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**MANUAL HANDLING OF A FOLDING ROPS WITH SUPPORTING DEVICES: USABILITY
EVALUATION IN A GROUP OF MALE AND FEMALE NOVICE USERS**

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ABSTRACT Many fatalities occur during tractor rollover accidents due to the Folding Rollover Protective Structure (FROPS) in folded-down position. Applying an Inclusive design perspective to the design of machinery can contribute eliminating those handling issues which hinder the correct use of the FROPS, making it easy to operate for all the users. Considering the importance of human variability for good design and based on the feminization of agriculture, in the present study eleven male and eleven female novice users of agricultural machinery were asked to raise a traditional FROPS and a modified one equipped with supporting devices (rod + gas spring). Usability of both FROPS was evaluated with a questionnaire on perceived effort, quality of the physical interaction and satisfaction and by the observation of the adopted postures. Modified FROPS was associated with higher usability compared to the traditional one: lower perceived effort, more comfortable postures and higher levels of satisfaction were reported. The on-field observations highlighted that the traditional FROPS was operated by seven males and all the females by standing on parts of the machine, thus risking to lose their balance and fall. Instead, the modified FROPS was operated by all the participants standing with their feet on the ground. In conclusion, the modified FROPS was easily and safely handled by all the users: designing technical solutions taking into account females, generally shorter and weaker than men, could be helpful to safeguard also other populations of workers (e.g. migrants) with small anthropometric dimensions and less muscular strength.

Keywords: Ergonomics, Feminization of agriculture, Foldable ROPS, Inclusive design, Tractor Safety, Usability.

INTRODUCTION Agriculture has been recognized as one of the most hazardous productive sectors (Fagnoli and Lombardi, 2020). The majority of all accidents in agriculture occurred during farm machinery operation, and tractor rollover is the main cause of both fatal and non-fatal accidents (Farm Injury-Resource Center, 2017). With the aim to avoid deaths and to reduce the severity of injuries, Rollover Protective Structures (ROPS - i.e. cabs or roll-bars) are mounted on agricultural and forestry tractors to absorb the impact energy resulted from the collision of the tractor with the ground surface and to protect the farm operator in case of tractor overturn (Ayers et al., 2016). Since the 1980s, a foldable roll-bar (FROPS) version has been introduced to allow tractors operating in low overhead clearance conditions and limited access storage (Myers, 2015). However, statistics reported that in the U.S. approximately 30% of tractor overturn-related injuries were due to tractors with no FROPS (Myers et al., 2008); similarly, in the European Union countries, 40% of all injuries during tractor rollovers occurred when FROPS was removed or it was not in its upright protective position (Hoy, 2009). Regarding the reasons why farmers leave the FROPS in the folded-down position, Khorsandi et al. (2016) showed that the process of raising the FROPS is time-consuming and strenuous for the operators, also because of the actuation torques required to raise a FROPS (Khorsandi and Ayers, 2018). In the same line, previous studies conducted among male Italian agricultural operators (Caffaro et al., 2019; Micheletti Cremasco et al., 2020) reported that farmers perceived FROPS handling as a time-consuming and uncomfortable operation. Moreover, these studies have also observed some criticalities in the reachability of FROPS, determining users' incongruous postures, unnatural gestures and unsafe behaviors when operating FROPS. These criticalities emerged especially among users with shorter stature. Since the FROPS needs to be manually operated, an effective design should take into account the reachability aspects and the users' anthropometric variability with the purpose to optimize this interaction in terms of safety and comfort. With regard to the interaction issue, it is important to bear in mind that any designed device that will be adopted by users should be "easy to use, easy to learn and helpful". Thus, usability considerations, such as who the users are and their experience with the tool designed, must be evaluated (Gould and Lewis, 1985). Based on previous results, it is important to point out that they regarded the human-FROPS interaction among male users only. Despite this, females have a significant role within the agricultural activities, considering their recent increasing participation in this sector in developed countries and the fact that in developing countries women already give an essential contribution to agriculture and rural economic activities (FAO, 2020). For instance, in the U.S., a little more than 36% of producers are women (United States Department of Agriculture, 2017); in Canada the 25% of farm owners are women and the 47% of the whole farming population is female (Dimich-Ward et al., 2004); in EU countries women make up below 50% of the rural population (Franić and Kovačićek, 2019); in areas such as Oceania, Southern Asia, and sub-Saharan Africa, more than 60% of women are employed in agriculture, whereas in least developed countries this value can reached the 80% (United Nations, 2015). In detail, for instance, in India, approximately 74% of the female workforce is involved in agricultural operations (Satyavathi et al., 2010). Considering this growing female farming population, there is a need to develop tools, machinery and equipment suiting also the capabilities of female agricultural workers (Agrawal et al., 2010), since it is well known that men and women have different strength and anthropometric characteristics. Unfortunately, in the

agricultural sector, machinery is still often developed taking into account the average man's body and strength, overlooking the women's physical needs and making the tools and equipment difficult or impossible for women to use. Indeed, females reported, on average, shorter body dimensions and strength compared with males (United Nations, 2020). For instance, in Bangladesh, the treadle pumps for irrigating fields were designed considering the average weight and strength of men, but were mostly used by women, who suffer pain and exhaustion as a result (United Nations, 2020). Therefore, it would be useful to investigate the criticalities and reachability issues during FROPS handling previously found among the male population, also among females.

Context and the aim of the present study The present study is part of a wider research project on the rear-mounted FROPS fixed on narrow-track wheeled tractors (with a track width of not more than 1150 mm) conducted in Italy, since also in this country, the 30% of tractor rollover fatalities from 2008 to 2014 resulted from the lack of FROPS or because it has been left in the lowered position (Pessina et al., 2016). From the previous observations, two main behaviors were detected to raise the FROPS: 1) the rear three-point lifting arms or the tow bar were used as platforms for the feet to reach and operate the folding bar, or 2) farmers raised FROPS maintaining their feet on the ground. Moreover, two of the interviewed farmers used the mirror shaft, when it is mounted as an additional element to the FROPS, to simplify and facilitate the FROPS handling. Similarly, during the interviews, many farmers pointed out the need to develop new solutions to increase FROPS reachability and provide more information about safer gestures to be adopted during FROPS handling. Based on these previous results, and adopting an Inclusive Design approach, the present study aimed to test the usability of a prototype of a supporting device fitted on a rear-mounted FROPS to enhance its safe and comfortable use. The FROPS with the added device was compared with a traditional one (i.e. without any added components). Considering the increasing feminization of agriculture also in the Italian context, and that nowadays in Italy 25% of the workers employed in this sector are females (INAIL, 2020), it is relevant to conduct usability tests taking into account the gender issue. Indeed, following the Inclusive design method, the developed prototype wanted to address the design needs of a broader range of farming operators, considering the existing differences among humans because of their gender, size, anthropometry and working capabilities (Hussain et al., 2013). Usability tests with both males and females allow us to detect possible future improvements, since female users are particularly disadvantaged in the interaction with heavy tractor components especially if they are placed at a greater distance from the ground.

MATERIALS AND METHODS

Sample Twenty-two users (males n=11 and females n=11) were involved in the study and were recruited among the students of an agricultural high school in the province of Cuneo, Piedmont region, Northwest of Italy. Only novice tractor drivers, i.e. with less than 5 years of driving experience (Kumar et al., 2001), were selected to participate in the study. The novice users' involvement is considered helpful and convenient in ergonomics research since they are able to identify the most severe issues in the interaction between the human being and the machine. Participation was voluntary and no incentives were

offered. Participants gave their written informed consent prior to their inclusion in the study.

Instruments The usability test was conducted using two structures which simulated real tractor dimensions and obstructions, based on measurements collected during previous investigations (Micheletti Cremasco et al., 2020). However, to ensure that the participants raised FROPS in safety conditions, some parts often used as a support for the feet during FROPS handling, i.e. the rear lower links of the rear three-point linkage and the rear power take-off protection (Micheletti Cremasco et al., 2020), were designed with measures greater than the real ones, providing an adequate standing surface (20x40cm for each foot, as illustrated in the OECD 2020, Code 7 p. 40). On each simulated tractor a rear-mounted FROPS was fixed and on only one of the two FROPS, the prototype of the supporting device, made by a rod and a gas spring, was welded. The gas spring fitted on the rear-mounted FROPS has been mounted on the left side and a rod with a padded handle has been mounted on the right side of the FROPS. The gas spring had a maximum arm length of 350 mm and a force of 350N, whereas the rod had a total length of 800 mm, including 160 mm of padded handle (see Figure 1). When the rod was not used, it remained anchored along the FROPS with a hook. Moreover, the prototype was designed so that none of the parts of the prototype can enter and infringe the clearance zone of the operator when he/she is seated in the driving position.



Figure 1. The prototype of the supporting devices fixed on the FROPS. On the right side the rod, and on the left side the gas spring were welded.

The usability of both FROPS was evaluated by means of observations and an ad-hoc questionnaire. With regard to the observations, participants were video recorded with two cameras stabilized on tripods to have both the lateral view and the posterior view. In the subsequent video analysis, it was observed whether both groups of participants (males and females) were able to complete the tasks required (or if they needed any help) and the postures adopted. The questionnaire was developed starting from the NASA Task-Load Index (TLX) (Hart and Field California Lowell Staveland, n.d.) and adjusted for the present investigation. Participants were asked to rate their agreement (from 1=not at all agree to 4=totally agree) with seven different questions (see Table 1) which allowed to investigate the effort, the quality of the physical interaction with the FROPS and the users' satisfaction. At last, a standard socio-demographic form gathered data on the participants' age, stature and body mass. Overall, the height of the participants ranged from the 5th to the 95th percentile of the European anthropometric dataset (Jurgens et al., 1998), accommodating approximately 90% of the population, as recommended in ergonomics design (Berlin and Adams, 2017).

Table 1. Items used to evaluate the usability of the testes FROPSs.

Category	ID	statements
Effort	Q1	It was strenuous
	Q2	The roll-bar was heavy
Quality of physical interaction	Q3	I had to adopt awkward postures
	Q4	I felt in an unstable position
Satisfaction	Q5	I managed the task in full autonomy
	Q6	I am satisfied of how I accomplished the task
	Q7	I felt awkward while performing the task

Procedure Participants were asked to raise both the traditional and the modified rear mounted FROPS and after each operation they were invited to complete its respective questionnaire section. Participants were asked only to perform both tasks standing behind the tractor and respecting the obstructions that might be present in the real context. In particular, even though the two structures simulated these overall tractors' obstructions, the space required by the rear wheel has been marked on the floor using a white adhesive tape. To avoid habituation and learning effects half of the participants were randomly selected to operate the traditional protective structure first, while the others started with the modified one.

Data analysis Mean ratings for each of the seven items of the questionnaire were computed. A one-way repeated-measure ANOVA was performed to compare the scores collected for the two FROPSs. The type of FROPS used (traditional vs modified) was the independent variable, gender was used as the between-subject variable and the seven items as within-subject variables. Bonferroni tests were performed as a *post-hoc* analysis for the interaction effects (FROPS*gender). The analyses were performed using IBM SPSS Statistical Package for Social Science v. 26.

RESULTS The participants had a mean age of 19.77 years (ranged from 18 to 24 years, SD = 2.02), a mean stature of 167.04 cm (minimum 1530 mm, maximum 1800 mm, SD= 6.61) and a mean body mass of 60.14 kg (minimum 40 kg, maximum 85 kg, SD= 9.27). With regard to participants' handgrip strength, the mean of 35.24 daN (SD=10.15) and 33.36 daN (SD=9.58) were recorded for the right hand and left hand respectively. Detailed information is reported in Table 2.

Table 2. Participants' main characteristics.

Gender	Age		Stature		Body mass		Right hand grip strength		Left hand grip strength	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Male	19.45	2.06	170.72	4.67	64.36	8.91	43.11	6.91	40.63	7.55
Female	20.09	2.02	163.36	6.15	55.90	7.91	27.36	5.95	26.08	4.60

Observations Ten out of eleven female participants were able to complete the raising task on the traditional FROPS. All the female participants used some parts of the simulated tractor (i.e. one rear lower link and rear power take-off) as a support for their feet during the traditional FROPS handling (Figure 2a and 2b). The same happened for eight male

participants (Figure 2c, and 2d) whereas the other three male participants raised the FROPS maintaining their foot on the ground (Figure 2e). These three participants were among those who had a greater stature (1800 mm, 1750 mm and 1700 mm). Other six participants who had a similar stature (1700 mm - 1750 mm) performed the raising task using tractor parts as a support for the feet (Figure 2d). When considering the FROPS with the supporting device, all the participants (males and females) successfully completed the raising task maintaining their feet on the ground. Therefore, none of the parts of the simulated tractor was used as a support for the feet. Nearly all the participants gripped the rod with both hands, and only three male participants gripped the rod and raised the FROPS with only one hand. Examples are reported in Figure 3.



Figure 2. Participants while raising the traditional FROPS: the shortest (a) and the tallest (b) female participants, the shortest male participant (c), the tallest male participants using parts of the structure as a support for the feet (d), and maintaining his feet on the ground (e).



Figure 3. Participants while raising the modified FROPS: the shortest (a) and the tallest (b) female participants, the shortest male participant who gripped the rod with both hands (c) and the tallest male participants who gripped the rod with one hand only (d, e). It has to be note that these last two participants raised the traditional FROPS differently (see Figure 2d and 2e).

Questionnaire Figure 4 shows the mean ratings given by the participants to the different items of the questionnaire concerning the effort (Q1, Q2), the quality of the physical interaction (Q3, Q4) and the satisfaction (Q5, Q6, Q7) for the two performances. Overall, both males and females reported lower ratings of effort and discomfort in the physical

interaction (in terms of postures, stability and feeling awkward) compared with the traditional one. For the item concerning awkward feeling lower ratings were reported for the modified FROPS; whereas for the other items concerning the perceived autonomy and satisfaction were reported higher ratings in both groups for the modified FROPS. In particular, for the two questions on the quality of the physical interaction (Q3 and Q4), the group of females drastically reduced their mean score compared to the group of males (Figure 5).



Figure 4. Mean ratings for each item reported by a) females and b) males. Questions and their respective ID are listed in Table 1.

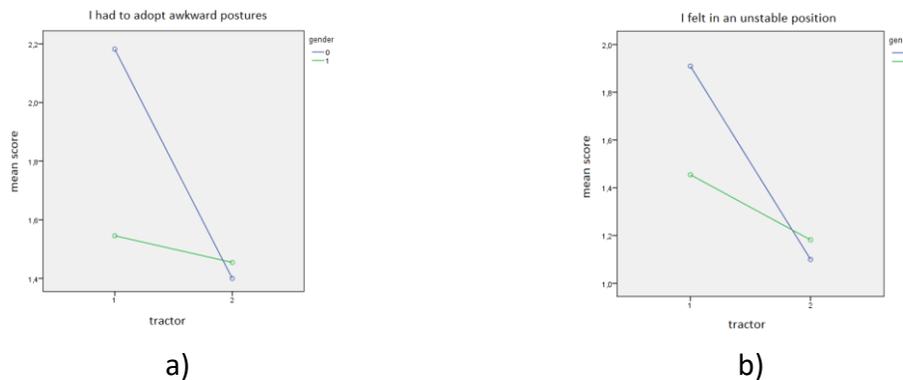


Figure 5. Chart for the items on the quality of the physical interaction, in which females drastically reduced their mean scores compared to the mean scores reported by males: a) Q3, “I had to adopt awkward postures” and b) Q4, “I felt in an unstable position”

The one-way repeated-measure ANOVA showed a significant interaction effect gender*FROPS ($F(8,13)=4.887$, $p=.006$). Post-hoc tests showed that female participants perceived the modified FROPS as significantly better than the traditional one in six out of seven items, whereas male participants perceived a significant improvement in handling the modified FROPS concerning two out of seven items. In details, females perceived significant improvement in the items Q1, Q2, Q3, Q4, Q6 and Q7, reporting p value respectively of $p=.032$, $p=.039$, $p=.017$, $p=.017$, $p=.037$, $p=.020$; whereas males perceived significant improvement in the items Q1 and Q2, that is the effort items, reporting p value respectively of $p=.005$ and $p=.010$. No main effects of either the type of FROPS or gender were detected ($F(8,13)=1.649$, $p=.203$ and $F(8,13)=.879$, $p=.558$, respectively).

DISCUSSION Previous evidence showed that reachability issues can significantly influence the human-FROPS interaction. The growing feminization of the agricultural sector

requires to pay particular attention to the topic of reachability since the female population has an average body size and strength lower than those reported by the male population. The present study represented a first attempt to address these issues, involving a group of male and female operators in the usability testing of a prototype of a supported FROPS. The results showed that following the principles of the Inclusive Design to develop new devices and testing their perceived quality in use, it may be possible to make more appreciated and comfortable changes. These considerations were mirrored by ease of use reported by the participants during the rod adoption and from the appreciation that emerged from the average scores of the questionnaire. Moreover, from the observation it was noticed that all the participants used the handling device successfully. Thus the devices added in the present investigation (in particular the rod) could be considered as a good design solution since it facilitated the utilisation of a product (FROPS) (Popovic, 2003). With concern to the postures, on the traditional FROPS the participants adopted postures and behaviors similar to those observed in previous investigations (Micheletti Cremasco et al. 2020), highlighting that in the modified FROPS, the prototype reduced the awkward postures, allowed to avoid the risk of falls that could be determined by the loss of balance and reduced situations that may injure the farm operator/farmworkers (Caffaro et al., 2017). Users' statures and reachability difficulties could not be considered the only factors able to affect operators' behaviors during Human-FROPS interaction (as observed among the taller male participants who used the rear three-point lifting arms or the tow bar as a support for the feet), but strength and low joint mobility could also play a role. The prototype also improved the FROPS reachability as its grip was easily accessible by all participants, even the shorter ones, making the raising task more comfortable, and reduced the effort demand. In detail, results are promising because more benefits were perceived by females despite they had a lower stature and a lower hand strength than that of the males. Until a final design version of the prototyped solutions is available, some consideration could be raised since, according to the FROPS testing standards, any change to the shape and structure of the FROPS could discredit the current test for the performance of the FROPS in case of a rollover event (OECD, 2020). Based on this, in future studies new strength tests of the FROPS should be performed. In addition, the present study involved a small group of novice tractor drivers. The involvement of a small number of participants in the present study is supported by the assumption reported by earlier studies (Faulkner, 2003), in which it was argued that just 5 participants could reveal about 80% of all possible criticalities in the use of a product. However, to obtain more generalizable results, a wider sample of both male and female users, with different levels of expertise, could be involved in future investigations. Although the sample is limited in size, the present study is still of interest, since it represents a first analysis in which female users were involved in FROPS usability tests with the aim to improve interaction with rear-mounted FROPS. Also, the study can be particularly useful considering that older farmers and migrants, who have anthropometric and functional characteristics different, are employed in this sector.

CONCLUSION The authors believe that the results of this study may raise useful considerations on the human machine interaction, accentuating the need to develop design solutions that can be easily used by as many potential users as possible. Considering that the agricultural workforce is increasingly composed of operators who

have different biomechanical, dimensional, and functional characteristics (older, migrant and women), the adoption of an inclusive design approach in designing agricultural machinery and equipment, which considers the existing differences among humans, is strongly recommended.

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