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Examination of Realism in a High-fidelity Tractor Driving Simulator

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Abstract

Transportation-related incidents are the leading cause of occupational fatalities for all industries in the U.S., including the agricultural industry, which suffers thou- sands of crashes involving farm equipment each year. Simulated driving studies offer a safe and cost-effective way to conduct driving research that would not be feasible in the real world. A tractor driving miniSim was developed and then evaluated for realism at the University of Iowa among 99 Midwestern farm equipment operators. It is important for driving simulators to have a high degree of realism for their results to be applicable to non-simulated driving operations. High-fidelity driving simulators facilitate extrapolations made by driving research but should be re-tested for realism when changes are made to the design of the simulator. The simulator used in this study emulated a tractor cab with realistic controls, three high-resolution screens, and high-fidelity sound. After completing a 10-minute drive, farm equipment operators completed a survey and scored four specific domains assessing specific characteristics (i.e., appearance, user interface, control, and sound) of the tractor simulator's realism using a seven-point Likert scale (from 0 = not at all realistic to 6 = completely realistic). An overall realism score and domain scores were calculated. Farm equipment operators were also asked to provide recommendations for improving the tractor miniSim. Overall, farm equipment operators rated the simulator's realism favorably (i.e., >3 on a scale from 0 to 6) for all individual items and domains. The appearance domain received the highest average realism score (mean = 4.58, SD = 1.03), and the sound domain received the lowest average realism score (mean = 3.86, SD = 1.57). We found no significant differences in realism scores across farm equipment operator characteristics. The most frequently suggested improvements were to tighten the steering wheel (27%), make the front tires visible (19%), and that no improvements were needed to improve the simulator realism (18%). This study demonstrates that the new trac- tor miniSim is a viable approach to studying farm equipment operations and events that can lead to tractor-related crashes. Future studies should incorporate the suggested improvements and seek to validate the simulator as a research and outreach instrument.

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Keywords

Driving simulator; Farm equipment operators; Realism; Tractors

Introduction

The agricultural industry has the highest rate of fatalities among all occupational industries in the U.S., with an annual fatality rate of 22.8 deaths per 100,000 full-time workers (BLS, 2017). This industry also has the highest nonfatal injury rate, averaging 5.7 cases per 100 full-time workers per year (BLS, 2016). Many of these injuries and fatalities can be attributed to agricultural equipment, particularly tractors (BLS, 2017; Peek-Asa et al., 2007; Toussaint et al., 2017).

While there are numerous studies detailing the factors in passenger vehicle crashes, the same cannot be said about agricultural equipment (Görücü et al., 2014; Harland et al., 2018). Research on agricultural equipment crashes frequently focuses on crash reports, which are often incomplete (Harland et al., 2018; Peek-Asa et al., 2007; Ranapurwala et al., 2019; Toussaint et al., 2017). Other studies focus on environmental factors, such as road conditions, but not driving performance factors (Greenan et al., 2016). Vehicle performance, such as braking, steering, center of gravity, and field of view, are very different between passenger vehicles and tractors. The vehicle size, wheels, and engine power, among other things, are also quite different. Furthermore, farm equipment studies using primary data sources and those examining driver characteristics (particularly among older farm equipment operators) preceding vehicle crashes are tenuous.

Whether due to safety, cost, or experimental control, simulated driving studies offer a safe, cost-effective, and with the use of smaller miniSim devices, portable way to conduct driving research that would not be feasible on public roadways (de Winter et al., 2012; Wassinek et al., 2006). Simulation allows researchers to measure how drivers respond to hazardous events in a simulated environment (designed to be realistic) without endangering the driver (Underwood et al., 2011). In addition to driver safety, use of a driving simulator in behavioral, operator performance, or crash research guarantees that different participants will experience identical driving conditions regarding route, traffic, lighting, weather, visual scene, and vehicle response (Kaptein et al., 1996). Results from simulation studies also typically require fewer resources to run and offer more experimental control than on-road research (Kaptein et al., 1996; Haug, 1990). Finally, although tractor-driving simulators have been built and used historically in product testing and driver safety, none of those simulators are mobile. Considering how common a barrier participant recruitment is within agricultural safety research, mobility is crucial for recruiting eligible participants and collecting data (Görücü et al., 2014; Deere, 2017, 2018; Prinz et al., 2009).

Whenever a new driving simulator is designed, it is important to make the experience as similar to real-world driving as possible (Weir and Clark, 1995). Driving simulators can be customized with regard to the visual scenery, the user interface of the cab such as position and response of vehicle controls (i.e., velocity and steering controls), the ability to control the simulated vehicle, and the sounds associated with driving the vehicle (Gruening et al., 1998). Once developed, realism surveys allow researchers to assess each feature and determine if changes are needed (Blana, 1996; Freeman et al., 1995). Realism surveys typically assess the simulated visual appearance of the road and other objects in the simulated drive using a Likert scale (typically ranging from 0 to 6, where 0 = not at all realistic and 6 = completely realistic), in which scores above 3 indicate a high degree of realism and functional correspondence with an actual tractor (Lee et al., 2013; Schwarz et al., 2003; Kay et al., 2013).

From this review of the literature, there is a paucity of research on assessing the realism of tractor simulators. One important gap is how and what to measure in such simulators. The purpose of this study was to examine four realism domains of a new tractor driving simulator (i.e., appearance, user interface, vehicle control, and sound) and whether realism varied by farm and farm equipment operator characteristics such as demographics (gender and age), farm type (crop, livestock, or mixed), and tractor characteristics (i.e., tractor age and the presence of a rollover protective structure (ROPS) or cab).

Materials and Methods

Design and Construction of New Tractor Simulator

Creating a simulator that mimics the appearance and feel of the vehicle type being studied is critical when conducting driving simulation research (Kaptein et al., 1996). To ap- proximate a realistic tractor cab, an existing heavy truck miniSim was repurposed and modified to represent the controls and interface of a John Deere tractor (fig. 1). This model originally simulated a semi-truck and was chosen because it had an interface similar to that used by most farmers.

A John Deere instrument panel (fig. 2a) was simulated on an LCD screen on the new tractor miniSim (fig. 2b). Tractor instrument panels have different features compared to passenger vehicles. For example, unlike a passenger vehicle, which prominently features a speedometer (measuring vehicle speed in miles per hour), tractor instrument panels typically feature a tachometer (measuring engine speed in revolutions per minute) prominently and may not even display a standard speedometer (fig. 2a).

Furthermore, unlike passenger vehicles, which have discrete gears and a gas pedal to control the vehicle speed, many tractors use an infinitely variable transmission (IVT) for gear shifting and a hand throttle to control the vehicle speed (fig. 3a). Therefore, a box was mounted to the right side of the tractor miniSim with hand-based speed controls including the IVT control and hand throttle (fig. 3b). The gas pedal was removed, leaving only a clutch pedal and brake pedal (fig. 3c).

Steering wheels tend to be wider on tractors (fig. 4a) compared to passenger vehicles. Sedans, sports utility vehicles, and pickup trucks tend to have steering wheels that are less than 16 inches in diameter, while tractor steering wheels are typically 16 to 18 inches in diameter. To account for this difference, the tractor simulator was outfitted with an 18-inch steering wheel (fig. 4b). Finally, due to the amount of vibration and off-road driving, tractors typically have a suspension seat; therefore, the existing seat was modified for the tractor miniSim to include a suspension base from an actual tractor cab (fig. 4c).

Because the tractor miniSim did not use an actual cab, cab features were added to the visual display on the simulator. These included the tractor hood and exhaust stack (fig. 1). The pillars of the tractor cab were not simulated as it was determined that the bezels of the TV monitors sufficiently recreated this effect and that adding the pillars might excessively obscure the driver's field of view. The eye point offset, which controls the position of the virtual cab relative to the driver's eye point, was raised and adjusted until a reasonable approximation was attained. This was done to compensate for the height of the tractor relative to the height of passenger vehicles. The tractor miniSim software was also repurposed using an existing vehicle dynamics model and visual models used on the NADS-1 simulator. The NADS-1 simulator is a motion-based ground vehicle driving simulator that com- bines motion, graphics, audio, control feel, and software to produce an experience very close to real-time driving (https://www.nads-sc.uiowa.edu/sim_nads1.php).

Virtual Environment and Scenario Authoring

A virtual environment displayed the ground, sky, buildings, and other static objects (e.g., trees, fences, billboards, and road signs) to simulate a driving environment that is typical of a rural community. This study used an existing virtual environment of rural road- ways and fields with dynamic objects such as vehicles and pedestrians added into the environment with controlled vectors (i.e., path and speed) to create scenarios. Vehicles (particularly pickup trucks) were added sporadically to model ambient traffic. Farm buildings were added to enhance the rural environment. A user-controlled tractor model was also created to allow participants to drive within the simulated environment.

Screening and Recruitment

Participants for this study were recruited from the University of Iowa's National Advanced Driving Simulator (NADS) participant registry and by distributing fliers with study information in agricultural extension offices and applicable retail stores (e.g., farm/tractor supply stores, co-ops, restaurants) in counties within a 30-mile radius of the NADS study site. To be eligible for the study, farm equipment operators needed to be at least 25 years old, have a valid driver's license, have at least three years of tractor operating experience, have operated a tractor in the past year, and be able to pass the Callahan six-item Mini Mental State Examination (Callahan et al., 2002). Additionally, farm equipment operators who had participated in a previous simulated driving study involving crash events or who had been dropped due to simulator sickness were considered ineligible for this study. Eligible farm equipment operators were scheduled for a single appointment, which lasted 60 to 90 minutes depending on time taken at NADS to complete the simulated drive and data collection.

Simulated Drive

Participants were given pre-recorded turn-by-turn directions by the miniSim during a 10-minute simulated drive. The drive began with participants driving the tractor on a farm driveway on a clear day (i.e., good weather, daylight). Passing a pedestrian near a mailbox, they made a left turn onto a two-lane rural road with no shoulder. Although the road had a posted speed limit of 55 mph, the tractor had a maximum speed of 20 mph. After several minutes of uneventful driving with ambient traffic, the participants encountered a rural four-way intersection without stop signs or stop lights. As the participants approached the intersection, a simulated semi-truck traveling perpendicular to the tractor also approached the intersection from the left. After the semi-truck had passed through the intersection, participants were instructed to make a right turn, placing them behind the semi-truck. After a few minutes of uneventful driving, the farm equipment operators were instructed to bring the tractor to a stop and place it into park on the side of the road to end the drive.

Data Collection and Variables

Participants traveled to the NADS in Iowa City for the simulated drive, administration of informed consent, and data collection. Prior to the simulated drive, all participants completed a pre-drive questionnaire that collected demographic information (i.e., age and gen- der), farm type (i.e., crop, livestock, or mixed), and information about the tractor that they drove most frequently (i.e., tractor age and the presence of a ROPS or cab). Tractors have varied substantially over the years in their size, power, and cab design (https://americanhistory.si.edu/tractor). Therefore, it was important to understand if the types of tractors driven by the participants affected their perceived realism of the simulated tractor. Participants were asked to provide the make, model, and year of the tractor they drove most frequently. They were also asked if the tractor they drove most frequently had an enclosed cab or a ROPS. Farm type was categorized as crop, mixed (e.g., crops and livestock), or other. Participants who did not work or live on a farm (n = 4), who only raised livestock (n = 1), or who lived on non-producing acreage (n = 2) were combined to make the “other” category due to the concern that they may not have as much experience driving tractors compared to participants from crop farms and mixed farms.

Prior to completing the simulated drive, all participants watched a short PowerPoint presentation demonstrating how to operate the simulator. Following the simulated drive, a self-administered realism survey was completed by each participant. The realism survey consisted of 15 questions using a seven-point Likert scale (where 0 = not at all realistic and 6 = completely realistic) as well as four open-ended questions. The survey was modified from a previous NADS simulator realism survey to include the new features of the tractor miniSim (Lee et al., 2013; Schwarz et al., 2003). The survey covered four domains: appearance, user interface, control, and sound. The five items in the appearance domain concerned the visual representation of simulated objects and asked participants to rate how realistic vehicles, pedestrians, and other objects appeared in the simulated environment. The five items in the user interface domain concerned the tactile feel of the tractor mini- Sim’s hardware and asked participants to rate how realistically the IVT, brakes, and other hardware responded to their input. The three items in the control domain concerned the response of the simulated tractor to driver input and asked participants to rate the ability to keep straight in the lane and the simulator’s response when braking and accelerating. The two questions in the sound domain concerned the sound of the tractor engine and the sound of other vehicles in the ambient traffic. The four open-ended questions asked:

1. What about the simulator seemed most unrealistic?

2. What could be done to make the simulator more realistic?
3. Was anything so unrealistic that it affected the way you drove?
4. Is there anything else you would like to say about our simulator or driving tractors?

Analysis

Descriptive statistics were calculated for the participant demographics (age and gender), characteristics of the tractor driven most frequently (tractor age and presence of a cab or ROPS), and farm type. Age was categorized into older farmers (65+ years) and younger farmers (25 to 64 years).

Approximately 25% of the participants did not know the age of the tractor they drove most frequently. However, 76% of them provided sufficient details regarding the tractor make and model that the tractor age could be deduced. Tractors manufactured before 1985 were categorized as antique tractors, while those manufactured in 1985 or later were categorized as modern tractors in accordance with the release of a new voluntary safety standard to sell all new tractors with ROPS (ASABE, 2017).

Mean realism domain scores for each participant were calculated by summing the item ratings within each domain and dividing that total by the number of item ratings in that domain (appearance maximum score = 30, user interface maximum score = 30, control maximum score = 18, and sound maximum score = 12). A total overall score was calculated for each participant using the sum of all 15 survey items.

The association between participant demographics (age and gender), tractor characteristics (tractor age and ROPS or cab installed), and realism scores were examined using t- tests when scores were normally distributed (i.e., user interface, control, and total realism) and using the Wilcoxon rank sum test when scores were not normally distributed (i.e., appearance and sound). Analysis of variance (ANOVA) was used to examine the association between farm type and normally distributed domain scores, and the Kruskal-Wallis test was used when scores were not normally distributed.

Responses from the four open-ended questions were analyzed using a hybrid of de- ductive coding for realism domains and inductive coding for subthemes and additional suggestions (Fereday and Muir-Cochrane, 2006; Linneberg and Korsgaard, 2019). If a participant made more than one comment on the same theme (e.g., if a participant mentioned that steering was most unrealistic and also mentioned fixing the steering to make it more realistic), it was only documented once. Comments were grouped by the four domains. Compliments about the simulator and comments that that did not clearly offer a suggestion for improvement were combined to form a “no suggested improvements” category.

Results

Study Population

A total of 156 farm equipment operators were contacted about the study, 118 of whom were identified through the NADS registry. The remaining 38 reached out to the research team after seeing a flier or news story. Among all contacted farm equipment operators, 134 (86%) were screened as eligible to participate. However, 35 of them were unable to find time to participate in the study, resulting in a final sample size of 99 farm equipment operators and a participation rate of 74%.

Approximately one-third of the study population was at least 65 years of age (range: 65 to 93, mean: 72 years). The younger farm equipment operators (<65 years) ranged from 25 to 61 years old, with a mean age of 41 years. The participants in this study were predominantly male (85%) (table 1). Of the tractors most frequently driven, almost half (49%) were categorized as modern, and most participants reported that their tractor had an enclosed cab or ROPS (63%). Over half of the participants worked on "mixed" farms that produced both crops and livestock (56%).

Realism Scores

The total realism score had an overall mean of 4.21 (SD = 0.99), with younger farm equipment operators scoring the simulator as slightly more realistic (mean = 4.41, SD = 0.98) than older farm equipment operators (mean = 4.12, SD = 0.98; table 2). Favorable scores (i.e., >3 on a scale from 0 to 6) were reported for all individual items and domains, regardless of age category (Schwarz et al., 2003; Kay et al., 2013). The appearance domain had the highest overall score (mean = 4.58, SD = 1.03), and the sound domain had the lowest average score (mean = 3.86, SD = 1.57).

The highest-scored individual items for older farm equipment operators were for appearance of the road (mean = 4.72, SD = 1.25) and appearance of the rural scenery (mean= 4.72, SD = 1.20). Younger farm equipment operators scored the appearance of the instrument panel as most realistic (mean = 4.61, SD = 1.31), followed by the appearance of other vehicles (mean = 4.52, SD = 1.26). The lowest-scored individual item for older farm equipment operators was the response of the steering wheel (mean = 3.13, SD = 1.88), while the response of the IVT control received the lowest realism score from younger farm equipment operators (mean = 3.67, SD = 1.45).

Measures of the association between the participant and farm characteristics and the realism domain scores are presented in table 3. No significant differences were observed between the participant and farm characteristics and the realism domain scores.

Changes Suggested by Participants

Suggestions from the participants for improving the tractor miniSim are presented in table 4. The most frequently suggested improvement was to tighten the steering in the user interface domain (n = 27). In the appearance domain, being able to see the tractor's front tires on the ground was the most common suggested improvement (n = 19). In addition to tightening the steering in the user interface domain, adding engine size options (n = 15) and adding more gears (n = 11) were frequently mentioned. In the control domain, adding an automatic transmission was suggested by two participants. There were five comments suggesting that the simulator be louder. Additionally, there were 18 comments that no improvements were needed to the simulator realism.

Discussion

Overall, the tractor simulator developed and used for this study received favorable realism scores, and no significant differences between farm equipment operator characteristics and the realism domains were observed. Realism scores for the simulator matched or exceeded scores observed in studies using similar simulators (Lee et al., 2013; Schwarz et al., 2003). We also received important feedback about how the simulator could be improved.

Favorable scores (i.e., >3 on a scale from 0 to 6) were seen for all individual items and realism domains of the participant survey. The appearance domain was the highest scoring domain and also contained the highest scoring individual items (e.g., appearance of the instrument panel, road, and other vehicles) regardless of age group.

The sound domain was the lowest scoring domain. When idling, tractors produce approximately 80 dB of noise, and can surpass 120 dB when working at full load. The danger to a person's hearing at this noise level is immediate. Therefore, to reduce the risk of hearing loss to the participants in this study, we kept the volume of the tractor simulator to 70 dB. Additionally, because of the noise produced by tractors, farm equipment operators are frequently unable to hear sounds produced by other vehicles. Therefore, being able to hear other vehicles is unrealistic in a tractor and may have contributed to the lower scores in the sound domain. These anomalies could be corrected by disabling the sounds of other vehicles in the scenario's program code or by running the simulator at full volume and supplying the participants with appropriate hearing protection. We also found that older farm equipment operators had lower sound domain scores than younger farm equipment opera- tors, which may be due to the higher prevalence of hearing loss in older adults (Cruickshanks et al., 1998).

The domain realism scores did not vary by age or other characteristics, which suggests that the perceived realism of the simulator was not influenced significantly by any of the factors examined. Therefore, modifications made to future generations of the tractor mini- Sim can focus on the domain scores and suggested improvements, regardless of farm equipment operator demographics and tractor characteristics.

Most of the comments were related to the appearance (n = 37) and user interface (n =60) domains. Several of the suggested improvements to the tractor miniSim were directly related to individual items on the realism survey. For example, the most common suggestion was to tighten the steering wheel on the simulator (n = 27). This likely corresponds to the lowest scoring individual questionnaire item ("response of the steering wheel"). Tightening the steering wheel could easily be achieved by increasing the tension of the steering column. The tractor miniSim was designed with power steering. While the steering wheel may have loosened over the course of the study due to frequent use, it is also possible that participants were biased by the presence of power steering, which many antique and some modern tractors do not have or may need to have repaired.

The second lowest scoring individual item (“ability to keep straight in your lane”) is potentially a direct effect of not being able to see the tires while driving, which was the second most common suggestion made by the participants for improving the simulator. This is important for tractors, as farm equipment operators frequently use the tires to estimate lateral distances on the road and in the field. One way to modify the tractor simulator would be to include additional monitors below the left and right screens or rotate the current monitors by 90°, which would increase the field of view and allow farm equipment operators to see the tire position on the road. This may also require adjusting the eye point and linking the tire rotation speed to the tractor model’s velocity.

Several participants suggested adding additional engine sizes and gears to represent a range of tractors. The engine horsepower for the tractor used in this study was greater than 100 hp. While beyond the scope of this study, future research should consider incorporating different sizes of tractor simulators. Separate models of tractors could include those with <40 hp, 40 to 99 hp, and 100+ hp based on horsepower categories used in the agricultural census. Studies could then allow participants to select the simulator most similar to the tractor they use on their farm. However, providing this feature would require the development of several tractor cabs due to the variations in hardware among tractor sizes.

This study has several limitations. First, a convenience sample was used to identify the study participants. Despite this, the characteristics of the farm equipment operator in this study were similar to national and state census data (USDA, 2017). For example, the mean age for our study population was 62.3 years, compared to the national mean age of 58.3 years. However, other characteristics of the study population were not consistent with what is known nationally. For example, while it is estimated that less than half of farm tractors have ROPS (Myers et al., 2009; Sorenson et al., 2010), a majority (63%) of the farm equipment operators in this study indicated that the tractor they drove most frequently had ROPS. This could be due to farmers having multiple tractors of varying ages on their farm (USDA, 2017). Future studies should seek to recruit farmer equipment operators who have experience with the specific model of tractor being simulated, or offer varying styles of tractor to better align with the farm equipment operator’s experience.

Second, the simulator used for this study was in the early stages of development and therefore had not been directly compared to real-world tractors or other driving simulators (such as NADS-1 and other miniSim cabs). Validation studies should be conducted using different simulated terrains to confirm that drivers operate the simulator similarly to their actual tractors and rate the realism in the same manner (Kamel Salaani et al., 2003a, 2003b; Garrott et al., 1997). Once validated, the tractor miniSim has potential for use in numerous research and educational programs.

Finally, several farm equipment operators in this study participated in previous simulated driving studies at the National Advanced Driving Simulator. Therefore, it is possible that they were comparing the realism of the tractor miniSim in this study to other types of driving simulators that they have driven in the past (e.g., a heavy semi-truck or passenger vehicle simulator). Future studies may want to screen out farm equipment operators who have participated in other simulated driving studies to eliminate comparisons between simulators. Future studies may also want to include multiple simulators and compare realism scores across simulator types (i.e., passenger vehicle, heavy truck, tractor).

Conclusions

This study demonstrated that the new tractor miniSim is a viable approach to studying farm equipment operations and events that can lead to tractor-related crashes. We found that farm equipment operators rated the simulator's realism favorably (i.e., >3 on a scale from 0 to 6) for all realism domains (appearance, user interface, control, and sound). We also found no significant differences in realism scores across farm equipment operator characteristics. Furthermore, in addition to improving participant safety by not using real- world tractors, use of a driving simulator in behavioral, operator performance, or crash research guarantees that different participants will experience identical driving conditions regarding the route, traffic, lighting, weather, visual scene, crash situation, and vehicle response. The tractor miniSim, with its high realism scores and versatility, is a promising new tool for studying human factors in tractor operation in real time.

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Highlights

- Describes the creation of a new high-fidelity tractor driving simulator.
- Describes the perceived realism of a tractor driving simulator among 99 Midwestern farm equipment operators.
- Examines how farm equipment operator characteristics affect perceived realism of a tractor driving simulator.
- Discusses potential improvements for future generations of tractor driving simulators.

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Figure 1.
New tractor miniSim.

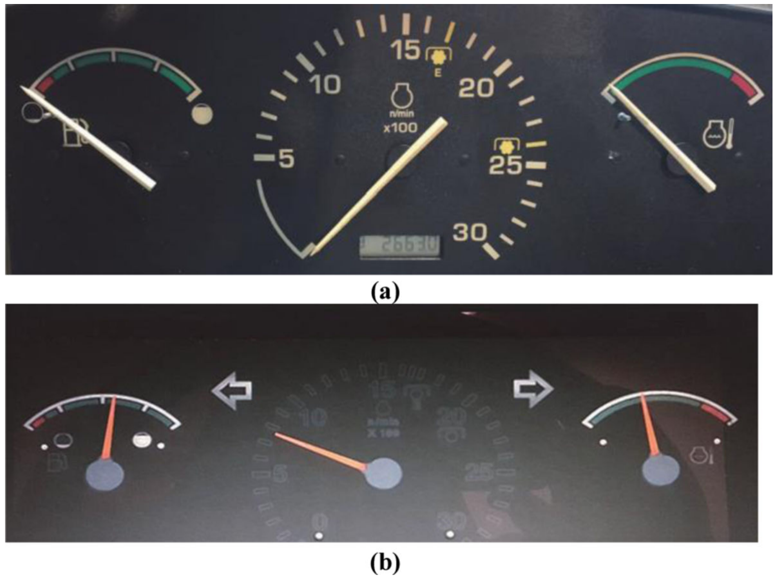
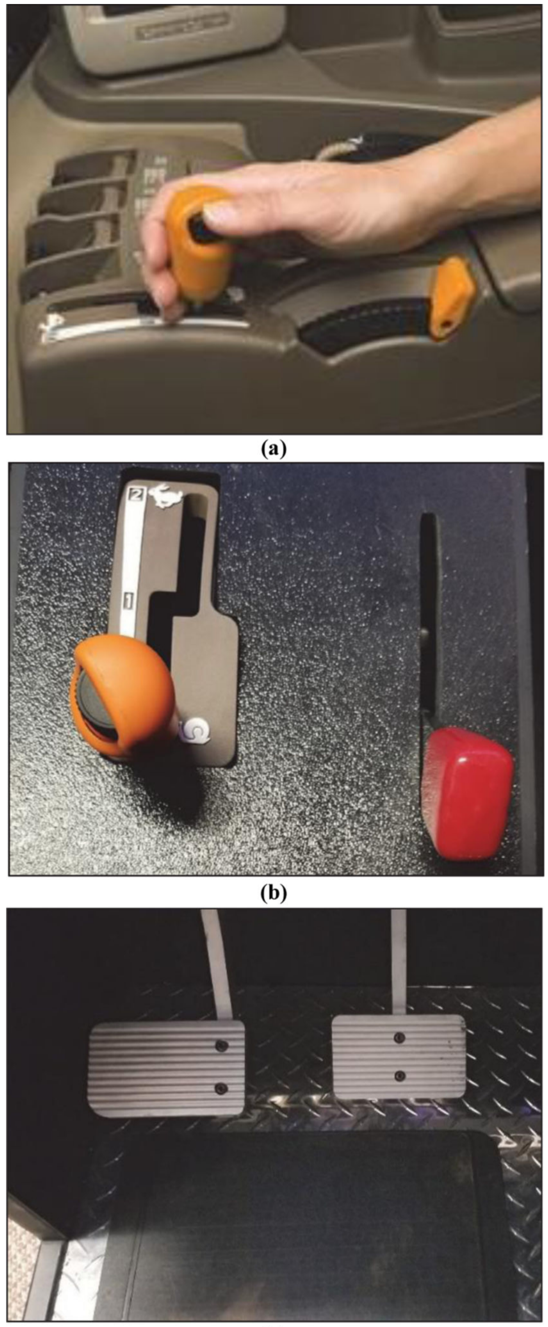


Figure 2.
Instrument panels from (a) an actual John Deere tractor and (b) the simulated instrument panel designed for the tractor miniSim.



(a) (b) (c)

Figure 3.

Hand and foot controls: (a) IVT control and hand throttle in an actual tractor, (b) miniSim IVT control and hand throttle, and (c) miniSim clutch and brake pedals.

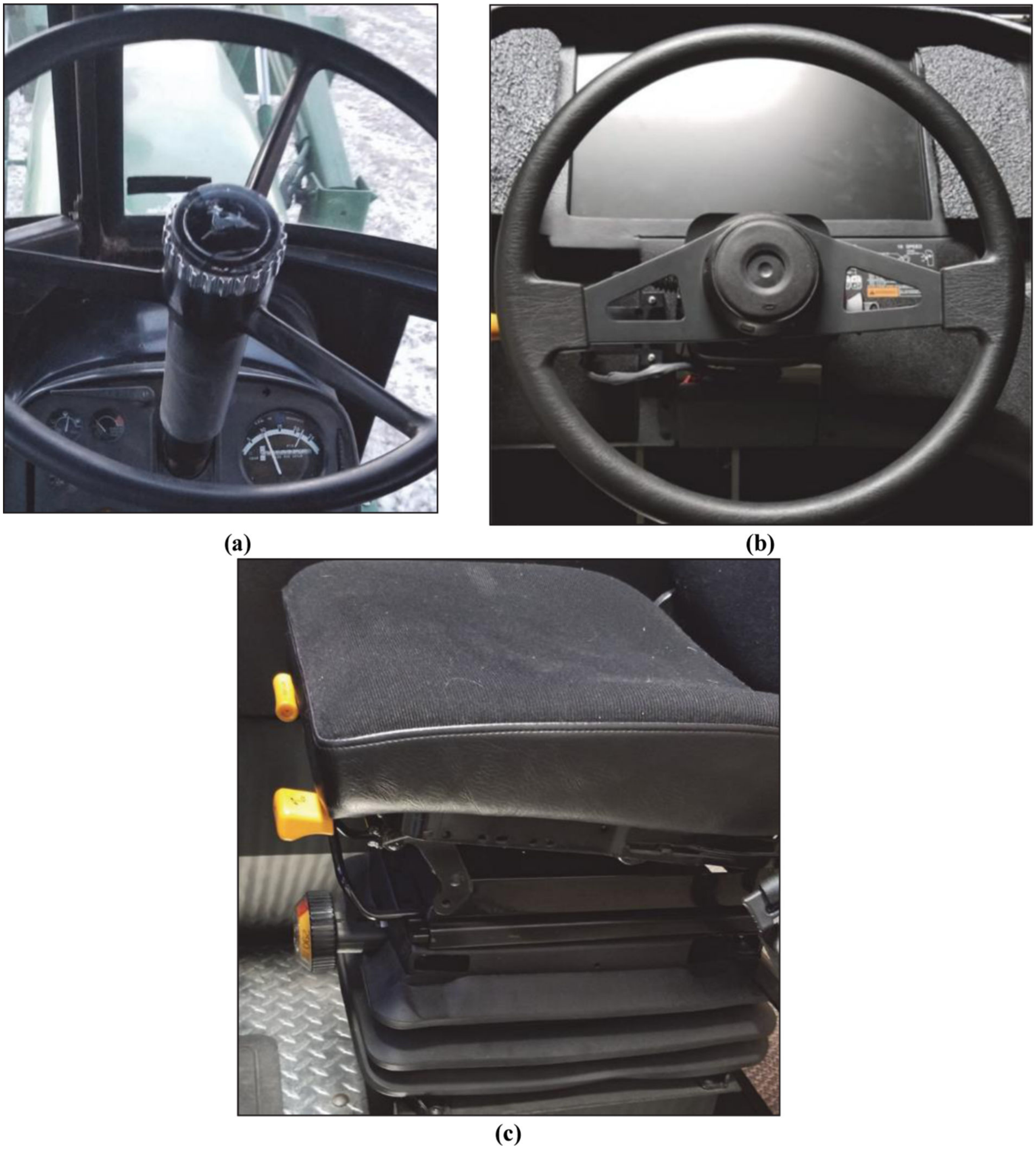


Figure 4.

Steering wheels (a) in an actual John Deere cab and (b) installed on the tractor miniSim, and (c) seat suspension installed on the tractor miniSim.

Table 1.

Farm equipment characteristics ($N = 99$).

Category	Value	*n*	%
Operator age	65+	31	31.3
	<65	68	68.7
Operator gender	Male	84	84.8
	Female	15	15.2
Tractor age	Antique (1940 to 1984)	45	45.5
	Modern (1985+)	48	48.5
	Unknown or missing	6	6.01
ROPS or cab	Yes	62	62.6
	No	37	37.4
Farm type	Crop	37	37.4
	Mixed	55	55.6
	Other	7	7.1

Table 2.

Realism scores by age group.

Realism Domains and Items	All Participants		Age 65+		Age <65	
	Mean	SD	Mean	SD	Mean	SD
Appearance domain						
Appearance of instrument panel	4.63	1.19	4.64	1.14	4.61	1.31
Appearance of road	4.63	1.25	4.72	1.25	4.45	1.26
Appearance of other vehicles	4.63	1.22	4.68	1.20	4.52	1.26
Appearance of rural scenery	4.56	1.30	4.72	1.20	4.23	1.45
Appearance of pedestrians	4.52	1.47	4.63	1.46	4.27	1.48
Total appearance domain	4.58	1.03	4.63	0.93	4.47	1.21
User interface domain						
Response of tachometer	4.31	1.45	4.25	1.50	4.43	1.36
Response of throttle	4.27	1.38	4.31	1.28	4.19	1.60
Response of brake pedal	3.92	1.47	4.00	1.46	3.71	1.51
Response of IVT control	3.91	1.47	4.01	1.48	3.67	1.45
Response of steering wheel	3.36	1.83	3.13	1.88	3.87	1.69
Total user interface domain	3.97	1.16	3.99	1.12	3.94	1.26
Control domain						
Sim response when accelerating	4.10	1.32	4.12	1.23	4.06	1.53
Sim response when braking	3.98	1.29	3.97	1.28	4.00	1.36
Ability to drive straight	3.52	1.62	3.25	1.70	4.10	1.27
Total control domain	3.87	1.10	3.78	1.10	4.12	1.10
Sound domain						
Sound of tractor	4.22	1.42	4.15	1.48	4.35	1.28
Sound of other vehicles	3.53	1.89	3.33	2.01	3.93	1.60
Total sound domain	3.86	1.57	3.72	1.65	4.13	1.40
Total realism score	4.21	0.99	4.12	0.98	4.41	0.98

Table 3.

Realism domains by participant and farm characteristics.

	Appearance		User Interface		Control		Sound		Total Realism	
Characteristic	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Operator age										
65+	4.63	0.93	3.99	1.12	3.78	1.1	3.72	1.65	4.12	0.98
<65	4.47	1.21	3.94	1.26	4.12	1.10	4.13	1.40	4.41	0.98
	(p = 0.73)		(p = 0.87)		(p = 0.19)		(p = 0.29)		(p = 0.26)	
Operator gender										
Male	4.56	1.07	4.01	1.78	3.92	1.11	3.82	1.59	4.18	1.02
Female	4.72	0.77	3.73	1.05	3.62	1.04	4.07	1.52	4.42	0.66
	(p = 0.83)		(p = 0.46)		(p = 0.35)		(p = 0.49)		(p = 0.54)	
Tractor age										
Antique	4.66	1.07	4.14	1.21	3.87	1.13	3.84	1.73	4.28	1.03
Modern	4.42)	1.03	3.76	1.12	3.82	1.12	3.84	1.48	4.10	0.97
	(p = 0.34)		(p = 0.16)		(p = 0.83)		(p = 0.88)		(p = 0.50)	
ROPS or cab										
Yes	4.68	1.04	3.95	1.21	3.94	1.14	4.02	1.62	4.38	1.02
No	4.44	1.00	4.01	1.11	3.77	1.05	3.60	1.48	4.00	0.92
	(p = 0.27)		(p = 0.82)		(p = 0.45)		(p = 0.16)		(p = 0.12)	
Farm type										
Crop	4.51	1.06	4.03	1.06	3.79	1.02	3.58	1.56	4.15	1.00
Mixed	4.55	1.01	3.87	1.23	3.88	1.11	3.96	1.55	4.18	0.98
Other	5.50	0.53	4.75	0.98	4.29	1.52	4.60	1.85	5.09	0.90
	(p = 0.15)		(p = 0.33)		(p = 0.55)		(p = 0.21)		(p = 0.29)	

Table 4.

Suggested improvements to the tractor simulator.

Appearance Domain (37 comments)	User Interface Domain (60 comments)	Control Domain (3 comments)	Sound Domain (7 comments)	Additional Suggestions (25 comments)
See the tires (19)	Tighten the steering (27)	Add automatic transmission (2)	Make tractor louder (5)	No changes needed (18)
Improve the rural environment (9)	Add engine size options (15)	Improve the brakes (1)	Add a radio (1) Add wind	Compliments for the study or simulator (3)
Increase the field of view (6)	Add more gears (11)		noise (1)	Use a real tractor cab (2)
Improve the tractor (3)	Add seat actuator for vibration (5)			Paint the hardware (1)
	Tilt steering column (2)			Add farm smells (1)