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(Article begins on next page)

1 Running head: ISSUES IN TRACTOR ROLLOVER PROTECTION

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

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17

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ISSUES IN TRACTOR ROLLOVER PROTECTION

22

Abstract

23

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

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

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

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

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

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

44

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

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

52

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Introduction

53
54

55 Tractor rollover has been reported as the main cause of both fatal and non-fatal accidents in
56 agriculture since the '50s (Abubakar, Ahmad, & Akande, 2010; Pessina, Facchinetti, & Giordano,
57 2016). In the United States, in the period between 2003 and 2010, 1474 workers in agriculture,
58 forestry, fishing, and hunting industries were killed due to tractor-related events, and 933 were
59 killed as a result of rollovers (US Department of Labor, 2012). Tractor rollover is the second cause
60 of fatalities in agriculture in Canada, with 143 cases out of 589 machinery-related fatalities during
61 2003-2012. As concerns the European Union countries, 158 road accidents involving agricultural
62 tractors occurred in 2015 (European Commission, 2017), however comparable data for rollover
63 accidents is not available (European Agricultural Machinery Association [CEMA], 2017). Among
64 the member states of the European Union, in Portugal 38.6% of 57 fatal tractor-related accidents in
65 the period 2005-2014 was due to rollover (Antunes, Cordeiro, & Teixeira, 2018). With regard to
66 Italy, 89 cases out of 121 tractor-related fatalities, in the year 2013, were caused by rollovers
67 (INAIL, 2015).

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

76 FROPS are made of two parts: the upper and folding frame and the lower part, the support,
77 fixed to the tractor body or chassis (Figure 1). The foldable frame is connected to the lower part by

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78 a pivot point and a pin, or a bolt, to keep it upright. By this construction, the height of the FROPS
79 can be significantly decreased, making this solution frequently adopted (Myers, 2015). FROPS are
80 placed in front or on the back of the tractor's driving station. The first solution is frequently adopted
81 on narrow vineyards and orchard tractors to reduce the interference of the protective structure with
82 the crop canopy, while the second solution is most commonly found on standard tractors.



83

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

85

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

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93 Regarding the reasons to leave the FROPS in the folded down position, Khorsandi et al.
94 (2016) argued that the process of raising the FROPS is time-consuming and strenuous for the
95 operators, also because of the actuation torques required to raise and lower a FROPS (Khorsandi &
96 Ayers, 2018). A multidimensional study conducted in a group of Italian agricultural operators
97 (Caffaro et al., 2019) showed that handling the FROPS was not associated with a high perceived
98 effort but it was considered by farmers time-consuming and uncomfortable. Indeed, the same
99 authors have observed some criticalities in the reachability of the FROPS, which determined
100 unnatural gestures, incongruous postures and unsafe behaviors in FROPS operation.

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

112 Moreover, some user factors such as previous experience, age and anthropometric
113 characteristics may influence the quality of the human-machine interaction and they should be taken
114 into account to optimize the interaction with the machine in terms of safety and comfort. Previous
115 experience with machine and its devices has been reported in the literature as a critical factor for
116 risky behaviors. According to some authors, familiarity may lead to an overconfidence in use,
117 supporting the adoption of unsafe or awkward routine behaviors (Elkind, 2008). However, other

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118 authors pointed out the opposite result. In this case, individuals in familiar situations might be more
119 likely to behave correctly and safely because they are more aware of the surrounding conditions
120 (Caffaro, Roccato, Micheletti Cremasco, & Cavallo, 2018). Age is known to affect individual
121 balance, articular capability and strength, increasing the risk of falling or of musculoskeletal injuries
122 (Caffaro et al., 2017; Holliday, 2010; Koolhaas, van der Klink, Groothoff, & Brouwer, 2012;
123 Pizzigalli, Micheletti Cremasco, Mulasso, & Rainoldi, 2016). Anthropometric characteristics
124 proved to be relevant aspects to be considered in the human-machine interaction. Those designers
125 who consider anthropometric measurements produce more accurate product dimensions and
126 features, well-received by consumers, and mostly adoptable (Ferguson, Greene, & Repetti, 2015).
127 Also, different levels of performance are referable to the variability in body size and shape across
128 different demographic groups (de Vries & Parkinson, 2014).

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

139

Materials and Methods

140

Sample and context of the study. Twenty farmers and sixteen different models of tractors

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from different brands available on the Italian market were involved in the study (Table 1). The

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participants were all males, because of the predominance of male workers among Italian farming

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population (ISTAT, 2013) . The tractors were standard-track tractors (i.e. track width larger than

144

1150 mm, according to OECD Tractor Codes, OECD, 2017) fitted with rear-mounted two-pillar

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FROPS. The main descriptive statistics of the participants and tractors involved in the study are

146

reported in Table 1.

147

Table 1. *Mean and standard deviation of the socio-demographic characteristics of the*

148

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

149

Note. In our dataset, participants' age and years of working experience in agriculture showed

150

a strong correlation ($\rho=.57$, $p<.01$). To avoid an excessive conceptual overlap and problems of

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empirical collinearity, for subsequent analysis, we reasoned in terms of years of experience rather

152

than in terms of age.

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

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

161 1. Participants' behavior when raising the FROPS of their own tractor was video-recorded. The
162 observations were carried out on participants' own tractor since we were interested in the
163 natural routine behavior, in the interaction with a familiar machine (McLaughlin, Fletcher,
164 & Sprufera, 2009). The observations were video-recorded using two orthogonal cameras
165 stabilized on tripods, one placed on the side of the participant (lateral view) and the second
166 one behind the participant's back (posterior view), to evaluate the adopted postures. Some
167 photographs were also taken from different views to optimize the analysis of the targeted
168 behaviors. These observational techniques are widely used to generate information about
169 automatic actions and to document natural task performance in a relatively unconstrained
170 environment (Kirwan & Ainsworth, 1992). Since observations may be supplemented by a
171 verbal description from the operator of the decision processes taking place (Kirwan &
172 Ainsworth, 1992), the participants were also asked to report any difficulties related to the
173 task and the interaction with the FROPS, adopting the 'thinking aloud' technique (Lewis,
174 1982) as in Ferrari and Cavallo (2012), to highlight any potential source of discomfort and
175 possible risk.

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

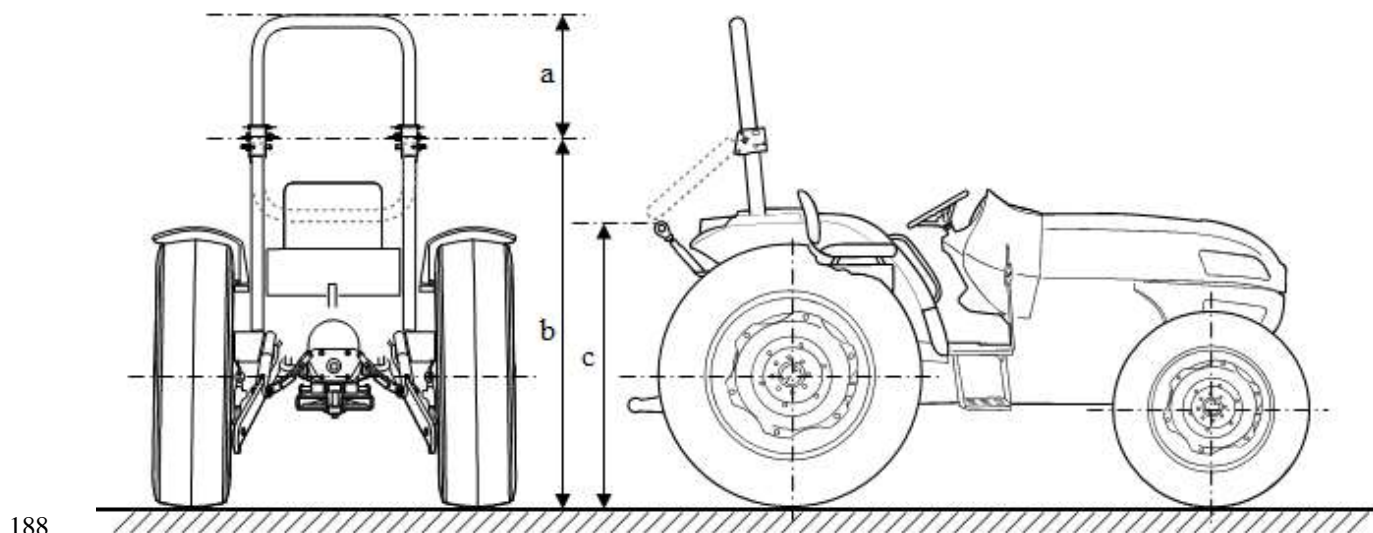
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178 with a digital laser rangefinder (Bosch DLE 50), i.e. vertical distance from ground-to-top of
179 folded ROPS, from ground-to-FROPS pivot pin, from FROPS pivot pin-to-top of FROPS in
180 upright position (Figure 2).

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

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

187

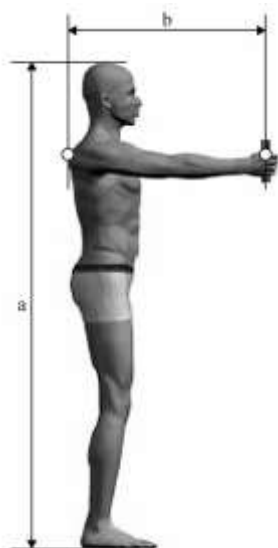


188

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

192

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194 *Figure 3.* Human anthropometric measurements considered in the study: a) stature and b)

195 grip-reach; forward reach (figure adapted from ISO 7250-1:2017).

196

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

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

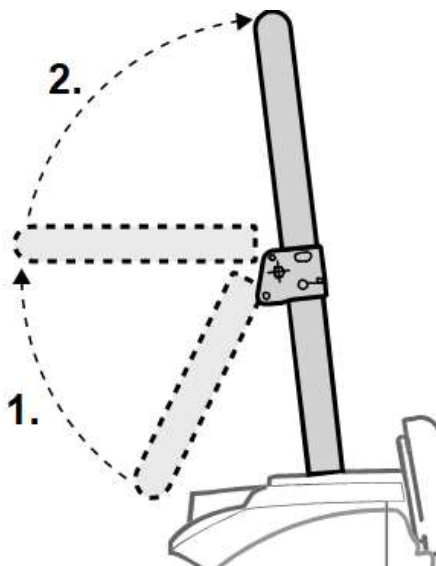
- 214 -Initial and final position of the operator, regular or uneven surface and general
215 characteristics of the environment;
- 216 -Trunk posture in terms of inclination, extension, twist and lateral flexion and head
217 inclination and extension;
- 218 -Left and right lower limb posture, knee flexion and thigh raising;
- 219 -Left and right foot posture, balance and type of support used considering the changing
220 during the task;
- 221 -Left and right upper limb posture, considering arm flexion, abduction, extension, flexion
222 and elbow extension;
- 223 -Left and right hand position during handling, considering the changing during the task, and
224 the use of one or both hands during the handling.

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

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

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

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254

255

Figure 4. Different phases in FROPS raising, based on observed behavioral patterns: 1)

256

rotation from the lowered to the horizontal position (from 0° to 90°); 2) rotation from the horizontal

257

position to upright position (from 90° to 180°).

258

259

Two main different patterns of behaviors involving both upper and lower limbs were also

260

detected in each of these phases. One of these patterns was partially modified compared to Caffaro

261

et al. (2019) thanks to further observations performed during the present study, leading to what is

262

represented in Figure 5.

263

To grasp the ROPS when it was fully lowered, 9 participants used some parts of the machine

264

(typically the lower links of the rear three-point linkage) as a platform to reach and operate the

265

FROPS when it was fully lowered, whereas other 11 participants raised the roll-bar by standing on

266

the floor (Figure 5a and 5b). In these two configurations, workers had aligned and symmetrical

267

shoulders and both the hands on the horizontal part of the roll-bar. The two different feet

268

placements were observed also in the second phase of FROPS operation (i.e. moving the roll-bar to

269

the upright position), together with two main types of hand gestures and placement: 11 participants

270

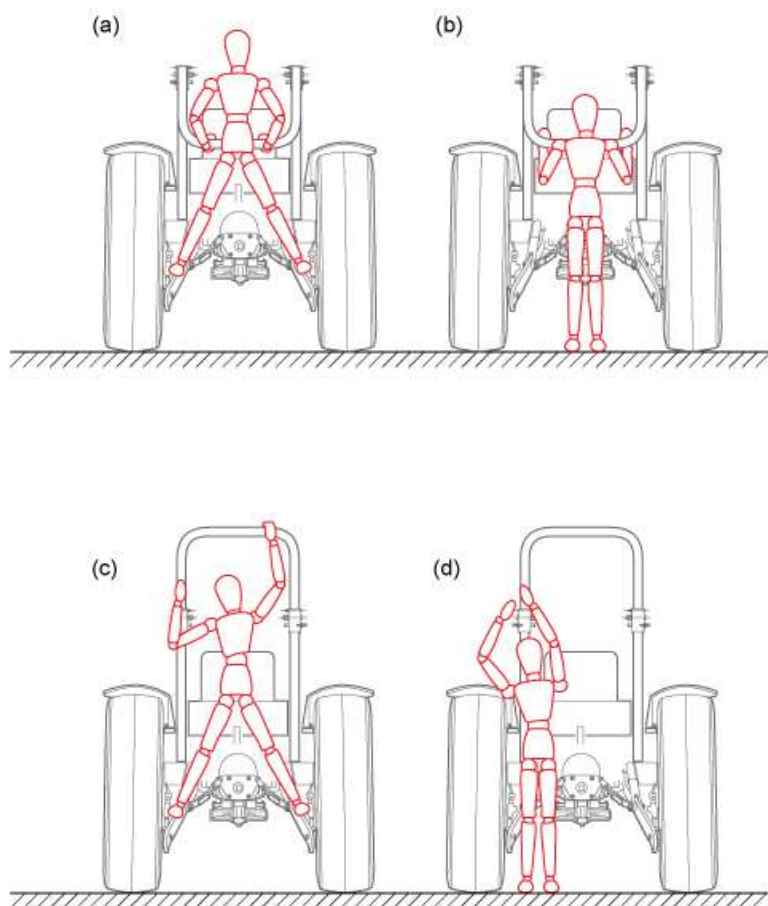
finished the raising task by pushing the roll-bar with both hands while 9 farmers by using only one

271

hand (the other one was used just as a support) (Figure 5c and 5d). In some of these cases a

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272 unilateral hyperextension of one side of the body was observed, where one hand was placed higher
273 than the other to completely lift the roll-bar.



274

275

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

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



298
299 *Figure 6.* Examples of unbalanced and uncomfortable postures and gestures performed by
300 the operators to raise the FROPS.

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

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

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

322

323 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**	-

324 *Significant at .05 level

325 **Significant al .01 level

326

Discussion

327

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

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

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

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

367 In the present study, differently from the previous literature (Caffaro et al., 2018; Elkind,
368 2008), operators' experience, in terms of working years in agriculture and frequency of use of
369 FROPS was not correlated with operators' behavior: both improvised and routine behavioral
370 patterns were related to the characteristics of the FROPS itself and to the anthropometric
371 characteristics of the individual, pointing out the need of rethinking machinery design taking into
372 account users factors as anthropometric variability.

373 **Limitations and future development of the study.** Some limitations of the present study
374 should be acknowledged. Only 20 participants were included in the study, due to the difficulties in
375 gathering operators for the trials, since they are spread across the region and have different paces of

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376 work. In future studies, it would be useful to involve larger samples of participants to obtain more
377 generalizable results. In addition, given the very limited participation of women in our study, we
378 could not investigate the effects of gender. Considering the recent increasing participation of
379 women in the agricultural sector (De Schutter, 2013), female characteristics, forces and behaviors in
380 FROPS operation should be taken into account in future studies. Finally, data was collected
381 involving 16 tractors: different models with different sizes and heights may be considered in a
382 future investigation.

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Conclusions

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

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

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Competing interests: None to declare.

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Key points:

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- The study identified critical behaviors performed in raising a foldable rollover

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protective structure (FROPS) on tractors, which may hinder the correct use of

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FROPS.

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- The results suggest that unsafe, uncomfortable and awkward behaviors were mainly

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due to FROPS technical characteristics.

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- The results highlight the importance of a redesign of FROPS which takes into

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account reachability issues and of providing affordances for the correct handling of

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the FROPS.

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556

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