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Falls from Agricultural Machinery: Risk Factors Related to Work Experience, Worked Hours, and Operators' Behavior

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Précis: Falls while dismounting the tractor represent a major source of injuries in agriculture. The study investigated the risk factors for fall accidents when egressing from agricultural tractors, pointing out the critical levels on which to intervene, with the re-design of the working strategies and the adoption of behavioral training methods.

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Abstract

Objective: We investigated the risk factors for falls when egressing from agricultural tractors, analyzing the role played by worked hours, work experience, operators' behavior, and near misses.

Background: Many accidents occur within the agricultural sector each year. Among them, falls while dismounting the tractor represent a major source of injuries. Previous studies pointed out frequent hazardous movements and incorrect behaviors adopted by operators to exit the tractor cab. However, less is known about the determinants of such behaviors. In addition, near misses are known to be important predictors of accidents but they have been under investigated in the agricultural sector in general, and as concerns falls in particular.

Method: A questionnaire assessing dismounting behaviors, previous accidents and near misses, and participants' relation with work was administered to a sample of Italian tractor operators (n=286).

Results: A mediated model showed that worked hours increase unsafe behaviors, whereas work experience decreases them. Unsafe behaviors in turn show a positive association with accidents, via the mediation of near misses.

Conclusions: We gave a novel contribution to the knowledge of the chain of events leading to fall accidents in the agricultural sector, which is one of the most hazardous industries.

Applications: Besides tractor design improvements, preventive training interventions may focus on the re-design of the actual working strategies and on the adoption of engaging training methods in the use of machinery, to optimize the learning of safety practices and safe behaviors.

Keywords: Accident analysis; Agricultural systems; Motor behavior; Slips and falls; Structural equation modeling

Introduction

More than 2.3 million deaths and 317 million accidents occur on the job annually, with an estimated cost equal to the 4 per cent of annual global Gross Domestic Product (GDP) (ILO, 2017). One of the most hazardous sectors in both developing and industrialized countries is agriculture, which employs an estimated 1.3 billion workers worldwide (half of the world's labour force, ILO, 2014).

Falls are one of the leading causes of fatal workplace injuries worldwide, with deaths exceeded only by highway injury, and are the leading cause of nonfatal injuries (Nordstrom et al., 1996). Falls are the first cause of death among farmers, mainly during roofing or roof repair work on farm buildings, while the most frequent non-fatal falls occur when climbing or descending a vehicle. In the United States, in 2015 falls to lower level accounted for 648 deaths in the private industry and 28 deaths in agriculture, while the non-fatal injury rates from these falls in private industry and in agriculture were 5.3 cases and 19.3 cases, respectively, per 10000 full-time workers (BLS, 2017). Similar rates are reported for other developed countries (Bancej & Arbuckle, 2000; Feyer et al., 2001; Kumar, Varghese, & Mohan, 2000).

A large proportion of fall-related injuries is associated with tractors, when mounting and especially dismounting the vehicle (Bancej & Arbuckle, 2000). Tractors are the most important machine for farms, playing a vital role in most of the farm operations, and also for manufacturing industry, with millions of units in use all over the world, and hundreds of thousands manufactured every year (Cavallo, Ferrari, Bollani, & Coccia, 2014). Since the 1980s many efforts have been made to increase the safety of the tractor drivers and the ergonomics of the driving station: the adoption of safety structures (closed cabs, frames, roll-bars), to protect the driver from injuries caused by vehicle overturns or rollovers, the use of suspended seats for ride improvement, and the enhancement of the means of access to the driving station (Cavallo, Ferrari, & Coccia, 2015). With regards to this, the dimensions and placement of doors, windows, and steps and handholds to entry and exit the tractor cab have been progressively improved, based on different standards and regulations (ANSI/ASABE AD26322-1:2008; Council of the European Union, 1980; ISO 4252:1983). Consistent with these standards, steps on agricultural machines are also typically designed with some type of non-slip surface and often have holes to prevent the accumulation of dirt and mud. Moreover, following the safety hierarchy protocol (Purschwitz, 2006), standardized safety signs (ISO 11684:1995) are affixed to the machine to warn the users against the residual risk of slips and falls.

Despite these interventions, falls from the vehicle are still a widespread phenomenon among tractor drivers, since the operators typically have to leave the tractor's driving position many times during daily work for different reasons, ranging from rest pauses, adjustment of implements, scheduled service of machinery, and other disturbances in the workflow (Leskinen et al., 2002). Merryweather, Pate, and Vemparala (2011) pointed out that 58.3% of the tractor operators they interviewed have slipped and fallen from the tractor when dismounting. These falls mainly occurred in the evening and during the summer months, when operators spend long hours on the tractor. Furthermore Nordstrom et al. (1996) reported a 3% increase in injury rate for each additional worked hour. Working alone may worsen the scenario, since this condition increases the time pressure, with many things to be done, and the need to undertake jobs that would ordinarily require more people to be done safely (McLaughlin & Mayhorn, 2011).

Despite the progressive improvement of the design characteristics of the machine, it is apparent that the behavioral factors during dismounting should not be overlooked to have a complete and informative picture on this kind of agricultural accidents (Hammer, 1991). The correct tractor egress described in international safety guidelines prescribes to descend backwards maintaining three-point contact (i.e. both feet and one hand or one foot and both hands) at all times and to avoid jumping (HSE, 2013; NIOSH, 2010). This reduces the possibilities of falling, which might result in severe acute traumatic injuries, and avoids cumulative stress on the knees and back, which can negatively affect mobility (Fathallah, Gronqvist, & Cotnam, 2000). Nevertheless, the literature shows frequent hazardous patterns of movements and incorrect behaviors (Grogran et al., 2014; Kleban, Mann, & Morrison, 2013), which are even more critical since they are typically executed in an automatic way, without conscious attention (Leskinen et al., 2002).

This form of habit raises some debate about the role played by work experience and familiarity with tasks, machinery, and equipment in affecting safe behaviors in farm operators. According to Elkind (2008), familiarity may lead to an overconfidence in the use of the devices, reducing the attention rate. This may cause operators to disregard safety procedures and rules, since they could ‘do it with their eyes shut’. On the other hand, Rogers, Lamson, and Rousseau (2000) pointed out the opposite result: individuals in familiar situations might be more likely to behave safely because they are more frequently exposed to the situation that enhances their awareness of the risks. This may increase compliance with safety practices.

When considering factors involved in the occurrence of an accident, another powerful predictor is represented by the *near misses*, i.e., unplanned events that did not result in any injury, illness, or damage only because of a fortunate break in the chain of events (National Safety Council, 2014). Usually each major accident is preceded by a number of near misses (Phimister, Oktem, Kleindorfer, & Kunreuther, 2000). Wright and Schaaf (2004) showed that near misses and accidents substantially share the same determinants. In this light, near misses are a proxy of being exposed to the risk of suffering a more serious accident. Near misses have been investigated in different industries (Markkula, Benderius, Wolff, & Wahde, 2012; Wu, Gibb, & Li, 2010; Zhang & Chan, 2016) but less considered in the agricultural sector (for exceptions see Kogler, Quendler, & Boxberger, 2015; Lilley, Feyer, Kirk, & Gander, 2002; Lundqvist & Gustafsson, 1992; Merryweather et al., 2011), especially as concerns falls from machinery. About this issue, Merryweather et al. (2011) showed that 83.3% of interviewed operators experienced a near miss when dismounting the tractor.

The size and power of tractors, especially for those performing drawbar works in large farms of the US Corn Belt, in Australia or in Argentina, have significantly increased. Therefore, also the tractors height above the ground has increased. Thus, the consequences of a possible fall during dismounting are likely to become more severe. The risk of fall exists also for small tractors, such as those for vineyard and orchard applications, particularly popular in the Mediterranean countries. They have tiny dimensions of access openings and the driver, for some operation such as pesticide application, has to wear cumbersome coverall, gloves, and other protective devices that may increase the possibility of falling while exiting the cab.

Based on these considerations, the aim of the present study was to investigate the risk factors for falls from agricultural tractors when egressing from the vehicle, analyzing operators' behavior, its determinants, and the role played by near misses. In particular, based on Merryweather et al. (2011) we expected worked hours to show a positive association with unsafe behaviors while egressing from the tractor cab (H1). With regards to work experience, because of the inconsistent results available in the literature, we made two alternative hypotheses compete. If, as in Elkind (2008), work experience mainly leads to overconfidence in the use of devices, it should show a positive association with unsafe behavior (H2a); on the contrary, if work experience, as in Rogers et al. (2000), mainly leads to an increased situation awareness, it should show a negative association with unsafe behavior (H2b). Furthermore, based on Wright and Schaaf (2004), we expected unsafe behaviors to have a positive association with near misses (H3). Finally, based on Phimister et al. (2000), we expected near misses to show a positive association with being involved in a fall accident (H4).

Materials and Methods

Participants. The study involved a sample of 286 regular users of agricultural machinery (268 men, M_{age} = 45.17 years, *SD* = 17.13), recruited among the visitors of the 35th National Exhibition of Agricultural Mechanization in Savigliano (March 18-20, 2016), the largest agricultural machinery exhibition in the Piedmont region (North-western Italy). Italy has the third largest tractor fleet after USA and Japan, with about 2 million tractors (Cavallo et al., 2014), and the Piedmont region is a good representation of the Italian farming system and rural population, since it includes approximately 10% of the total Italian Utilized Agricultural Area and over 61,000 out of the 1,620,884 Italian agricultural holdings operate in this region (INEA, 2014). The study was approved by the Research Advisory Group (RAG) of the Institute for Agricultural and Earthmoving Machines of the National Research Council of Italy (IMAMOTER-CNR).

Instrument. Participants were administered a 19-item paper-and-pencil questionnaire, designed based on previous instruments (Glasscock, Rasmussen, Carstensen, & Hansen, 2006), on the analysis of the egressing behaviors reported in the literature (Leskinen et al., 2002) and of the evidence from a preliminary qualitative study (Caffaro et al., in press). The questionnaire was pilot-tested before being used in the present investigation and was composed of 4 sections.

In the first section, participants were administered a list of 4 adverse work environment factors: sufficient manpower (con-trait), interruptions by machinery, interruptions by on-farm visits, and work delay due to the adoption of safety measures. Participants were asked to rate on a 4-point scale (1 = never, 4 = always) how often these 4 working situations occurred in their farm. The 3 items about manpower and interruptions came from Glasscock et al. (2006) and the work delay due to the adoption of safety measures emerged as a relevant issue in enhancing workload in agricultural tasks in a preliminary qualitative study (Caffaro et al., in press).

In the second section participants had to report on a 4-point scale (ranging from 1 = not risky at all to 4 = very risky) how risky they considered the following tasks in machinery operations: moving equipment near power lines, manually-feeding a woodchipper, using a wood splitting machine/circular saw, using the tractor on field without seat belts, handling round bales with a front-end loader, working with machinery near ponds or ditches, cleaning the manure spreader while it is in motion, getting off the tractor without turning the engine off. Items about power lines and working near ponds were taken from Whitman and Field (1995), whereas the other items were operations or tasks which are more likely to lead to an accident according to Italian national safety statistics (INAIL, 2015).

The third section investigated the behaviors adopted when egressing from the tractor driving station. Participants were asked to indicate the behavior they usually adopted when exiting the cab by choosing between two pictures representing two different ways of dismounting (0 = forward facing, 1 = backward facing). Furthermore, they were asked how often they jumped from the last step of the access path while egressing from the tractor (1=never; 4=always). The items were designed considering the two more frequent behaviors performed by the tractor drivers when egressing from the vehicle (Leskinen et al., 2002) and these behaviors were investigated by means of pictures based on previous studies in which these materials proved to be useful to gather information about safety practices and behaviors (Bush et al., 2014). After reversing the first item, the point-biserial correlation between the two items was positive and significant (r_{pb} = .26, p < .001). Since the two items had two different ranges, we averaged them after recoding the second into a 0-1 range) using the following formula: recoded $item_i=[x_i\text{-}min(x)]/[max(x)\text{-}min(x)]$, where recoded $item_i$ is the value of the recoded item for the i^{th} individual, x_i is the value of the original item for the i^{th} individual, and min(x) and max(x) are respectively the minimum (i.e., 1) and the maximum (i.e., 4) value of the original item. We used this average score as our quantification of participants' unsafe behaviors.

In the fourth section, participants had to indicate how often in the 12 months preceding the survey they were involved in 5 different types of events involving agricultural machinery, using a 3-category format (0 = never; 1= once; 2 = twice or more): fall from the vehicle; run over/crush by the vehicle; being struck by flying objects, broken parts, or hydraulic fluid; side/rear rollover; road accident with tractor/equipment. Participants were asked to answer the items twice, reporting how often they have been involved with (i.e. accident) and without (i.e. near miss) suffering an injury. The list of events was created based on the most common types of accidents involving agricultural machinery, according to the statistics from the Italian Workers' Compensation Authority (INAIL, 2015). After dichotomizing participants' answers (contrasting the 0 and the other responses), we computed two scores as the sums of the responses to the first and to the second version of the batteries, respectively used as the operationalization of the number of accidents and of near misses occurred in the 12 months preceding the survey.

A standard socio demographic form, assessing also participants' relation with work (average worked hours per week on farm and years of farm work) closed the questionnaire. Trained research assistants handed out the questionnaire to people walking through the exhibition. The questionnaire was in Italian and its completion took approximately 5-6 minutes. No incentive was offered to induce visitors to participate in the survey. The response rate was approximately 85%.

For the aims of the present investigation, we analyzed only the variables regarding the dismounting behaviors (third section of the questionnaire), reported accidents dealing with falls from the vehicle (fourth section), and the socio demographic information.

Statistical analyses. We tested our four hypotheses using a mediated model, in which, consistent with our expectations, worked hours per week and years of experience were independent variables, fall accidents was the dependent variable, and unsafe behaviors and near misses were mediators, i.e., at the same time causes of fall accidents, and effects of worked hours per week and years of experience. The paths displayed in the model represent the regression coefficients (β coefficients) of each dependent variable on its predictors. We tested the model using a structural equations model (Maximum Likelihood extraction), resorting to Amos 20 (Arbuckle, 2014). We chose 0.05 as a-priori α level to evaluate the significance of the relations we have analyzed. We evaluated the fit of the model via the combination of different indexes: the Tucker-Lewis coefficient (*TLI*: Tucker & Lewis, 1973), the comparative fit index (*CFI*: Bentler, 1990), and the Root Mean Square Error of Approximation (*RMSEA*: Steiger, 1980). Based on Bentler (1990) we considered the *CFI* and the *TLI* as satisfactory if higher than .90 and the *RMSEA* if lower than .05.

Results

Table 1 reports the descriptive statistics for the variables we used and the correlations among them.

Table 1. *Descriptive statistics for the variables we used and correlations among them*

	Mean	SD	1	2	3	4	5
1. Worked hours per week	39.97	23.72	-	.42*	.15*	-.03	-.02
2. Years of work experience	1.58	.57		-	.05	.10	-.05
3. Unsafe behaviors	.41	.35			-	.19*	.03
4. Near misses	.11	.37				-	.39*
5. Accidents	.04	.23					-

Note. * $p < .05$.

Figure 1 displays the mediated model we have tested. Consistent with H1 and H2b, and contrary to H2a, unsafe behaviors showed a positive association with worked hours and a negative association with work experience (R^2 = .04). Moreover, respectively consistent with H3 and H4, unsafe behaviors showed a positive association with near misses (R^2 = .04) that, in their turn, showed a positive association with involvement in a fall accident (R^2 = .15).

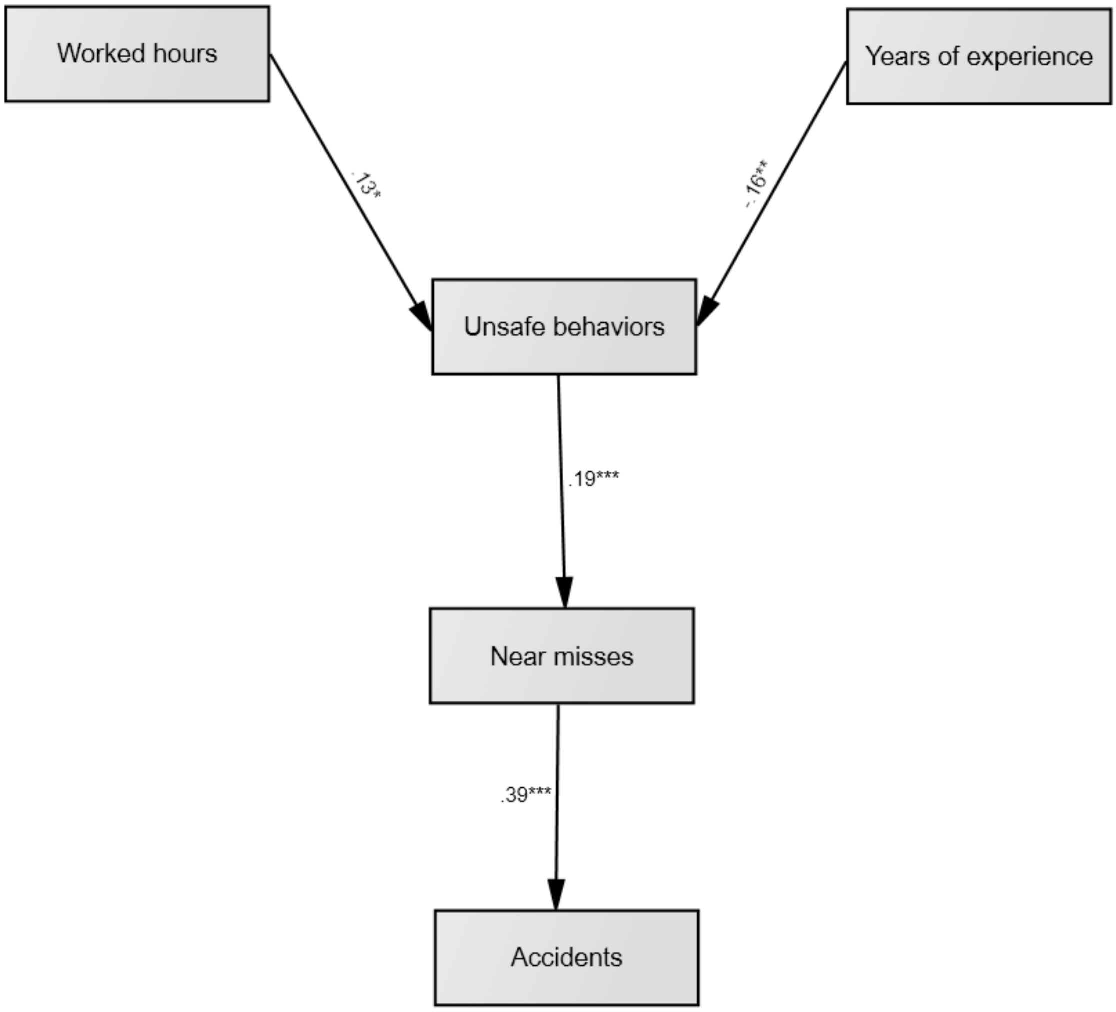

Figure 1. Years of experience in agriculture and worked hours per week predict accidents via the mediation of unsafe behaviors and near misses. Errors are omitted; standardized parameters (i.e., regression β coefficients) are displayed.

Table 2 shows that, even if small, all of the indirect effects we detected were significant. The fit of the model was very good, *TLI* = 1.00, *CFI* = 1.00, *RMSEA* = .00 (90% *CI* .00, .07). Supplementary analyses tested the structural invariance of the model across farmers working (n=102) and not working (n=184) alone. Based on Reise, Widaman, and Pugh (1993), we compared the fit of a baseline model, in which we tested our model simultaneously on both groups of participants, with that of an invariant model, in which we constrained the parameters to be equal across participants working vs. not working alone. The hypothesis of invariance can be accepted if the difference in the χ^2 value of the invariant model compared to that of the baseline model is not significant for a number of degrees of freedom equal to the difference in degrees of freedom of the two models, i.e., if constraining the parameters to invariance does not determine a significant worsening in the model fit. For our model, the hypothesis of invariance could be accepted. Indeed, the fit of the baseline model, $\chi^2(12) = 15.596$, $p = .210$, $CFI = .911$, $TLI = .946$, $RMSEA = .032$ (90% CI = .000, .073) was statistically equal to that of the invariant model $\chi^2(16) = 19.186$, $p = .259$, $CFI = .941$, $TLI = .952$, $RMSEA = .026$ (90% CI = .000, .064), $\Delta\chi^2(4) = 3.590$, $p = .464$. Thus, the parameters we estimated were statistically equal among farmers working vs. not working alone.

Table 2. *Indirect associations of years of experience and worked hours per week in agriculture with near misses and accidents and of unsafe behaviors with accidents*

	Years of experience in agriculture	Worked hours per week	Unsafe behaviors	Near misses
Unsafe behaviors				
Near misses	-.00*	.00*		
Accidents	.00*	.00*	.01*	

Note. * $p < .05$.

Discussion

The present study investigated the risk factors for falls from agricultural machinery, considering the role played by the working situation and operators' behavior. By using a mediation model, the present results add a novel contribution to the knowledge of the chain of events leading to occupational accidents among farmers, focusing on one type of accident (i.e. falls while egressing from the tractor) which is one of the main causes of injury among the agricultural operators. In particular, we showed that work experience and worked hours are, respectively, negatively and positively associated with unsafe egressing behaviors, i.e. facing forward and jumping from the last step. These behaviors, in turn, are positively associated with the probability of being involved in fall accidents, with the mediation of the involvement in near misses.

The results of the present study are consistent with those reporting a positive association between worked hours and involvement in accidents both in agriculture/forestry sector (Lilley et al., 2002) and in other industries (Blasche, Pasalic, Bauböck, Haluza, & Schoberberger, 2016; Lombardi, Folkard, Willetts, & Smith, 2010). With regards to tractors in particular, previous studies reported a positive association between worked hours and musculoskeletal symptoms/ accidents (Torèn, Öberg, Lembke, Enlund, & Rask-Andersen, 2002). However, our research, being based on a mediated model, helped understand the reasons of this association, showing that it is mediated by being involved in unsafe behaviors. Actually, the longer hours the operator works, the more frequent the occasions to leave the driving station to accomplish different tasks. This is likely to increase fatigue and reduce alertness, causing errors and thus enhancing the possibility of being injured in an accident (Greubel & Nachreiner, 2013). Interventions addressing this issue may focus on a redesign of the working strategies (Baron, Estill, Steege, & Lalich, 2001), for instance by training the workers to have some systematic rest breaks during the working hours or assisting farmers in managing external pressures (Kirkhorn, Earle-Richardson, & Banks, 2010). The relationships between the variables we pointed out were equal across farmers who work vs. do not work alone, showing that potential training interventions should address the whole farming population, whether they are lonely farmers or not.

Worker's experience reduces unsafe behaviors. The outcome of the study contributes to the debate on the consequences of familiarity with tasks and machinery (Elkind, 2008; Rogers et al., 2000), strengthening the assumption of the protective role of this variable. This result may be interpreted by considering that by developing familiarity with the machine through routine upkeep and inspection, the operator can make more intelligent decisions to reduce the safety hazards related to the machine. In this light, preventive interventions could be designed to enhance this expertise, in particular for novice operators, and not supported by the protective role played by work experience. Engaging training methods as behavioral modeling techniques, as hands-on demonstrations and behavioral simulations (House et al., 2016), may be adopted, to promote a correct and safe use of machinery and therefore reduce accidents in the use of machinery (Burke et al., 2006). In addition, as pointed out by Scott, Miller, and Hallas (2006) training should be administered by people who have experienced the job and are be able to make the potential risks and dangers real by using anecdotes of personal experience and the experiences of colleagues. All the training activities to reduce and prevent tractor-related falls could be promoted through a wide range of networks including rural media, farmer organizations, local offices of relevant organizations and government departments, and farm machinery dealers.

In the present study, near misses showed a strong positive association with fall accidents. This result confirms the importance of investigating near misses in order to prevent more serious accidents (OSHA, 2015), also in the agricultural sector. As noticed by Wright and Schaaf (2004), the collection of data about near misses is not very widespread and it needs to be made more common. By means of targeted programs it would be possible to early identify critical factors leading to accidents and to intervene to eliminate or reduce them (Kogler et al., 2015). For instance, farmers could be trained to recognize and annotate near misses and to discuss them with their peers. This could be the basis for the development of a farm safety plan considering corrective modifications to the work environment and practices, whose application may be checked during on-farm visits (Caffaro et al., in press).

Some limitations of the present study should be acknowledged. The survey was carried out in the Piedmont region, North-western Italy, and the participants were selected among the visitors of an exhibition. In agricultural research, exhibitions are often considered suitable places for collecting data on wide-ranging groups of agricultural workers (Caffaro & Cavallo, 2015; Caffaro, Mirisola, & Cavallo, 2017; Görücü, Cavallo, & Murphy, 2014). Despite this, our participants cannot be considered representative of the entire Piedmont agricultural population, also because not all the people who were addressed agreed to participate. Possible future research will benefit from larger samples of farmers and agricultural workers, randomly selected among those involved in the official census, to obtain more generalizable results. The investigation could be also extended to other agricultural equipment, for which falls represent one of the major causes of injury and death, such as harvesting machines, combines, handling machinery, and motorized picking platforms (Fathallah, 2010; Kaustell, Mattila, & Rautiainen, 2011; Mattila et al., 2008). Another limitation is that the data on near misses and accidents were solely based on self-reports and the recall covered a quite long, although standard, period (12 months). Thus, it is possible that the participants' responses have been affected by memory bias, resulting in a gap between self-reported and actual involvement in the different events (Burton & Blair, 1991). A longitudinal analysis based on a systematic recording (as in McGwin, Enochs, & Roseman, 2000) of accidents would be advisable in a future development of the study, to obtain more accurate results. This systematic report would also allow to ask about the physical environment conditions (i.e., snow, mud, rain, light) present at the time of the accident, to investigate also the role played by these variables in the occurrence of an accident (Merryweather et al., 2011).

Furthermore, the data about egressing behaviors were self-reported. As in Grogran et al. (2014), and in Mann et al. (2016), it would be interesting to increase our understanding of the factors contributing to a fall from agricultural machinery via an observation and motion analysis of the egress behavior performed by the operator, to also quantitatively assess the biomechanical load associated with different egressing behaviors.

Finally, despite the present study being focused on the behavioral components of the risk of falls and related interventions at individual level, it should be considered that in the hierarchy of safety controls, the first level of intervention to reduce risks is represented by the design features of the vehicle (Purschwitz, 2006). A future development of the study considering both a kinematic analysis, the participants' anthropometric characteristics, and the design features of the participants' tractor access path (as in Mann et al., 2016) would help to understand the role played by all these variables in the rising of a fall accident. Possible uncompliance with standards and regulations in force in machinery design (for example, nearly 40% of the 1.75 million tractors in Italian farms are outdated, with safety concerns, being more than 30 years old, Cavallo et al., 2014) may be detected through engineering-based inspections, and features needing improvement could be identified by discussing with the operators about the benefits/disadvantages of the actual design strategies (Day & Rechnitzer, 2004). This would allow to intervene on both the components of the human-machine interaction (i.e.not only the subject-related, but also the machinery-related characteristics), promoting both technical interventions on the machinery and a continuing education of the operators, in a multidimensional occupational health and safety program (Smith, 2001). Promotion of these initiative should include opportunities for farmers to actually try out some new design solutions by having displays at field days and shows, engineer workshops, farm machinery dealers, and other relevant locations. Training events may be organized at the same locations.

Despite these limitations, the study has some important strengths, with regards to the variables investigated and the statistical analyses adopted. Concerning the variables, the study considered the relationship between near misses and accidents. As reported in the literature, near misses occur more frequently and are smaller in scale than serious accidents, and usually each major accident is preceded by a number of near misses (Phimister et al., 2000). This is the case also of the present study, in which near misses had an average occurrence nearly three times larger than the accidents (Table 1). This evidence may suggest that investigating near misses on even small groups of participants could offer a sufficient variability to represent the risk of accidents also in wider populations. Regarding the statistical analysis, the adoption of the mediated model made it possible to clarify the processes behind some previous evidence reported in the literature with regards to the relationship between worked hours and accidents.

Conclusions

The chain of events leading to an occupational injury deserves particular attention in agriculture, due to the high hazardousness of this sector. One of the main causes of injuries is represented by falls, especially while dismounting the tractor. With regards to this issue the critical role played by unsafe behavior as exiting facing forward or jumping from the steps is well documented in the literature (Grogran et al., 2014). Nevertheless, little information is available about which variables affect these unsafe behaviors. This study showed the role played by worked hours and work experience in, respectively, enhancing and decreasing unsafe behaviors. Therefore, preventive training interventions could focus on the re-design of the actual working strategies and on the adoption of engaging training methods as behavioral modeling in the use of machinery, to optimize the learning of safety practices and safe behaviors. Interventions should also focus on near misses, making the report and the analysis of these events a widespread and systematic practice among farmers and farm workers (OSHA, 2015).

Competing interests: None to declare.

Key points:

- The study showed that different variables intervene at different steps in the occurrence of a fall accident when dismounting agricultural tractors.
- The results suggest the need for multilevel training interventions focused on both working strategies and individual behaviors.
- The results highlight the importance of investigating near misses in order to prevent injuries in the agricultural sector.

References

American National Standards Institute (2008, Rev. 2012). *Tractors for agriculture and forestry - Safety - Part 1: Standard tractors (*ANSI/ASABE AD26322-1). St. Joseph, MI: American Society of Agricultural and Biological Engineers.

Arbuckle, J. L. (2014). *Amos (Version 20.0)* [Computer Program]. Chicago: IBM SPSS.

Bancej, C., & Arbuckle, T. (2000). Injuries in Ontario farm children: a population based study. *Injury Prevention, 6*(2), 135-140.

Baron, S., Estill, C., Steege, A., & Lalich, N. (2001). *Simple solutions: Ergonomics for farm workers.* Report Number: DHHS/PUB/NIOSH-2001-111. Cincinnati, OH: National Institute for Occupational Safety and Health. Retrieved from https://www.cdc.gov/niosh/docs/2001-111/pdfs/2001-111.pdf

Bentler, P. M. (1990). Comparative fit indexes in structural models. *Psychological Bulletin, 107*(2), 238-246.

Blasche, G., Pasalic, S., Bauböck, V. M., Haluza, D., & Schoberberger, R. (2016). Effects of rest-break intention on rest-break frequency and work-related fatigue. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 59*(2), 289-298.

Bureau of Labor Statistics (2017). Injuries, illnesses, and fatalities. Retrieved from https://www.bls.gov/iif/home.htm

Burke, M. J., Sarpy, S. A., Smith-Crowe, K., Chan-Serafin, S., Salvador, R. O., & Islam, G. (2006). Relative effectiveness of worker safety and health training methods. *American Journal of Public Health*, *96*(2), 315-324.

Burton, S., & Blair, E. (1991). Task conditions, response formulation processes, and response accuracy for behavioral frequency questions in surveys. *Public Opinion Quarterly, 55,* 50-79.

Bush, D. E., Wilmsen, C., Sasaki, T., Barton-Antonio, D., Steege, A. L., & Chang, C. (2014). Evaluation of a pilot promotora program for Latino forest workers in southern Oregon. *American Journal of Industrial Medicine, 57*(7), 788-799.

Caffaro, F., & Cavallo, E. (2015). Comprehension of safety pictograms affixed to agricultural machinery: A survey of users. *Journal of Safety Research, 55*, 151-158.

Caffaro, F., Lundqvist, P., Micheletti Cremasco, M., Nilsson, K., Pinzke, S., & Cavallo, E. (in press). Machinery-related perceived risks and safety attitudes in senior Swedish farmers. *Journal of Agromedicine*.

Caffaro, F., Mirisola, A., & Cavallo, E. (2017). Safety signs on agricultural machinery: pictorials do not always successfully convey their messages to target users. *Applied Ergonomics*, *58*, 156-166.

Cavallo, E., Ferrari, E., Bollani, L., & Coccia, M. (2014). Attitudes and behaviour of adopters of technological innovations in agricultural tractors: A case study in Italian agricultural system. *Agricultural Systems*, *130*, 44-54.

Cavallo, E., Ferrari, E., & Coccia, M. (2015). Likely technological trajectories in agricultural tractors by analysing innovative attitudes of farmers. *International Journal of Technology, Policy and Management, 15*(2), 158-177.

Council of the European Union (1980). *Council Directive 80/720/EEC of 24 June 1980 on the approximation of the laws of the Member States relating to the operating space, access to the driving position and the doors and windows of wheeled agricultural or forestry tractors.* Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31980L0720

Day, L., & Rechnitzer, G. (2004). Safe tractor access platforms: From guidance material to implementation. *Journal of Agricultural Safety and Health, 10*(3), 197-209.

Elkind, P. D. (2008). Perceptions of risk, stressors, and locus of control influence intentions to practice safety behaviors in agriculture. *Journal of Agromedicine, 12*(4), 7-25.

Fathallah F. A. (2010). Musculoskeletal disorders in labor-intensive agriculture. *Applied Ergonomics, 41*(6), 738-743

Fathallah, F. A., Gronqvist, R., & Cotnam, J. P. (2000). Estimated slip potential on icy surfaces during various methods of exiting commercial tractors, trailers and trucks. *Safety Science*, *36*(2), 69-81.

Feyer, A. M., Williamson, A. M., Stout, N., Driscoll, T., Usher, H., & Langley, J. D. (2001) Comparison of work related fatal injuries in the United States, Australia, and New Zealand: method and overall findings. *Injury Prevention, 7*(1), 22–28.

Glasscock. D. J., Rasmussen, K., Carstensen, O., & Hansen, O. N. (2006). Psychosocial factors and safety behaviour as predictors of accidental work injuries in farming. *Work & Stress, 20*(2), 173-189.

Görücü, S., Cavallo, E., & Murphy, J. D. (2014). Perceptions of tilt angles of an agricultural tractor. *Journal of Agromedicine, 19*(1), 5-14.

Greubel, J., & Nachreiner, F. (2013). The validity of the risk index for comparing the accident risk associated with different work schedules. *Accident Analysis & Prevention*, *50*, 1090-1095.

Grogran, J. P., Morrison, J. B., & Mann, D. D. (2014), Development of equipment for in-field recording of cab ingress/egress behavior. In: *Proceedings of the International Conference of Agricultural Engineering*, Zurich, Switzerland, 06-10 July 2014.

Hammer, W. (1991). Safe access to farm tractors and trailers. *Journal of Agricultural Engineering Research, 50*, 219-237.

House, T., Schwebel, D. C., Mullins, S. H., Sutton, A. J., Swearingen, C. J., Bai, S., & Aitken, M. E. (2016). Video intervention changes parent perception of all-terrain vehicle (ATV) safety for children. *Injury Prevention, 22*(5), 328-333.

HSE (2013). *Using tractors safely. A step-by-step guide*. Sudbury, Suffolk, UK: Health and Safety Executive. Retrieved from http://www.hse.gov.uk/pubns/indg185.pdf

ILO (2014). *Agriculture; Plantations; Other Rural Sectors.* Retrieved from http://ilo.org/global/industries-and-sectors/agriculture-plantations-other-rural-sectors/lang--en/index.htm

ILO (2017) *Safety and health at work.* Retrieved from http://www.ilo.org/global/topics/safety-and-health-at-work/lang--en/index.htm

INAIL (2015). *Relazione audizione Commissione Agricoltura e Produzione Agroalimentare* [Report to the Commission for Agriculture and Agri-food Production]. Retrieved from https://www.senato.it/application/xmanager/projects/leg17/attachments/documento_evento_procedura_commissione/files/000/002/524/INAIL.pdf

INEA (2014). *Italian agriculture in figures 2014*. Retrieved from https://moodle2.units.it/pluginfile.php/107699/mod_resource/content/1/Figures.pdf

International Organization for Standardization (1983). *Agricultural tractors - Operator' s workplace, access and exit – Dimensions* (ISO 4252). Geneva, Switzerland: Author.

International Organization for Standardization (1995). *Tractors, machinery for agriculture and forestry, powered lawn and garden equipment -- Safety signs and hazard pictorials - General principles* (ISO 11684). Geneva, Switzerland: Author.

Kaustell K. O., Mattila T. E. A., & Rautiainen R. H. (2011). Barriers and enabling factors for safety improvements on farms in Finland. *Journal of Agricultural Safety and Health, 17*(4), 327-342.

Kirkhorn, S. R., Earle-Richardson, G., & Banks, R. J. (2010). Ergonomic risks and musculoskeletal disorders in production agriculture: recommendations for effective research to practice. *Journal of Agromedicine*, *15*(3), 281-299.

Kleban, N., Mann, D., & Morrison, J. (2013). *Position analysis of tractor ingress and egress. Paper n. CSBE13-009.* CSBE/SCGAB Annual Conference. Saskatoon, SK: University of Saskatchewan, 7-10 July 2013.

Kogler, R., Quendler, E, & Boxberger, J. (2015). Near accidents with agricultural vehicles, machinery and equipment in Austria in the year 2013. *Agricultural Engineering International: CIGR Journal*, *17*, 141-157.

Kumar, A., Varghese, M., & Mohan, D. (2000). Equipment-related injuries in agriculture: an international perspective, *Injury Control and Safety Promotion*, *7*(3), 175-186.

Leskinen, T., Suutarinen, J., Väänänen, J., Lehtelä, J., Haapala, H., & Plaketti, P. (2002). A pilot study on safety of movement practices on access paths of mobile machinery. *Safety Science*, *40(7)*, 675-687.

Lilley, R., Feyer, A. M., Kirk, P., & Gander, P. (2002). A survey of forest workers in New Zealand: Do hours of work, rest, and recovery play a role in accidents and injury? *Journal of Safety Research*, *33*(1), 53-71.

Lombardi, D. A., Folkard, S., Willetts, J. L., & Smith, G. S. (2010). Daily sleep, weekly working hours, and risk of work-related injury: US National Health Interview Survey (2004–2008). *Chronobiology international*, *27*(5), 1013-1030.

Lundqvist, P., & Gustafsson, B. (1992). Accidents and accident prevention in agriculture a review of selected studies. *International Journal of Industrial Ergonomics*, *10*(4), 311-319.

Mann, D. D., Hesketh, A., & Morrison, J. B. (2016). Comparison of forward-facing and backward-facing tractor egress. *Canadian Biosystems Engineering*, *58*, 2.1-2.8.

Markkula, G., Benderius, O., Wolff, K., & Wahde, M. (2012). A review of near-collision driver behavior models. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *54*(6), 1117-1143.

Mattila, T. E. A., Kaustell, K. O., Rautiainen, R. H., Pitkänen, T. J., Lötjönen, T., & Suutarinen, J. (2008). Slip, trip, and fall injuries in potato, sugar beet, and open field vegetable production in Finland. *Ergonomics*, *51*(12), 1944-1959.

McGwin, G., Enochs, R., Roseman, J.M. (2000). Increased risk of agricultural injury among African-American farm workers from Alabama and Mississippi. *American Journal of Epidemiology*, *152*(7), 640-650.

McLaughlin, A. C., & Mayhorn, C. B. (2011). Avoiding harm on the farm: Human factors. *Gerontechnology*, *10*(1), 26-37.

Merryweather, A. S., Pate, M. L., & Vemparala, S. (2011). *Self-reported tractor operator falls, ergonomics and musculoskeletal pain. ASABE Paper No. 1111334.* St. Joseph, MI: American Society of Agricultural and Biological Engineers.

National Safety Council (2014). *Near miss reporting systems*. Retrieved from http://www.nsc.org/JSEWorkplaceDocuments/How-To-Conduct-An-Incident-Investigation.PDF

NIOSH (2010). *Worker safety on the farm.* Washington DC: National Institute for Occupational Safety and Health. Retrieved from https://www.cdc.gov/niosh/docs/2010-137/pdfs/2010-137.pdf

Nordstrom, D. L., Layde, P. M., Olson, K. A., Stueland, D., Follen, M. A., & Brand, L., (1996). Fall-related occupational injuries on farms. *American Journal of Industrial Medicine*, *29*, 509–515.

OSHA (2015). *Incident [Accident] investigations: a guide for employers.* Retrieved from https://www.osha.gov/dte/IncInvGuide4Empl_Dec2015.pdf

Phimister, J. R. , Oktem, U., Kleindorfer, P. R., & Kunreuther, H. (2000). *Near-miss system analysis: phase I.* Retrieved from http://opim.wharton.upenn.edu/risk/downloads/wp/nearmiss.pdf

Purschwitz, M. A. (2006). Personal protective equipment and safety engineering of machinery. In J. E. Lessenger (Ed.), *Agricultural Medicine. A practical guide* (pp. 53-69). New York: Springer.

Reise, S. P., Widaman, K. F., & Pugh, R. H. (1993). Confirmatory factor analysis and item response theory: Two approaches for exploring measurement invariance. *Psychological Bulletin, 114*(3), 552-566.

Rogers, W.A., Lamson, N., & Rousseau, G. K. (2000). Warning research: an integrative perspective. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 42*, 102-139.

Scott, A., Miller, M., & Hallas, K. (2006). *The underlying causes of falls from vehicles associated with slip and trip hazards on steps*. *Research Report 437.* Sudbury, Suffolk, UK: Health and Safety Executive.

Smith, G. S. (2001). Public health approaches to occupational injury prevention: Do they work? *Injury Prevention, 7*(suppl. I), 3-10.

Steiger, J. H. (1980). Structural model evaluation and modification: An interval estimation approach. *Multivariate Behavioral Research, 25*(2), 173-180.

Torèn, A., Öberg, K., Lembke, B., Enlund, K., & Rask-Andersen, A. (2002). Tractor-driving hours and their relation to self-reported low-back and hip symptoms. *Applied Ergonomics*, *33*(2), 139-146.

Tucker, L. R., & Lewis, C. (1973). A reliability coefficient for maximum likelihood factor analysis. *Psychometrika, 38*(1), 1-10.

Whitman, S. D., & Field, W. E. (1995). Assessing senior farmers' perceptions of tractor and machinery-related hazards. *Journal of Agricultural Safety and Health, 1*, 199-214.

Wright, L., & Schaaf, T. (2004). Accident versus near miss causation: a critical review of the literature, an empirical test in the UK railway domain, and their implications for other sectors. *Journal of Hazardous Materials, 111*, 105-110.

Wu, W., Gibb, A. G., & Li, Q. (2010). Accident precursors and near misses on construction sites: An investigative tool to derive information from accident databases. *Safety Science*, *48*(7), 845-858.

Zhang, T., & Chan, A. H. (2016). The association between driving anger and driving outcomes: a meta-analysis of evidence from the past twenty years. *Accident Analysis and Prevention,* 90, 50-62.

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