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Running head: ISSUES IN TRACTOR ROLLOVER PROTECTION

Tractor rollover protection: is the incorrect use of Foldable Rollover Protective Structures (FROPS) due to human or to technical issues?

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Abstract

Objective: To identify the critical behaviors that may hinder the correct use of Foldable Rollover Protective Structures (FROPS) on tractors and to explore the influence of user factors and FROPS technical characteristics.

Background: FROPS are effective in preventing fatal injuries in rollover accidents if they are in the upright position. However, many farmers leave FROPS folded down.

Methods: Twenty farmers and sixteen models of tractors were involved in the study. Operators were observed while raising the FROPS and the observed behaviors were correlated with user factors and FROPS technical features.

Results: In the initial rotation of the FROPS, higher lowered roll-bar to ground distance and FROPS pivot-pin to ground distance, required more awkward and unbalanced postures ($p=.02$ and $p=.01$, respectively). When rotating the FROPS in upright position (phase 2), smaller stature of the participants and higher FROPS pivot-pin to ground distance were significantly correlated with using the tractor's rear three-point lower links as a supporting surface ($p=.01$, and $p=.02$, respectively).

Conclusion: FROPS might be revised considering users’ comfort in use and anthropometric variability, to improve reachability, avoid risky behaviors and enhance FROPS operation.

Application: Technical solutions to enhance FROPS accessibility may be developed, particularly by providing safe surfaces to support operators and highlighting the hand grip point. Further best practices and information on correct gestures and operation about how to handle the FROPS should be included in the tractor manual.

Keywords: Agriculture; Foldable rollover protective structure; Safety; Tractor; User factors

Précis: Participants' behavior when handling Foldable Rollover Protective Structures on tractors was analyzed, to identify critical issues hindering the safe use of FROPS. Different behavioral patterns were identified and correlated with user factors and FROPS measures. Design solutions and behavioral guidelines may be developed to enhance the correct use of FROPS.

Introduction

Tractor rollover has been reported as the main cause of both fatal and non-fatal accidents in agriculture since the ‘50s (Abubakar, Ahmad, & Akande, 2010; Pessina, Facchinetti, & Giordano, 2016). In the United States, in the period between 2003 and 2010, 1474 workers in agriculture, forestry, fishing, and hunting industries were killed due to tractor-related events, and 933 were killed as a result of rollovers (US Department of Labor, 2012). Tractor rollover is the second cause of fatalities in agriculture in Canada, with 143 cases out of 589 machinery-related fatalities during 2003-2012. As concerns the European Union countries, 158 road accidents involving agricultural tractors occurred in 2015 (European Commission, 2017), however comparable data for rollover accidents is not available (European Agricultural Machinery Association [CEMA], 2017). Among the member states of the European Union, in Portugal 38.6% of 57 fatal tractor-related accidents in the period 2005-2014 was due to rollover (Antunes, Cordeiro, & Teixeira, 2018). With regard to Italy, 89 cases out of 121 tractor-related fatalities, in the year 2013, were caused by rollovers (INAIL, 2015).

The combined use of a Rollover Protective Structure (ROPS) and a seatbelt proved to be the most effective way to prevent deaths during rollover accidents (Cavallo et al., 2014; NIOSH, 2009). ROPS are structures that absorb a portion of the impact energy generated by the tractor weight in a rollover accident. They decrease the risk of a severe injury by providing the operator with an adequate clearance zone (OECD, 2017). To facilitate tractor operation in low overhead clearance zones, foldable ROPS (FROPS) have been developed since the ’80, a period where most of the technological progress in tractor’s design dealt with the adoption of features to improve its safety and ergonomics (Cavallo, Ferrari, & Coccia, 2015).

FROPS are made of two parts: the upper and folding frame and the lower part, the support, fixed to the tractor body or chassis (Figure 1). The foldable frame is connected to the lower part by a pivot point and a pin, or a bolt, to keep it upright. By this construction, the height of the FROPS can be significantly decreased, making this solution frequently adopted (Myers, 2015). FROPS are placed in front or on the back of the tractor's driving station. The first solution is frequently adopted on narrow vineyards and orchard tractors to reduce the interference of the protective structure with the crop canopy, while the second solution is most commonly found on standard tractors.

Figure 1. Example of a rear Foldable Rollover Protective Structure in upright position.

However, a new issue raised in the past years (Myers, 2009) since a high incidence of fatal injuries in tractor rollover accidents with folded down FROPS has been reported, both in the USA and in Europe (Fargnoli, Lombarbi, Haber, & Puri, 2018; Hoy, 2009; NIOSH, 2015). For instance, in the European Union member states, 40% of serious injuries and deaths during tractor rollovers occurred when a foldable ROPS was not deployed into its protective position (Hoy, 2009). In Italy, in 2016, 90 out of 114 fatal accidents involving tractors were rollovers, and about 19% of these fatalities resulted from FROPS in the folded-down position (Fargnoli et al., 2018).

Regarding the reasons to leave the FROPS in the folded down position, Khorsandi et al. (2016) argued that the process of raising the FROPS is time-consuming and strenuous for the operators, also because of the actuation torques required to raise and lower a FROPS (Khorsandi & Ayers, 2018). A multidimensional study conducted in a group of Italian agricultural operators (Caffaro et al., 2019) showed that handling the FROPS was not associated with a high perceived effort but it was considered by farmers time-consuming and uncomfortable. Indeed, the same authors have observed some criticalities in the reachability of the FROPS, which determined unnatural gestures, incongruous postures and unsafe behaviors in FROPS operation.

With regard to this last issue, previous studies demonstrated that the quality of human-tractor interaction is affected by technical safety requirements as much as by reachability and comfort in use (Ferrari & Cavallo, 2013). ROPS design characteristics and dimensions depend on operators' safety and protection needs if a rollover occurs, and are defined by the requirements to be met in FROPS testing (Ayers, Khorsandi, John, & Whitaker, 2016). However, since the FROPS has to be manually operated, an effective design should take into account the reachability aspects, respecting users' variability. Indeed, as reported in the ergonomic literature, to develop human centered products, human factors as sizes, shapes of people, and questions concerning the positioning and comfort in use have to be considered. Thus, in the human-machine interaction, the reaching and grasping issues referring to the fact that everyone can reach and operate the controls need to be verified (Naumann & Rötting, 2007).

Moreover, some user factors such as previous experience, age and anthropometric characteristics may influence the quality of the human-machine interaction and they should be taken into account to optimize the interaction with the machine in terms of safety and comfort. Previous experience with machine and its devices has been reported in the literature as a critical factor for risky behaviors. According to some authors, familiarity may lead to an overconfidence in use, supporting the adoption of unsafe or awkward routine behaviors (Elkind, 2008). However, other authors pointed out the opposite result. In this case, individuals in familiar situations might be more likely to behave correctly and safely because they are more aware of the surrounding conditions (Caffaro, Roccato, Micheletti Cremasco, & Cavallo, 2018). Age is known to affect individual balance, articular capability and strength, increasing the risk of falling or of musculoskeletal injuries (Caffaro et al., 2017; Holliday, 2010; Koolhaas, van der Klink, Groothoff, & Brouwer, 2012; Pizzigalli, Micheletti Cremasco, Mulasso, & Rainoldi, 2016). Anthropometric characteristics proved to be relevant aspects to be considered in the human-machine interaction. Those designers who consider anthropometric measurements produce more accurate product dimensions and features, well-received by consumers, and mostly adoptable (Ferguson, Greene, & Repetti, 2015). Also, different levels of performance are referable to the variability in body size and shape across different demographic groups (de Vries & Parkinson, 2014).

Based on the previous considerations, the purpose of the present study was to analyze the human-tractor interaction focusing on FROPS handling, and to identify critical behavioral patterns while raising the FROPS. In addition, we intended to explore the relation between the observed behavioral patterns and different user factors (i.e. stature, reachability, age, expertise) and FROPS dimensional features to point out critical variables, which may hinder the operators from raising the FROPS after lowering it to pass an obstacle. The present study, built on Caffaro et al. (2019), widens the sample of participants and analyses the influence of user factors and machine features on the behaviors adopted to handle the FROPS. The final aim was to highlight critical issues concerning the human-FROPS interaction, to identify possible technical improvements of the roll-bar as well as behavioral guidelines to promote a safe and comfortable handling of FROPS.

Materials and Methods

Sample and context of the study. Twenty farmers and sixteen different models of tractors from different brands available on the Italian market were involved in the study (Table 1). The participants were all males, because of the predominance of male workers among Italian farming population (ISTAT, 2013) . The tractors were standard-track tractors (i.e. track width larger than 1150 mm, according to OECD Tractor Codes, OECD, 2017) fitted with rear-mounted two-pillar FROPS. The main descriptive statistics of the participants and tractors involved in the study are reported in Table 1.

Table 1. *Mean and standard deviation of the socio-demographic characteristics of the participants and technical features of the tractors involved in the study.*

	Variable	Mean	SD
Participants	Age (years)	49.24	11.49
	Working experience in agriculture (years)	23.13	17.66
	Stature (cm)	175.52	8.26
	Forward reach (cm)	74.48	6.18
Tractors	Distance ground-crossbar in lowered position (mm)	1319.75	156.69
	Distance ground-FROPS pivot pin (mm)	1865.67	150.69
	Distance FROPS pivot pin-top (mm)	602.33	128.06

Note. In our dataset, participants' age and years of working experience in agriculture showed a strong correlation (rho=.57, p<.01). To avoid an excessive conceptual overlap and problems of empirical collinearity, for subsequent analysis, we reasoned in terms of years of experience rather than in terms of age.

The study was performed in Northwestern Italy, Piedmont region, which is one of the Italian regions with the higher number of fatal overturning accidents involving tractors (Pessina & Facchinetti, 2017). The study was approved by the Research Advisory Group (RAG) of the Institute for Agricultural and Earthmoving Machines (IMAMOTER) of the National Research Council of Italy (CNR).

Instruments. Different measurements of both the components of the human-machine interaction (i.e. the participant and the tractor) were taken, to analyze the quality of the interaction and to identify critical aspects which may hinder FROPS operation:

1. Participants' behavior when raising the FROPS of their own tractor was video-recorded. The observations were carried out on participants' own tractor since we were interested in the natural routine behavior, in the interaction with a familiar machine (McLaughlin, Fletcher, & Sprufera, 2009). The observations were video-recorded using two orthogonal cameras stabilized on tripods, one placed on the side of the participant (lateral view) and the second one behind the participant's back (posterior view), to evaluate the adopted postures. Some photographs were also taken from different views to optimize the analysis of the targeted behaviors. These observational techniques are widely used to generate information about automatic actions and to document natural task performance in a relatively unconstrained environment (Kirwan & Ainsworth, 1992). Since observations may be supplemented by a verbal description from the operator of the decision processes taking place (Kirwan & Ainsworth, 1992), the participants were also asked to report any difficulties related to the task and the interaction with the FROPS, adopting the 'thinking aloud' technique (Lewis, 1982) as in Ferrari and Cavallo (2012), to highlight any potential source of discomfort and possible risk.

2. Three machine dimensional features, which emerged as particularly salient in the human-tractor interaction in the preliminary study (Caffaro et al., 2019) were measured

with a digital laser rangefinder (Bosch DLE 50), i.e. vertical distance from ground-to-top of folded ROPS, from ground-to-FROPS pivot pin, from FROPS pivot pin-to-top of FROPS in upright position (Figure 2).

3. Anthropometric measurements of stature and forward reach were performed using Sieber Hegner SH101 anthropometer as ISO 7250-1:2017 standard recommends, and in accordance with ISO 7250-1:2017 procedures and methods (Figure 3).

Participants were also administered a standard socio-demographic form which contained two open ended questions: the first about the frequency of folding/raising operation of the FROPS and the second concerning the reasons for lowering the FROPS and possible criticalities in handling it.

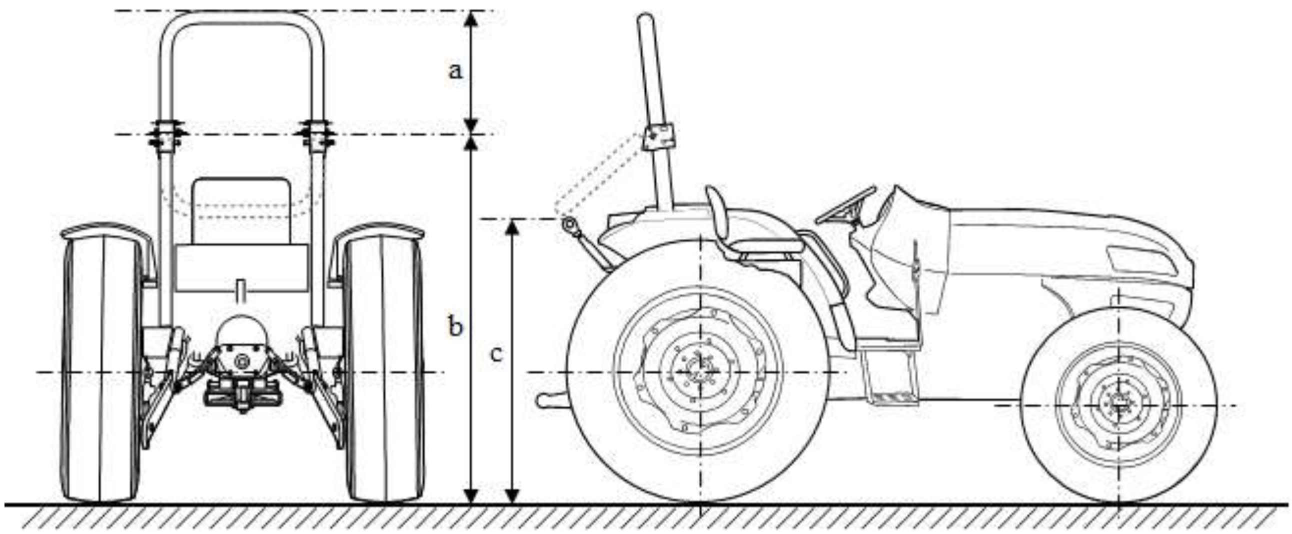

Figure 2. Tractor measurements: a) vertical distance from FROPS pivot pin-to-top in upright position, b) vertical distance from ground-to-FROPS pivot pin, c) vertical distance from ground-to-top of folded ROPS.

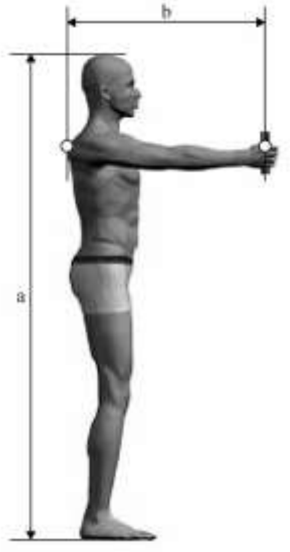

Figure 3. Human anthropometric measurements considered in the study: a) stature and b) grip-reach; forward reach (figure adapted from ISO 7250-1:2017).

Procedure. We were interested in operators owning a standard-track tractor fitted with rear-mounted two pillar FROPS. Thus, a list of possible participants respecting these selection criteria was provided by the dealers of various brands of agricultural machinery in the province of Cuneo and Asti, Piedmont Region, North West of Italy. Farmers were contacted by telephone and, if willing to participate, they were met at their own farm. At the beginning of the visit, the socio-demographic form was administered and the frequency of FROPS operation discussed. Then the participants were asked to lower and raise the FROPS of their tractor as they usually did (or would have done, if they had not operated it before at all), while explaining what they were doing and any possible difficulty in performing the task. After that, the dimensional features of the FROPS were measured and anthropometric measurements performed. Each visit lasted about 20 minutes. The participation was voluntary and all the farmers gave their written informed consent prior to their inclusion in the study.

Data analysis. Two independent experts in physical ergonomics analyzed the videos using an observational grid. The grid provided different postural and behavioral categories which are known to be critical variables when assessing postural comfort/discomfort and (un)safe behaviors (ISO 11226:2000; Kroemer & Grandjean, 1997), adjusted for the type of task considered, i.e. handling the FROPS:

-Initial and final position of the operator, regular or uneven surface and general characteristics of the environment;

-Trunk posture in terms of inclination, extension, twist and lateral flexion and head inclination and extension;

-Left and right lower limb posture, knee flexion and tight raising;

-Left and right foot posture, balance and type of support used considering the changing during the task;

-Left and right upper limb posture, considering arm flexion, abduction, extension, flexion and elbow extension;

-Left and right hand position during handling, considering the changing during the task, and the use of one or both hands during the handling.

Considering the combination of all these aspects, two phases in the FROPS raising task and two patterns of behaviors and gestures of both upper and lower limbs in each phase were identified.

For subsequent analysis, the four identified behavioral patterns were grouped according to the raising phase they referred to, leading to two different variables, each coded as 0-1:

1. “Behavior adopted in Phase 1”: operator with symmetrical shoulders, both hands on the horizontal part of the roll-bar, and feet on some parts of the tractors (coded as 0) or feet on the floor (coded as 1);

2. "Behavior adopted in Phase 2": operator with asymmetrical shoulders, one hand on the vertical part of the roll-bar and the other on the horizontal part, and feet on some parts of the tractor (coded as 0), or asymmetrical shoulders with both the hands on the nearest vertical part of the roll-bar, and feet on the floor near the side of the tractor (coded as 1).

These variables were then correlated with user factors (i.e. working experience, frequency of FROPS operation, stature and reachability) and FROPS measures (i.e. overall height from ground-to-top of folded ROPS, vertical distance ground-to-FROPS pivot pin, and vertical distance FROPS pivot pin-to-top). Due to the small sample size, Spearman's Rho correlation coefficients were computed using SPSS v. 24.

Results

As concerns the frequency of FROPS operation, 8 interviewees reported to keep the device always in upright position, while 7 of them declared a seasonal handling of the device: they typically had to move it several times in different periods of the year, to work under hazelnut trees or into the wood. Five operators reported a frequent folding down of the FROPS, to work in greenhouses, or to store the tractor in the warehouse. Regarding the critical aspects in FROPS operation, 11 participants declared that especially raising the FROPS was uncomfortable because of the height of the roll-bar and due to a lack of adequate feet support and grasping points.

Considering the placement of the participants and the gestures performed during the FROPS-raising task, Caffaro et al. (2019) identified 2 different phases: i.e. moving the folded roll-bar from 0 to about 90 degrees (Phase 1) and then from 90 to 180 degrees (Phase 2) (Figure 4).

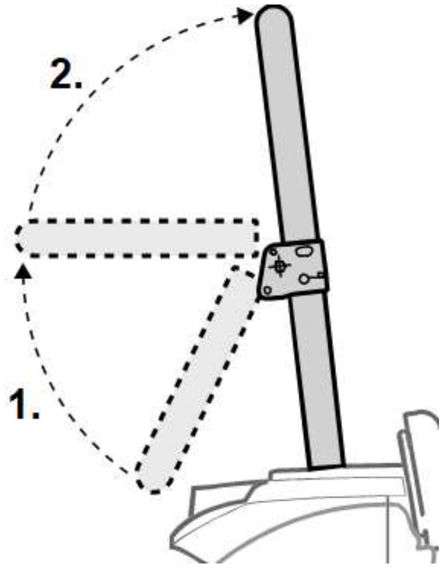

Figure 4. Different phases in FROPS raising, based on observed behavioral patterns: 1) rotation from the lowered to the horizontal position (from 0° to 90°); 2) rotation from the horizontal position to upright position (from 90° to 180°).

Two main different patterns of behaviors involving both upper and lower limbs were also detected in each of these phases. One of these patterns was partially modified compared to Caffaro et al. (2019) thanks to further observations performed during the present study, leading to what is represented in Figure 5.

To grasp the ROPS when it was fully lowered, 9 participants used some parts of the machine (typically the lower links of the rear three-point linkage) as a platform to reach and operate the FROPS when it was fully lowered, whereas other 11 participants raised the roll-bar by standing on the floor (Figure 5a and 5b). In these two configurations, workers had aligned and symmetrical shoulders and both the hands on the horizontal part of the roll-bar. The two different feet placements were observed also in the second phase of FROPS operation (i.e. moving the roll-bar to the upright position), together with two main types of hand gestures and placement: 11 participants finished the raising task by pushing the roll-bar with both hands while 9 farmers by using only one hand (the other one was used just as a support) (Figure 5c and 5d). In some of these cases a unilateral hyperextension of one side of the body was observed, where one hand was placed higher than the other to completely lift the roll-bar.

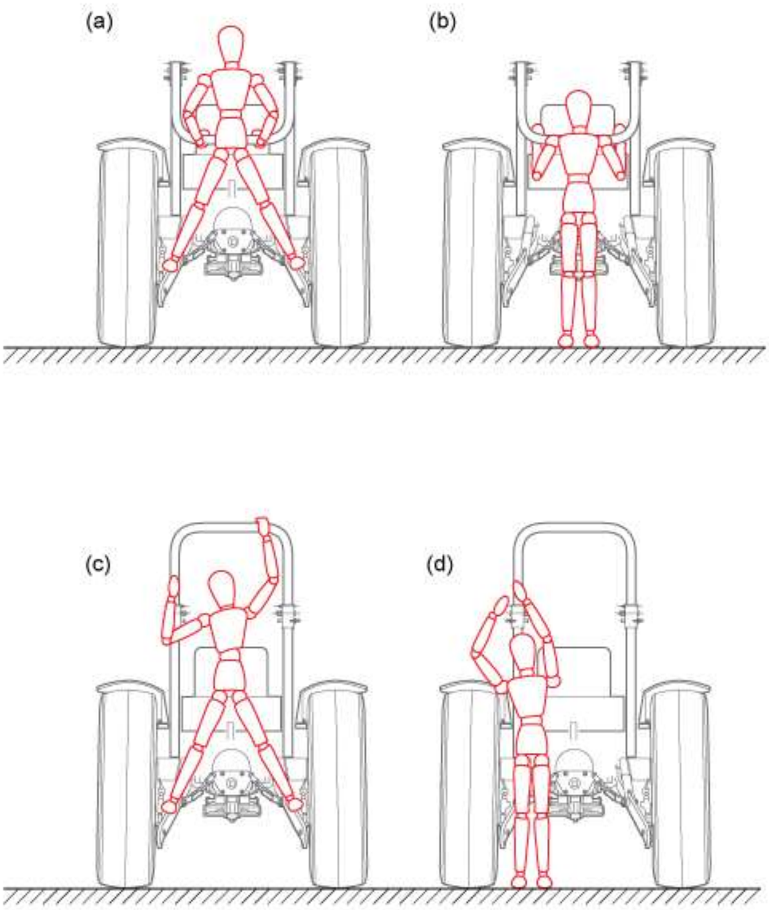

Figure 5. Typical placement and postures adopted by the operators to grasp the roll-bar in its lowered position and to move it to the upright position. Phase 1: (a) standing on some parts of the machine, or (b) standing on the ground, with aligned and symmetrical shoulders, and both the hands on the horizontal part of the roll-bar. Phase 2: (c) standing on some parts of the machine, with unaligned shoulders and asymmetrical upper limb position, with one hand on the vertical part of the roll-bar and the other one on the horizontal part of it, or (d) standing on the ground with the feet near to one side of the tractor, asymmetrical shoulders and both the hands on the nearest vertical part of the roll-bar (one over the other).

The observed behavioral patterns presented some postural criticalities, for both the upper and lower limbs. A lack of adequate support of the feet may expose the operators to the risk of falling and it induced awkward postures which mainly concerned the shoulders and the spinal column. The shoulders were asymmetrical during the final phase of the task, both when standing on the ground and on some parts of the tractor. Mostly in the case of handling from the ground, the lifting operation was not finished with both hands but by accompanying the roll-bar toward its upright position with just one hand: this asymmetrical posture determined a unilateral lengthening of the muscular bundles of the back and it was often associated with a redistribution of weight on the lower limbs, moving the feet or raising the heels, thus decreasing their area of support, which may therefore create a risk for operator's safety and health. Among the operators who raised the FROPS standing on some parts of the tractor, a posterior hyperextension of the back and of the neck was observed, determined by the lack of a standing surface. Even this movement can cause health risks for the operator, such as contractions at lumbar and neck level, but also safety risks, such as the risk of falling (Figure 6).

Figure 6. Examples of unbalanced and uncomfortable postures and gestures performed by the operators to raise the FROPS.

The statistical analysis showed some significant correlations between the behavioral patterns performed in phases 1 and 2 and some user factors and FROPS dimensional characteristics (Table 2). In particular, the variable "Behavior adopted in phase 1" showed a significant positive correlation with the lowered roll-bar-to-ground distance and with the ground-to-pivot pin distance: higher distances between the crossbar in the lowered position and the ground and between the FROPS pivot pin and the ground required riskier behaviors, i.e. using part of the tractor as a supporting surface for the feet (*rho*=-.52, p=.02 and *rho*=-.59, p=.01, respectively). The other variables considered (i.e. stature, forward reach, working experience, frequency of FROPS operation and distance FROPS pivot pin-top) did not show any significant correlation with the observed behavior (all p>.05, see Table 2).

With regard to "Behavior adopted in phase 2", the variable showed a significant positive correlation with participant's stature (*rho*=.55, p=.01) and negatively correlated with ground-to-pivot pin distance (*rho*=-.51, p=.02): the taller the participants were, the more they stood on the ground, whereas the higher the distance between the FROPS pivot-pin and the ground was, the more the participants climbed up on the tractor's rear three-point linkage lower links using them as a supporting surface. Work experience, forward reach, frequency of FROPS operation, distance ground-crossbar in lowered position and distance FROPS pivot pin-top were not significantly correlated with behavior in phase 2 (all p>.05, see Table 2).

Finally, the behaviors observed in the two FROPS raising phases positively correlated with each other (*rho*=.82, p=.01), pointing out some consistency in the behavioral strategies adopted by the participants to operate the FROPS from the lowered to the upright position (Table 2).

Table 2. Variables considered in the study and their correlations.

	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. Stature	-								
2. Forward reach	.51*	-							
3. Working experience	.36	.21	-						
4. Frequency of FROPS operation	-.12	.18	-.09	-					
5. Distance ground- lowered crossbar	.02	.26	.24	.41	-				
6. Distance ground-FROPS pivot pin	.00	.27	.36	.38	.79**	-			
7. Distance FROPS pivot pin-top	.21	-.26	.29	-.21	-.39	-.50*	-		
8. Behavior in phase 1	.34	.32	.00	-.03	-.52*	-.59**	.18	-	
9. Behavior in phase 2	.55*	.34	.02	-.08	-.41	-.51*	.28	.82**	-

*Significant at .05 level

**Significant al .01 level

Discussion

In this study, an analysis of the interaction between the operators and the foldable ROPS fitted on their own tractors was performed, to identify critical behaviors, which may affect the misuse of FROPS. Overall, the present study showed that handling the roll-bars fitted on standard tractors (i.e. track width larger than 1150 mm, OECD, 2017) required awkward gestures, incongruous postures and behaviors which were perceived as uncomfortable by the operators, and may therefore lead to the choice of leaving the FROPS in a folded-down position. The observed behavioral patterns were also correlated with both FROPS and human characteristics: the ground-to-FROPS pivot pin distance in particular influenced the grasping point of the roll-bar in its lowered position and caused the operators to use part of the tractor as a supporting surface for the feet. In addition, in the first phase also the distance of the grasping point from the ground influenced the interaction with the FROPS, while in the second phase people with the shortest stature were those who performed more unsafe behaviors and adopted awkward and unbalanced postures.

Some of the performed behaviors could also increase the risk of falling or cause biomechanical overload. Falls from the machine are the major source of injury in agriculture (Bancej & Arbuckle, 2000; Fargnoli et al., 2018) and are often caused by incautious operator's behavior during the interaction with agricultural machinery (Caffaro et al., 2018). Work-related musculoskeletal injuries are one of the main work-related diseases among agricultural workers, since the type and nature of the tasks in the agricultural sector often require incongruous, awkward postures and muscle overloading, which represent the major risk factors for developing musculoskeletal injuries (Walker-Bone & Palmer, 2002). Supporting comfortable and safe placement and movements of the operators while handling the FROPS appears therefore to be a relevant issue, not only to enhance the correct use of FROPS but also to prevent health and safety risks while operating it.

The place where the operators stood while accompanying the FROPS to the upright position, was also related to their stature, therefore the grasping points have to be designed considering the reach capabilities of the users. Reach points need to be designed to induce appropriate working positions for all the users, referring to static and dynamic anthropometric data set (Ahlstrom & Longo, 2003) as suggested in the Design for All ergonomic approach (Steinfeld & Maisel, 2012).

Based on the present observations, some technical solutions and guidelines may be useful to increase operators' safety and comfort during the interaction with FROPS. Together with an evaluation of possible technical modifications to the height of the FROPS pivot pin and grasping point, the presence of some platforms able to elevate the base of support of the operators' feet, with a sufficient space to stand in a safe position, may be recommended, to increase the reachability of the FROPS and to encourage a safer and more comfortable operation. In addition, the recommended grasping areas and places to stand for the operator may be embossed, or identified by means of colored labels also on the FROPS and the machine itself, acting as an affordance (Gibson, 2015) capable to suggest the correct behavior to the user. The same information may be integrated and reinforced by being reported with simple drawings also in the operator manual, which is considered the complete reference source for safe machine operation (Tebeaux, 2010).

In the present study, differently from the previous literature (Caffaro et al., 2018; Elkind, 2008), operators' experience, in terms of working years in agriculture and frequency of use of FROPS was not correlated with operators' behavior: both improvised and routine behavioral patterns were related to the characteristics of the FROPS itself and to the anthropometric characteristics of the individual, pointing out the need of rethinking machinery design taking into account users factors as anthropometric variability.

Limitations and future development of the study. Some limitations of the present study should be acknowledged. Only 20 participants were included in the study, due to the difficulties in gathering operators for the trials, since they are spread across the region and have different paces of work. In future studies, it would be useful to involve larger samples of participants to obtain more generalizable results. In addition, given the very limited participation of women in our study, we could not investigate the effects of gender. Considering the recent increasing participation of women in the agricultural sector (De Schutter, 2013), female characteristics, forces and behaviors in FROPS operation should be taken into account in future studies. Finally, data was collected involving 16 tractors: different models with different sizes and heights may be considered in a future investigation.

Conclusions

The analysis performed in the present study showed that many participants had some difficulties to complete the task without some kind of support for the feet, adopting incongruous and unsafe postures and gestures (leading for instance to the risk of pinching or falling from improvised places to stand). Participants' behavior in handling the FROPS was related to the height of the pivot pin of the folding frame of the FROPS, to the FROPS grasping point when in folded-down position and also to human stature when accompanying the FROPS in the upright position.

The present study suggests that the design of foldable rollover protective structures may need to be revised, considering not only safety requirements but also reachability aspects and comfort in use, to encourage a proper use of the roll-bar. Taking into account operators' anthropometric variability may be particularly relevant to enhance a proper use of the FROPS also among users with different biomechanical, dimensional and functional characteristics (e.g. aged people, women or migrant workers), whose presence is increasing among the workforce population of the developed countries (De Haan & Rogaly, 2002; De Schutter, 2013; Ilmarinen, 2005). Finally, some visual cues on the correct grasping points and places to stand may be provided onto the FROPS and the machine themselves and/or also into the operator manual, to guide the user toward a safe and comfortable handling behavior.

Competing interests: None to declare.

Key points:

- The study identified critical behaviors performed in raising a foldable rollover protective structure (FROPS) on tractors, which may hinder the correct use of FROPS.
- The results suggest that unsafe, uncomfortable and awkward behaviors were mainly due to FROPS technical characteristics.
- The results highlight the importance of a redesign of FROPS which takes into account reachability issues and of providing affordances for the correct handling of the FROPS.

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Federica Caffaro is a psychologist and a Ph.D. in Applied Psychology and Ergonomics. She took part in different projects regarding workplace safety, occupational health, and users' comfort. Her research activities at the Institute for Agriculture and Earth-Moving Machines (IMAMOTER) of the National Research Council (CNR) of Italy deal with ergonomics and human factors in the interaction between the operators and agricultural machinery.

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Giuseppe Paletto is a technical assistant at the Institute for Agriculture and Earth-Moving Machines (IMAMOTER) of the National Research Council (CNR) of Italy. He is in charge of the trials for the certification of performance and safety of agricultural machinery with regard to noise and vibration and protective structures.

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