Factors like size, location and layout of controls affect the operator's comfort and efficiency. In this study a tractor cab has been evaluated by expert and novice operators under dynamic conditions. The evaluation referred to a tractor available on the European market and participants resulted pleased with the level of comfort experienced during the trials. At the same time the low cost evaluation gave evidence of which aspects were prised and which other were criticized.

Interestingly, it resulted that the perception of comfort in agricultural cab is influenced by lateral visibility. Results suggested that a large door increases the level of comfort perceived by the operators, improving lateral visibility as well as allowing them to exit the workspace in a safer and easier way. It is interesting to notice that in ISO 5721 (1989) the visibility measure is defined by rear and forward visibility, while lateral visibility is not considered.

A proper association between controls and task, along with logical grouping of controls, is essential in a human-machine system in order to be judged as comfortable. The main remarks operators reported are related to the 3 point linkage control type and location. The wheel control doesn't match operator's mental image of the task. In this case, a throttle to move up and down would be a better fit to the action of raising and lowering an implement. Additionally, to some participants the position of the quick switch was not comfortable as it required paying too much attention to correctly complete the task.

Furthermore, controls need to be easy to use and intuitive. Participants, especially experts, preferred mechanical interaction (i.e., lever) to digital one. Indeed, a lever indicates possibilities for action –called affordances (Gibson, 1977) - in a direct way without requiring cognitive processing.

The study confirmed that a low cost investigation can give insight on operator's workspace comfort, which is a complex and multifaceted construct affected by a variety of factors. Significant differences on the level of visibility, noise and concentration were found between novices and expert participants, suggesting that a complete list of elements affecting positively or negatively the quality of the interaction could be obtained only by involving users with different level of expertise.

A comfortable cab design plays an important role in the perception of machine overall quality. Manufacturers of agricultural machines are seeking more effective ways to improve cab design to meet customer expectations of vehicle comfort. In general, companies know that easy-to-use and comfortable products are acknowledged and appreciated by consumers. Hence, improving cab comfort will distinguish their product from others on the market.

Despite some limits, the study suggests that modifications to tractor interior workspace design (such as location, arrangement, size, and type of controls, display etc.) could be easily made to positively affect the operators' perceived comfort. Future work should include hand dominance differences, and elements related to on-

road tasks, such as the turn signal lever, the control of radio and air-conditioning system.

References

Andreoni, G., Santambrogio, G.C., Rabuffetti, M., & Pedotti A. (2002). Method for the analysis of posture and interface pressure of car drivers. *Applied Ergonomics*, *33*, 511–522.

Directive 2003/37/EC (2003) of the European Parliament and of the Council of 26 May 2003 on type-approval of agricultural or forestry tractors, their trailers and interchangeable towed machinery, together with their system, components and separate technical units and repealing Directive 74/150/EEC.

Directive 2006/42/EC (2006) of the European Parliament and of the Council of 17 may 2006 on machinery, and amending Directive 95/16/EC (recast).

Driessen, M.T., Anema, J. R., Proper, K. I., Bongers, P.M., & van der Beek, A. J. (2008). Stay@Work: Participatory Ergonomics to prevent low back and neck pain among workers: design of a randomised controlled trial to evaluate the (cost-)effectiveness. *BMC Musculoskeletal Disorders*, *9*, 145.

Gibson, J.J. (1977). The theory of affordances. In *Perceiving, Acting and Knowing*. R. Shaw and J. Bransford, ed. Hillsdale, NJ.: Erlbaum.

Gibson, W.H., Megaw, E.D., Young, M.S., &Lowe, E. (2006). A taxonomy of human communication errors and application to railway track maintenance. *Cognition, Technology & Work*, 8, 57–66.

Haapala, H.E.S. (2006). *Usability as a challenge in precision agriculture.* Proceedings of the Computers in Agriculture and Natural Resources 4th World Congress, *ASABE 2006*, USA, 89-93.

Hsieh, H.F. & Shannon, S. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, 15:1277-1288.

ISO 4253 (1993). Agricultural tractors – Operator's seating accommodation – Dimensions.

ISO 5721 (1989). Tractors for agriculture - Operator's field of vision.

ISO 9241-110 (2006). Ergonomics of human-system interaction -- Part 110: Dialogue principles.

ISO 9241-210 (2010). Ergonomics of human-system interaction -- Part 210: Human-centred design for interactive systems.

ISO 14738 (2002). Anthropometric Requirements for the Design of Workstations at Machinery.

ISO 15077 (2008). Tractors and self-propelled machinery for agriculture and forestry – Operator controls – Actuating forced, displacement, location and methods of operating.

Kuijt-Evers, L.F.M., Krause, F., & Vink, P. (2003). Aspects to improve cabin comfort of wheel loaders and excavators according to operators. *Applied Ergonomics*, *34*, 265-272.

Liaoa, M.H., & Drury, C. G. (2000). Posture, discomfort and performance in a VDT task. *Ergonomics*, *43*, 345-359.

Likert, R. (1932). A Technique for the Measurement of Attitudes, *Archives of Psychology*, No.140.

Looze, M.P., Kuijt-Evers, L.F.M. &van Dieën, J.H. (2003). Sitting comfort and discomfort and the relationships with objective measures. *Ergonomics*, *46*, 985-997.

Lueder, R.K. (1983). Seat comfort: a review of the construct in the office environment. *Human Factors*, *25*, 701-711.

Marras, W.S., & Karwowski, W. (2006). The Occupational Ergonomics Handbook: Interventions,Controls, and Applications in Occupational Ergonomics, 2nd ed. Boca Raton FL: CRC Press.

SAE (2003). Terminology for Agricultural Equipment J1150.

Stanton, N.A., & Salmon, P.M. (2009). Human error taxonomies applied to driving: a generic driver error taxonomy and its implications for intelligent transport systems. *Safety Science*, *47*, 227–237

Vink, P. (2005). *Comfort and design. Principles and good practice*. CRC Press: Hoboken.

Weber, R.P. (1990). *Basic Content Analysis*, Second Edition. Newbury Park, CA: Sage Publication.

Wulff, I.A.,Westgaard, R.H., & Rasmussen, B. (1999). Ergonomic criteria in large-scale engineering design—II. Evaluating and applying requirements in the real world of design. *Applied Ergonomics*, *30*, 207–221.