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Virtual reality for public health: a study on a VR intervention to enhance occupational injury prevention

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ABSTRACT

Background Agriculture is one of the most hazardous occupations in the USA. Especially, tractor rollover incidents are the leading cause of farming-related injuries or deaths. This study examines the effect of a VR intervention (Virtual Reality Intervention for Safety Education; VRISE) on behavioral intentions for occupational safety and identifies a psychological mechanism that shows how the immersive technology works.

Methods VRISE was developed by a multidisciplinary team of agricultural educators, computer scientists and communication specialists. It was designed to provide a virtual environment where users practice tractor operation and try to avoid several rollover hazards. The participants (291 high school students) were recruited at the 2019 National Future Farmers Association Convention & Expo and randomly assigned to one of three conditions: two different types of control groups ($Control_1$: No treatment group and $Control_2$: 2D Screen group) and the treatment group.

Results Findings show that, through the immersive VR experience, the VR intervention enhanced perceived threat of tractor-related accidents which in turn, led to improved behavioral intentions for tractor safety.

Conclusions Findings shed light on the effectiveness of a VR intervention to improve public health outcomes, especially in occupational safety education, where unsafe practices often result in injury and fatality.

Keywords Virtual Reality, Experience of Immersion, Occupational Safety, Agricultural Injury Prevention, Tractor Rollover

Background

Agriculture is one of the most hazardous occupations in the USA.[1] Particularly, transportation incidents are the leading cause of farming-related injuries or deaths.[2] Among agricultural vehicles and machinery, tractors are the main cause of accidental deaths for people living or working on farms as well as farm visitors.[3] News reports on agricultural youth injuries showed tractor-related incidents accounted for about one-third of the vehicle-related injuries and 41.5% of the tractor-related incidents were fatal.[4]

With advances in what is termed 'thin computing technology' and affordability of head-mounted devices,[5] virtual reality (VR) has become a popular approach in the field of public health. VR refers to a technology that presents computer-generated real or simulated environment in which the user explores and manipulates the 3D sensory environments and objects in real-time.[6] When immersed in the VR environment, the user experiences telepresence[7] and behaves similarly when in real life.[8] VR has been applied to diverse eHealth interventions, such as health professions education,[6] physical training,[9] rehabilitation therapy[10] and acrophobia treatment.[11] Meta-analyses have examined the effectiveness of VR interventions in enhancing positive health and education outcomes. These studies have revealed outcomes related to gaining knowledge and cognitive skills;[6] enhancing

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frequency of physical activity and strength of physical performance;[9] improving patients' recovery of physical impairment and activity limitation;[10] and improving the acrophobia symptoms, such as the anxiety and avoidance severity.[11]

VR has been applied to studying human behaviors in the context of safety education as well, especially when it provides the opportunity to have immersive experience of a risky situation that cannot be experienced safely within a classroom or laboratory environment.[12] Thus, VR could provide an innovative solution that prevents tractor-related injury incidents. VR simulates experiences of the real world through mediated processes,[13] which allow developers and researchers to create 3D computer-generated environments in which the actions of users can be immersed.[14] In addition, VR content can often be designed to be more interesting and enjoyable than traditional educational materials.[15] Therefore, if effective, a VR intervention could enhance tractor safety education, as it provides an immersive environment of tractor-related activities in diverse situations without actual risk of injuries.

Although VR has great potential as an occupational safety and injury prevention intervention in terms of both educational effectiveness as well as cost-effectiveness, this technology has been seldom applied to agricultural safety education. Therefore, this study aimed to develop a VR intervention for tractor safety education and to examine its effectiveness as an innovative public health intervention. The effectiveness is tested by investigating the intervention effects on users' perceived threat of tractor rollover accidents and their intentions for adopting safe tractor operation behaviors.

Development of Virtual Realty Intervention for Safety Education

To explore the effectiveness of VR for an intervention for tractor safety education, Virtual Realty Intervention for Safety Education (VRISE) was developed by a multidisciplinary team that included communication, computer science and agricultural education scholars. It is designed for use with a VR headset, but users can operate the virtual tractor without the headset, accessing the simulation by watching the laptop monitor or TV screen connected to the laptop. Unity 2D and 3D software was the application used as the development framework. The Unity application provides default assets, tools and structures used to build own virtual farmscape environment that included several rollover hazards, such as a pond hidden by a hill or sloping terrain and uneven roads (Appendix Fig 1). In addition, our development team obtained other virtual assets such as a tractor, animals and ambient sounds to provide a realistic and immersive experience. The simulation also modified the physics of the tractor parameters (e.g. the center of mass and acceleration of tractor) to make it easier to roll over in areas displayed in the VR environment terrain. A VRISE trial episode in this study took about 2.5 minutes.

VR allows for tailored messaging by incorporating virtual representations of the relatable real world where users can gain knowledge through experience with the help of the virtual transportation of the temporal and physical world.[13,16] In other words, within the immersive VR environment, users can see, hear and feel such realities,[17] and experience the feeling of *being there* through virtual interaction with the objects included in the environment.[18] Thus, immersion into a virtual environment creates a sense of presence which can produce direct experience that would otherwise have to be learned through passive education.[19] For safety education, VR can be a beneficial tool to increase risk perception with vividly immersed experiences of negative health outcomes and provide opportunities to practice preventative behaviors.[20] Considered safety training has been empirically tested to be more effective through direct experiences than passive training,[21] VRISE could make users perceive threats of tractor rollover incidents, as it provides an immersive experience of risky situations that seems very realistic for VR users.

H1: Participants who use VRISE (treatment group) will have higher levels of perceived threat of tractor rollover accidents than those who do not use VRISE ($Control_1$: H1a) and who use VRISE on a 2D screen ($Control_2$: H1b).

Several behavioral theories such as the health belief model (HBM) and the extended parallel process model (EPPM) have proposed the relationship between perceived threat and behavior.[22,23] In both models, perceived threat refers to a construct that combines perceived susceptibility and perceived severity.[22,23] HBM posits that two of the conditions that motivate people to engage in a health behavior are: (i) people believe that their chances of getting a disease or a health condition (i.e. perceived susceptibility) are high and (ii) people believe that the seriousness of getting a disease or a health condition (i.e. perceived severity) is high.[24] Similarly, EPPM posits that when facing a risk, individuals first appraise the perceived susceptibility and the perceived severity of the risk.[23] Although the effect of perceived threat on behaviors depends on other factors such as perceived efficacy, perceived threat is a necessary antecedent for individuals to consider behavior changes.[25]

Several studies have examined if perceived threat is related to occupational safety behaviors across industries. Basil *et al.* found that construction trainees who read high severity and high susceptibility messages had higher intentions to take protective actions in workplace.[26] In addition, occupational

Table 1 Effects of VR intervention on perceived threat of tractor rollover

			95% CI				95% CI	
	B (se)	*t*	*LL*	*UL*	*B (se)*	*t*	*LL*	*UL*
Constant	5.205 (1.250)	**4.164*****	2.741	7.670	4.734 (1.326)	**3.570*****	2.118	7.351
Age	−0.012 (0.073)	−0.164	−0.157	0.133	0.051 (0.077)	0.660	−0.101	0.203
Gender	0.137 (0.200)	0.686	−0.258	0.533	0.302 (0.229)	1.319	−0.150	0.754
Tractor	−0.253 (0.207)	−1.224	−0.660	0.154	−0.486 (0.239)	**−2.031***	−0.958	−0.014
$Treatment_1$	0.292 (0.100)	**2.932****	0.096	0.488				
$Treatment_2$					0.145 (0.212)	0.708	−0.268	0.568
	$R^2 = 0.052$; F = 2.803, $P = 0.027$; $N = 211$				$R^2 = 0.046$; F = 2.148, $P = 0.077$; $N = 184$			

Note: a. $Treatment_1$: $Control_1$ (No Treatment) versus VRISE.

b. $Treatment_2$: $Control_2$ (2D screen) versus VRISE.

Boldface indicates statistical significance (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$).

safety studies found that risk perception, which is closely related to the concept of perceived threat, were positively correlated with safety behaviors such as industrial workers' noise protection behaviors,[27] pilots' safety operations[28] and highway emergency responders' use of protection devices and adherence to safety procedures.[29]

H2: VR group participation (compared to no treatment group) will increase perceived threat of tractor rollover accidents and the heightened perceived threat, in turn, will increase the user's behavioral intention to operate tractor safely (H2a) and install rollover protection structure (H2b).

VR allows users to have an experience of immersion. Immersion engages users to a point that distorts time and results in a heightened sense of engagement,[30] and thus, the use of VR has been studied in conjunction with the understanding of immersion. For example, higher sense of presence, a core dimension of the experience of immersion, has been linked to creating an experience that can create lasting outcomes, such that the priming and the heightened salience from the virtual experiences could result in parallel behavior in a nonvirtual environment.[31] A meta-analysis also found that an increased sense of presence can magnify mediated communication effects such as VR.[32] However, the use of VR has been sparsely investigated for the occupational safety outcomes. Therefore, it would be worthwhile to investigate the roles of experience of immersion for the VR intervention effects on safety education outcomes.

RQ1: Will the experience of immersion mediate the effects of VRISE on perceived threat of tractor rollover accidents (RQ1a) and the user's safety behavior intentions—operating tractor safely (RQ1b) and installing a rollover protection structure (RQ1c)?

Methods

Study design and participants

The study was approved for inclusion of human subjects by Institutional Review Board at the authors' institution. The experiment was conducted at the National Future Farmers Association (FFA) Convention & Expo, which was held at Indianapolis from 30 October to 2 November 2019 with 69 944 attendees. The National FFA is a youth organization that has more than 700 000 members, and >13 000 FFA advisors and agriculture teachers in the USA.[33] The convention provided an ideal environment to recruit the target users of VRISE, young people currently working or planning to work in agricultural industries or farming operations, who would benefit most from VRISE. The experiment was limited to high school students who visited the booth of the Southeast Center for Agricultural Health and Injury Prevention at the convention.

After providing consent, the participants were randomly assigned to one of three conditions: two different types of control groups ($Control_1$: No treatment group and $Control_2$: 2D Screen group) and the treatment group (VR; Appendix Fig 2). Specifically, students assigned to $Control_1$ answered the survey without or before operating VRISE and those who were assigned to $Control_2$ answered the survey after operating VRISE without a VR headset, only watching the 2D TV screen. Participants assigned to VRISE group completed the survey after they operated the VR immersive intervention while wearing a VR headset. A total of 291 high school students participated and received campaign giveaways (e.g. free t-shirts and safety ear plugs) for participation. The mean age of the participants was 15.9 years old (SD = 1.4), and 55.3% of participants were male ($n = 161$). Majority of

Table 2 Indirect effects of VR intervention on behavioral intentions to operate tractor safely and install ROPS

	Effect	*SE*	*Confidence interval (95%)*	
			LL	*UL*
Treatment$_1$ > perceived threat > BI$_1$	0.0894	0.0376	0.0255	0.1742
Treatment$_1$ > perceived threat > BI$_2$	0.1418	0.0556	0.0393	0.2586

Note: a. $N = 211$.

b. Treatment$_1$: Control$_1$ (no treatment) versus VRISE.

c. BI$_1$, behavioral intention to operate a tractor safely.

d. BI$_2$, behavioral intention to install ROPS.

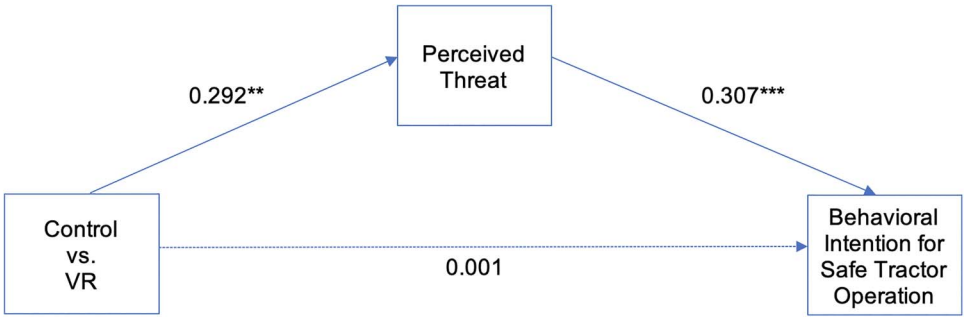

Fig. 1 Perceived threat mediates the relationship between VR intervention usage and safety operation intentions. *Note*: Beta = Unstandardized Coefficients. Boldface indicates statistical significance (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$).

the participants were Caucasian/White ($n = 260$, 90%). About 75.8% of participants' families owned one or more tractors ($n = 219$) and among them 85.8% had prior experience operating a tractor ($n = 188$).

Statistical analysis

First, an ordinary least square (OLS) regression was employed to test both of the VR effects on perceived threat about tractor rollover accidents, compared to the Control$_1$ (No treatment: H1a) and Control$_2$ groups (2D screen: H1b). Age, gender and tractor operation experience were also entered in the regression model to avoid potential confounding effects. Second, the mediation hypotheses (H2 and RQ1) were also tested using the PROCESS model, an OLS and logistic regression path analysis modeling tool, which is based on a Bootstrap approach, a nonparametric technique that makes no assumptions about the sampling distribution of statistics.[34,35]

Measures

Experience of immersion

Participants were asked to indicate their level of agreement on a 7-point scale about the six statements that capture the three dimensions of experience of immersion: sense of presence, flow and cognitive absorption.[30] These six items were only asked of the participants who tested VRISE either on a 2D screen (Control$_2$) or with a VR headset ($\alpha = 0.81$, M = 4.84, SD = 1.37).

Perceived threat

Perceived threat was measured by asking how participants evaluated the severity of tractor rollover accidents (i.e. perceived severity) and their chance of being involved in tractor rollover accidents (i.e. perceived susceptibility) on a 7-point scale (Appendix 3; $\alpha = 0.89$, M = 5.50, SD = 1.40).

Behavioral intentions for safe tractor operation and rollover protective structures installation

Two behavioral intentions were measured for the safety behaviors: (i) safe tractor operation and, (ii) rollover protective structures (ROPS) installation. Participants were asked to indicate on a 7-point scale how much they would agree or disagree with the following statements, 'If I operated a tractor in the *real* world, I would operate the tractor with caution' (M = 6.26, SD = 1.18) and "If I operated a tractor in the *real* world, I would install a Rollover Protection Structure unless the tractor already has it (M = 5.93, SD = 1.54).

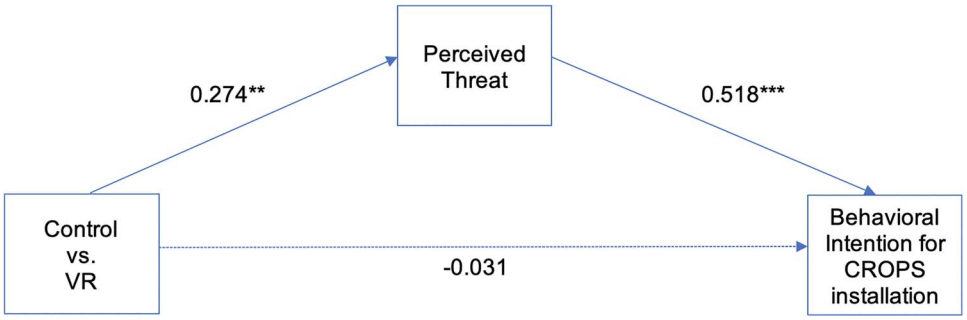

Fig. 2 Perceived threat mediates the relationship between the VR intervention usage and ROPS installation intentions. *Note*: Beta = Unstandardized Coefficients. Boldface indicates statistical significance (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$).

Control variables

Two demographic variables, age (M = 15.9, SD = 1.4) and gender (male = 161, 55.5%; female = 129, 44.3%), and a variable accounting for tractor operation experience, were included in the mediation analyses as controls. Tractor operation experience was measured with a dichotomous item asking if participants had operated a tractor before. Out of 291 respondents, 211 (72.5%) answered that they operated a tractor before.

Results

H1 predicted that participants in the VR group will have higher levels of perceived threat of tractor rollover accidents than those who did not use the VR intervention (H1a) and who used the intervention on a 2D screen (H1b). As expected, people who used VRISE had significantly higher levels of perceived threat of tractor rollover accidents than participants who did not use the VR intervention ($b = 0.29$, se = 0.10, $t = 2.93$, $P = 0.004$). However, there was no difference in perceived threat between the participants who used the intervention with VR headsets and on a 2D TV screen ($b = 0.15$, se = 0.21, $t = 0.71$, $P = 0.480$; see Table 1). Thus, H1a was supported, but not H1b.

This study also examined the mediating roles of perceived threat in the relationship between the VR intervention usage and safety behavioral intentions (H2). As Figure 1 and Table 2 show, the VR condition (versus no treatment) had a significant impact on perceived threat ($b = 0.292$, se = 0.100, $t = 2.932$, $P = 0.004$) and the perceived threat enhanced participants' behavioral intention to operate tractors safely ($b = 0.307$, se = 0.053, $t = 5.816$, $P < 0.001$). The indirect effect test result shows that perceived threat fully mediates the relationship between VR intervention usage and the intention for safe tractor operation (effect size = 0.089, se = 0.038, 95% CI = [0.026, 0.174]). Thus, H2a was supported. Likewise, perceived threat mediated the effect of VR intervention use on behavioral intention to install ROPS (see Fig. 2), as VR intervention usage influenced perceived threat ($b = 0.274$, se = 0.099, $t = 2.759$, $P = 0.006$) and, in turn, the perceived threat increased behavioral intention ($b = 0.518$, se = 0.064, $t = 8.130$, $P < 0.001$). The mediation hypothesis (H2b) was also supported (effect size = 0.141, se = 0.056, 95% CI = [0.039, 0.259]). Notably, however, there were no direct effects of the VR intervention use on safety behavioral intentions to operate tractors safely and to install ROPS.

To provide more compelling explanation about the effects of VR intervention on safety behaviors, this study also examined the mediating role of experience of immersion in the relationships between the VR intervention usage and perceived threat (RQ1a), which eventually influence behavioral intentions to operate tractors safely (RQ1b) and to install ROPS (RQ1c). As Figure 3 and Table 3 show, the VR condition (versus 2D screen) had sequential effects on experience of immersion ($b = 0.441$, se = 0.208, $t = 2.123$, $P = 0.035$) and experience of immersion on perceived threat ($b = 0.297$, se = 0.073, $t = 4.051$, $P < 0.001$) and finally perceived threat on participants' behavioral intention to operate tractors safely ($b = 0.373$, se = 0.064, $t = 5.872$, $P < 0.001$), whereas the VR intervention usage had no direct effects on perceived threat and behavioral intention. Experience of immersion did not influence behavioral intention either. The true indirect effect of the VR intervention usage on behavioral intention via experience of immersion and perceived threat in order was estimated to lie between 0.001 and 0.114 with 95% CI (effect size = 0.049, se = 0.029).

Regarding behavioral intention to install ROPS (see Fig. 4 and Table 4), the VR condition (versus 2D screen) had initial effects on experience of immersion ($b = 0.425$, se = 0.208, $t = 2.044$, $P = 0.042$) and, in turn, experience of immersion influenced perceived threat ($b = 0.297$, se = 0.074, $t = 4.025$, $P < 0.001$) and perceived threat enhanced participants' behavioral intention to install ROPS

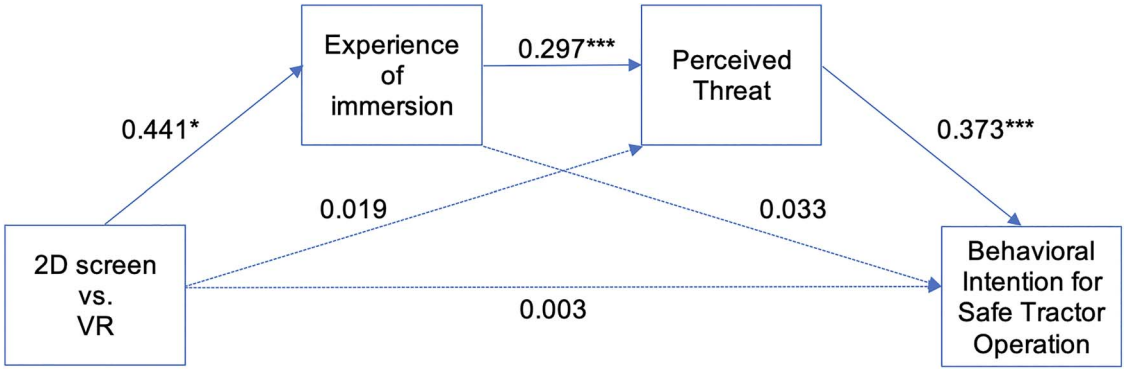

Fig. 3 Sequential mediation effect on safety operation intentions. *Note*: Beta = Unstandardized Coefficients. Boldface indicates statistical significance (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$).

Table 3 Indirect effects of VR intervention on behavioral intention to operate a tractor safely

	Effect	*SE*	*Confidence interval (95%)*	
			LL	*UL*
$Treatment_2$ > Immersion > BI_1	0.0144	0.0287	−0.0449	0.0765
$Treatment_2$ > Threat > BI_1	0.0072	0.0807	−0.1384	0.1848
$Treatment_2$ > Immersion > Threat > BI_1	0.0488	0.0287	0.0011	0.1140
TOTAL	0.0704	0.0858	−0.0855	0.2559

Note: a. $N = 184$.

b. $Treatment_2$: $Control_2$ (2D screen) versus VR.

c. Immersion: experience of immersion.

d. Threat: perceived threat.

e. BI_1: behavioral intention to operate a tractor safely.

($b = 0.379$, se = 0.080, $t = 4.771$, $P < 0.001$). For the ROPS installation behavior, experience of immersion had a significant effect on behavioral intention ($b = 0.262$, se = 0.081, $t = 3.220$, $P = 0.002$), while there were no direct effects of VR intervention usage on perceived threat and behavioral intention. The indirect effect of the VR intention usage on behavioral intention via experience of immersion and perceived threat was statistically significant (effect size = 0.048, se = 0.030, 95% CI = [0.0004, 1208]).

Discussion

Main finding of this study

This study aimed to develop a VR intervention for safety education of tractor operation and test the effectiveness of the VR intervention, as it related to identifying underlying psychological mechanisms that shows how the immersive media technology works in the context of occupational safety. The findings shed light on the psychological mechanisms that the VR system impacts immersion experience and perceived threat, and in turn influences two different types of tractor safety behaviors, safe tractor operation and installation of ROPS, which are equally important to preventing tractor rollover injury events.

What is already known on this topic

Although Krijn *et al.* stated that sense of presence is important in VR interventions,[36] the study of VR and presence remains elusive as the research literature considers it to be vital for experiencing immersion but has not fully defined its effects.[37] In addition, in agricultural context, there is limited research on how perceived threat is related to safety behaviors. One study which tested the relationship between parents' risk perception and their adoption of recommended safety changes to protect their children from farm work risks only found weak correlations.[38] As safety education interventions, VR has been tested in several public health domains, such as safety behaviors on construction sites,[39] fire safety,[40]

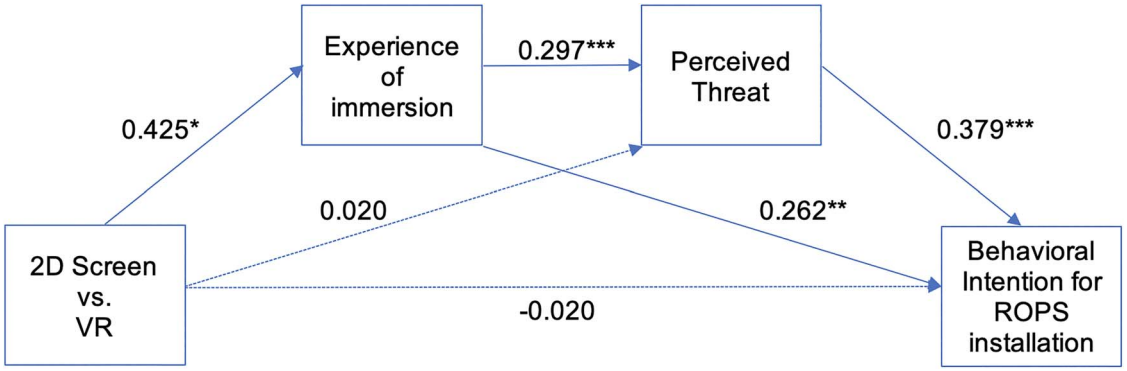

Fig. 4 Sequential mediation effect on ROPS installation intentions. *Note*: Beta = Unstandardized Coefficients. Boldface indicates statistical significance (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$).

Table 4 Indirect effects of VR intervention on behavioral intention to install ROPS

	Effect	*SE*	*Confidence interval (95%)*	
			LL	*UL*
$Treatment_2$ > Immersion > BI_2	0.1113	0.0723	−0.0019	0.2757
$Treatment_2$ > Threat > BI_2	0.0074	0.0841	−0.1488	0.1912
$Treatment_2$ > Immersion > Threat > BI_2	0.0477	0.0303	0.0004	0.1208
TOTAL	0.1664	0.1226	−0.0602	0.4278

Note: a. $N = 183$.

b. $Treatment_2$: $Control_2$ (2D screen) versus VR.

c. Immersion: experience of immersion.

d. Threat: perceived threat.

e. BI_2: behavioral intention to install ROPS.

flooding,[41] vehicle accidents in tunnel situations,[42] and in the training of medical, nursing and clinical profession students.[43] However, it has been seldom tested in the context of agricultural safety behaviors, despite being suggested as an effective tool in health communication studies.[43]

What this study adds

This study examined the direct and indirect effects of a VR intervention on several cognitive and behavioral outcomes, which helps us to evaluate the effectiveness of VR as an agricultural safety education intervention. Specifically, this study empirically showed the mediating roles of experience of immersion between the use of VRISE and changes in behavioral intention. It also confirmed the mediating role of perceived threat not only in the relationship between the VRISE use and behavioral intentions, but also in the relationship between the experience of immersion and behavioral intentions. With these findings from the mediation analyses, we have a better understanding regarding how the VR effects behavioral intention, a key dimension of any safety education intervention. In summary, this study shows the potential of a VR immersion system in safety education and unveils a psychological mechanism of how the VR intervention works.

Limitation of this study

Although the National FFA convention provided a great opportunity to recruit those who benefit from the VR intervention, there are also notable barriers in conducting an experiment. Due to hundreds of students crowded in the exhibition hall where the booth was located, we could not execute random assignment systemically nor measure the time taken for each participant's trial. Although this study included demographic variables and tractor operation experience as control variables, future research needs to test the similar hypotheses under more tightly controlled situations, such as a laboratory experiment. Second, the participants did not receive the same promotional goods for their participation due to the shortage of certain goods, such as t-shirts. Participants did not know what promotional goods they would

receive for their participation, but we cannot completely rule out the effects of different compensation for experimental participation. Third, the participants were restricted to high school students, although VRISE could be effective in other age groups, such as middle school students or even people in their twenties and thirties. Future research should expand the target of VR interventions and test their effectiveness across different age groups. Finally, VRISE presents several dangerous situations that a tractor operator could confront in the farm and open field. It would be more effective if VRISE included more obstacles based on the actual tractor rollover accident reports.

Conclusion

As the availability of immersive media technology advances and the costs become lower, VR intervention is gaining in popularity and available in many domains of our life.[12] The findings of this study imply that VR could play a more important role in agricultural and other occupational safety education applications across industries. In particular, VR provides an immersive experience of risky situations without actual risk of injuries and a cost-effective and sustainable tool for safety education. In conclusion, this study provides a basis to recommend more active adoption of VR and other immersive environments to address the occupational health and injuries problems that often have more serious impact on young workers, the target population of this study. Public health educators and practitioners should consider integrating VR for agricultural and occupational safety programs.

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