Research article

Virtual skills training: the role of presence and agency

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Abstract

Virtual reality (VR) simulations provide increased feelings of presence and agency that could allow increased skill improvement during VR training. Direct relationships between active agency in VR and skill improvement have previously not been investigated. This study examined the relationship between (a) presence and agency, and (b) presence and skills improvement, via active and passive VR simulations and through measuring real-world golf-putting skill. Participants (n = 23) completed baseline putting skill assessment before using an Oculus Rift VR head-mounted display to complete active (putting with a virtual golf club) and passive (watching a game of golf) VR simulations. Measures of presence and agency were administered after each simulation, followed by a final putting skill assessment. The active simulation induced higher feelings of general presence and agency. However, no relationship was identified between presence and either agency or skill improvement. No skill improvement was evident in either the active or passive simulations, potentially due to the short training period applied, as well as a lack of realism in the VR simulations inhibiting a transfer of skills to a real environment. These findings reinforce previous literature that shows active VR to increase feelings of presence and agency. This study generates a number of fruitful research questions about the relationship between presence and skills training.

1. Introduction

Virtual Reality (VR) involves the computer-generated simulation of a three dimensional image, environment or scenario that can be interacted with in a seemingly real or physical way through the use of multiple sensory channels, including visual, auditory and tactile stimuli (Adamovich et al., 2009; Henneberg, 2017). VR platforms allow virtual environments to become interactive and engaging for users as they are more immersive than in past experiments with earlier technologies such as the use of computerized games or television sets (Gorini et al., 2011; Lee, 2004; Slater and Wilbur, 1997).

Immersion in VR constitutes the extent to which the sensory cues of a VR platform replicate real life (Slater, 2003). Continual presence improvement has led to increases in the accessibility and number of practical applications of VR (Juan and Pérez, 2009; Tussyadiah et al., 2018). Originally VR was used primarily for entertainment purposes, however, it is now applied in the field of psychology (Ke and Im, 2013; Peperkorn et al., 2015; Wiederhold and Wiederhold, 2005) for usability testing (Bowman and McMahan, 2007), as well as skills training in a variety of areas including medical, industrial and sporting settings (Chao et al., 2017; Gurusamy et al., 2008; Munz et al., 2007).

When examining VR, user experience can be captured by the construct of presence. The definition of presence is frequently debated, however common themes can be identified within the literature. Presence is the subjective feeling of “being there” within a constructed virtual environment and behaving and feeling as if this mediated environment was the real world (Brade et al., 2017; Sanchez-Vives and Slater, 2005; Slater et al., 2007). High presence in VR enhances user experience in a VR simulation (Cheng et al., 2014). Prior research indicates that task engagement and performance is generally greater when a higher level of presence is experienced (Ogbangwo et al., 2014; Slater et al., 2007), although the specific assessment of use of VR to entrain skills has not been adequately examined with modern technologies. As laboratory studies in VR tend to attract small samples, with few studies incorporating a longitudinal design, our understanding of presence has been limited to short-term post-experience reports.

Numerous variables influence the experience of presence. The fidelity of a virtual environment, that is, how similar the content of the simulation is to the real world, allows for increased believability of the virtual environment, contributing to presence (Schuemie et al., 2001; Slater et al., 1994; Yu et al., 2012). The user's ability to participate in and modify the virtual environment, or their level of interactivity, can also influence presence (Schuemie et al., 2001). Similarly, user engagement, referring to involvement and interest in the virtual environmental content, also contributes to presence (Diemer et al., 2015; Lessiter et al., 2001). Variations in the technical specifications of VR software and hardware also exerts a large impact on the experience of presence. Technical factors include the objective properties of the display, navigation methods, and user interfaces (Lorenz et al., 2015; Witmer and Singer, 1998), as well as visual and audio quality (Bowman and McMahan, 2007). The technical specifications of VR equipment can therefore have an overarching effect on the fidelity, interactivity, and level of engagement of the virtual environment.

In addition to factors that can increase the feeling of presence there are also those that can decrease it. Distracting or low-quality technologies and interfaces reduce feelings of presence (Held and Durlach, 1992). Some VR simulations can also produce negative effects in users, such as disorientation or nausea (LaViola, 2000; Lombard and Ditton, 1997). These effects are more likely to be produced by more immersive technologies and can interfere with the experience of presence. Changes in VR application and software available have also not adequately been regarded in their role of sustaining presence. For example, it is not entirely clear to what extent hardware or software specific attributes are relevant predictors of presence, and whether a straight correlation between “modernity” of technology/software and quality of presence can be presumed.

1.1. Agency and the skills-training connection

A specific aspect of a virtual environment, related to the user's level of interactivity, is whether the simulation provides an active or passive experience. Active VR experiences involve a greater level of participation and interactivity with the virtual environment, allowing higher levels of presence to be experienced as users feel more engaged (Sekhavat and Nomani, 2017). Freeman, Lessiter, Pugh and Keogh (2005), highlighted the difference between active and passive simulations, while demonstrating their influence on presence.

Their study compared two groups of participants that could either actively or passively navigate a virtual environment. The active condition involved participants being able to control their own movements and where they went, whilst those in the passive condition had no control over their movements in the virtual environment.

The ability to actively engage in a virtual environment and control one's actions relates to the concept of agency. Agency is defined as having a sense of ownership and control over one's actions (Friston, 2012; Haggard and Chambon, 2012; Pacherie, 2007). Being able to interact with the environment and control one's movements in active VR scenarios allows this feeling to be developed, even though a person's body is not physically in virtual space (Kong et al., 2017). Kokkinara, Kilteni, Blom, and Slater (2016) found that certain factors assist in generating agency in VR, including (i) viewing the world from a first-person perspective; (ii) being able to move freely and do as one intends within the virtual environment.

An immediately feasible way to invest a VR participant with a sense of agency is to provide them with a goal and the possibility of achieving that goal through self-directed physical movement. This allows for the training of motor skills used in sport a suitable context in which to examine agency in VR. Prior studies have investigated the efficacy of VR in training motor skills such as bowling (Siemon et al., 2009), dart throwing (Tirp et al., 2015) and basketball shooting (Wiemeyer and Schneider, 2012). Using VR to train these skills provides an alternative to in-vivo training potentially provides an enhanced, configurable learning environment, allowing skills to be developed in shorter time periods (Satava et al., 2003). Virtual training also offers other benefits including increased flexibility regarding space or resources, as well as a safe environment to train complex or dangerous tasks (Bowman and McMahan, 2007; Rauter et al., 2013). However, it can be difficult for VR training to improve skills to the same degree as real life or allow these skills to be transferred to a real environment (Tirp et al., 2015; Wiemeyer and Schneider, 2012). Numerous reasons, such as the lack of visual accuracy/realism in VR environments, as well as discrepancies in sensorimotor control, have been mentioned earlier which relate to these difficulties. Examining agency and presence in a training context may identify factors that can improve the efficacy of VR skills training.

VR skills training has proven to be an effective supplement to real life training methods. Studies by Gray (2017) and Lammfromm and Gopher (2011) show that in training baseball batting and juggling, VR training paired with real life training leads to greater skill improvement when compared to real life training on its own. VR alone has not shown strong effects in training real-world motor skills, so paired training programs compensating for deficits in the fidelity of the virtual environment, or for differences in the movements required to perform the targeted skill (Kaber et al., 2014; Zhang et al., 2016). Comparing real-world and VR-based rowing training programs, Rauter et al. (2013) demonstrated that a VR simulation with minimal discrepancies to real life could facilitate skill development to an extent comparable to real life training and transferrable to a real environment.

VR technologies have been speculated to assist in learning and training in various domains, from sports psychology to educational contexts. From a behavioural stance, the mechanism of skills improvement is traditionally measured as an increase in base-level scores. However, a broader definition of skills development must also encompass the application of environment-specific knowledge and psychological predictors such as personal confidence. Whilst the primary aims of VR-based intervention may be to improve one's results at a given task, it is important to consider the role of presence and agency in VR in skills habituation. For instance, a golf player immersed in a golf course simulation may benefit from visuospatial presence of the environment (i.e., an increased comfort with this scenario) prior to the implementation of any scheduled skills-training. The former may have an important performance priming that is not as easily discernible in less-immersive skills training regimens (e.g., watching an expert golf player on a television screen).

Multiple factors enable effective VR motor skills training. How accurately the simulation replicates the real world is one factor, whilst the capability to allow a motor skill to be performed identically in VR as it is in a real environment is the other. These factors are comparable to those shown to positively influence presence (Schuemie et al., 2001). Therefore, facilitating agency and presence in a virtual environment could improve motor skill training outcomes. It should be noted, however, that even if a VR simulation does not allow all motor demands of a skill to be met cognitive aspects of that skill may still be improved, which can contribute to increased performance (Lammfromm and Gopher, 2011). The continued identification of methods for improving VR skills training will assist in this form of training becoming a practical standalone method. Specifically, understanding the relationship between presence, agency, and skills improvement could help shed light on the discrepancies between skills refinement in VR and real-world skills improvement.

This study examined the relationship between presence and motor skills training by comparing active and passive VR scenarios. The motor skill that was the focus of training was putting of a golf ball. The aim of the present study was to examine the relationships between presence, agency, and skill improvement, in both active and passive VR golf-putting simulations. It was hypothesised that (i) the active simulation would induce higher feelings of presence and agency than the passive simulation; (ii) the active simulation would allow greater skill improvement than the passive simulation; and (iii) higher feelings of presence would be associated with higher feelings of agency, as well as greater skill improvement across active and passive simulations.

2. Methods

2.1. Participants

The study comprised 23 volunteers recruited via social media releases and advertisements posted at RMIT University in Melbourne, Australia. The sample consisted of 13 males and 10 females with ages ranging from 18 to 59 years (M = 28.65, SD = 13.15). Ethics approval to conduct this research project was granted by the RMIT University College of Science, Engineering and Health College Human Ethics Advisory Network.

3. Materials

3.1. Hardware

A first-generation Oculus Rift VR head-mounted display (HMD) was used to view the virtual environments. The Oculus Rift is comprised of an in-built screen display, headphones and optional hand-held controllers.

3.2. Application and video

The virtual reality application “Cloudlands VR Minigolf” (developed by Futuretown Inc.) was used to provide the active simulation. The application is geared towards entertainment rather than formal golf training. Despite this, the scenario was deemed suitable as it facilitated the visuospatial mechanics of putting well for the current proposed experiment. Furthermore, the Futuretown Inc. description of the simulation states “Cloudlands uses an intuitive control mapping between the virtual putter and your Samsung GearVR controller to make swinging feel natural, just like swinging a real putter. Expect real-life golf skills to translate into the virtual world” (from the Futuretown Inc. website), which made this simulation amenable to skills-related testing.

A 360° video (https://www.youtube.com/watch?v=J_TfvNIMwL4&&feature=share) involving several adults putting on a golf course putting green was used to create the passive simulation. This video was recorded from a stationary tripod located at the centre of a putting green, allowing participants to observe the putting techniques of other individuals. This video was used to provide a passive VR experience and allow participants to passively experience the skill of putting being performed. Screenshots from “Cloudlands VR Minigolf” can be seen in Fig. 1.

1. Download : Download high-res image (298KB)
2. Download : Download full-size image

Fig. 1. Screenshot from the “Cloudlands VR Minigolf” application.

3.3. Golf equipment

To assess the skill of putting before and after the VR simulations a 7-foot practice putting mat, several golf balls, and a two-way putter were used. The two-way putter allowed both left- and right-handed participants to use the same equipment.

3.4. Questionnaires

Two questionnaire measures were administered to participants. These questionnaires were preceded by a brief series of demographic questions querying participant gender, age, experience with golf, and familiarity with VR technology.

3.4.1. Independent television commission sense of presence inventory (ITC-SOPI)

The shortened version of the Independent Television Commission Sense of Presence Inventory (ITC-SOPI) (Lessiter et al., 2001) is a 12-item measure of subjective presence and was developed from the original 44 item-ITC-SOPI. Participants were asked to respond to questions on a 5-point Likert scale ranging from (Strongly agree) to (Strongly disagree). The ICT-SOPI assesses presence as four factors: (i) spatial presence, a general measure of the participant's sense of being located in a virtual environment; (ii) engagement, which measures participant level of involvement and interest in the virtual environment; (iii) ecological validity, measuring the believability and realism of the virtual environment; and (iv) negative effects, measuring participant's adverse psychological or physiological reactions to VR technology use. The ITC_SOPI has shown adequate internal reliability on each of the four factors (Cronbach's α ranging from .76 to .94), and validity has been established through comparison of scores across different media formats.

3.4.2. Sense of agency rating scale (SOARS)

The Sense of Agency Rating Scale (SOARS) (Polito et al., 2013) is a 10-item measure of the subjective sense of agency. Participants respond to questions on a 7-point Likert scale ranging from ranging from (Strongly agree) to (Strongly disagree). Agency is measured as two factors: (i) involuntariness, subjective experience of a reduction in control in one's own actions; and (ii) effortlessness, subjective experience of the ease with which actions occur. Scores from each factor are combined to provide a total score for subjective agency. To facilitate intuitive comparison with other variables, traditional SOARS scoring was reversed for the present study, so that higher scores indicated greater feelings of agency. The SOARS demonstrates good internal consistency (Involuntariness Cronbach's $\alpha = .91$, Effortlessness Cronbach's $\alpha = .73$), and has been validated through comparison with other measures of agency and has been applied within VR contexts (Pritchard et al., 2016).

4. Experimental

A repeated measures design with counterbalancing was adopted, therefore participants completed both the passive and active VR simulations in randomised order.

Participants performed a baseline skill assessment of putting a golf ball, assessed by the number of putts out of 10 that were successfully hit into the hole using the practice putting mat. Each shot was taken 2 metres directly away from the hole. Following this skill assessment, participants used the Oculus Rift HMD to engage in both the "Cloudlands VR Minigolf" (the active condition), and 360° video (the passive condition) simulations. These simulations were completed in a random order. After each simulation the participants completed the questionnaires in the following order: demographic questions (baseline only), the ITC-SOPI and SOARS. Participants also completed the putting skill assessment after each simulation.

For the active simulation participants used the Oculus handheld controllers to practice their putting skills by interacting with the virtual environment. They were instructed to make their putting action as realistic as possible. Participants spent 10 min using the practice setting in the "Cloudlands VR Minigolf" application.

For the passive simulation, participants were instructed to watch the 360° video and observe the putting done by the individuals displayed. The video lasted 2 min and 50 s. After the first simulation was completed participants would wait 5 min before commencing the next simulation. Results from the putting skill assessments and questionnaires were recorded electronically with no identifiable information recorded.

5. Results and discussion

Table 1 shows the results of the paired samples t-tests comparing mean scores of the presence scales and total agency scores between the active and passive conditions. Assumptions of normality were tested and found to be satisfactory for all variables. Results from the paired sample t-tests showed significant differences in Engagement ($p = .01$), Ecological Validity ($p < .01$), Negative Effects ($p = .01$) and Total Agency ($p = .01$) between conditions. No significant difference was found between conditions for Spatial Presence. This same pattern of results was obtained from a series of Mann-Whitney U tests when using non-parametric testing (seen in Table 2).

Table 1. Paired samples t-tests comparing ITC-SOPI scales, total agency scores and post simulation putting scores between active and passive conditions.

Scale	Active condition	Passive condition	Paired samples t-test	
	M (SD)	M (SD)	t score	p score
SP	4.19 (.37)	3.93 (.56)	1.95	.06
E	4.04 (.77)	3.36 (.92)	2.88	.01
EV	3.09 (1.01)	3.96 (.60)	-3.98	<.01

Scale	Active condition	Passive condition	Paired samples t-test	
	M (SD)	M (SD)	t score	p score
NE	2.71 (.84)	2.03 (.70)	2.81	.01
TA	8.13 (.79)	7.09 (1.59)	2.92	.01
PUTT	3.13 (2.24)	3.43 (2.59)	0.28	.78

Note. Degrees of freedom at 22 for all t-tests displayed. N = 23 for both active and passive conditions. SP = Spatial Presence scale, E = Engagement scale, EV = Ecological Validity scale, NE = Negative Effect scale, TA = Total Agency Scale, PUTT = Post simulation putting scores.

Table 2. Mann-Whitney U tests comparing ITC-SOPI scales, total agency scores and post simulation putting scores between active and passive conditions.

Scale	Active condition	Passive condition	Mann-Whitney U test		
	M (SD)	M (SD)	U score	z score	p score
SP	4.19 (.37)	3.93 (.56)	183.00	-1.84	.07
E	4.04 (.77)	3.36 (.92)	146.00	-2.63	.01
EV	3.09 (1.01)	3.96 (.60)	135.50	-2.86	<.01
NE	2.71 (.84)	2.03 (.70)	128.00	-3.04	<.01
TA	8.13 (.79)	7.09 (1.59)	158.00	-2.35	.02
PUTT	3.13 (2.24)	3.43 (2.59)	250.50	-0.31	.76

Note. N = 23 for both active and passive conditions. SP = Spatial Presence scale, E = Engagement scale, EV = Ecological Validity scale, NE = Negative Effect scale, TA = Total Agency Scale, PUTT = Post simulation putting scores.

A between-subjects ANCOVA was conducted with spatial presence as the dependent variable and Engagement, Ecological Validity, Negative Effects and Total Agency as the covariates. The assumptions of independence between covariates and homogeneity of slopes were satisfied. The ANCOVA showed Spatial Presence scores were significantly higher in the active condition when controlling for the other presence and agency scales, Spatial Presence, F (1, 46) =

6.61, p = .01. Engagement, Ecological Validity and Total Agency were all significant covariates in predicting Spatial Presence, Engagement, F (1, 46) = 9.91, p < .01, Ecological Validity, F (1, 46) = 8.02, p < .01, Total Agency, F (1, 46) = 5.25, p = .03.

Paired samples t-tests revealed no significant difference between the number of puts hit after completing the active (M = 3.13, SD = 2.24) or passive (M = 3.43, SD = 2.59) VR simulations, t(21) = -.68, p = .51. As well as between baseline putting scores (M = 2.57, SD = 2.12) and scores after the active simulation, t(21) = -1.23, p = .23, or passive simulation, t(21) = -.68, p = .51. However, assumptions of normality were violated for the baseline putting scores as well as the post passive and post active simulation putting score variables. To account for this Log10 transformations were applied to these variables. The paired samples t-tests using the transformed variables also revealed no significant difference between the number of puts hit after completing the active or passive VR simulations, t(21) = 0.28, p = .78. This was also done between baseline putting scores and scores after the active simulation, t(21) = -.48, p = .64 or passive simulation, t(21) = -.92, p = .37. The same pattern of results was obtained when using non-parametric testing.

Table 3 shows correlations between the ITC-SOPI presence scales, agency and post simulation putting scores within the passive VR condition. Table 4 shows the correlations within the active VR condition. No significant relationships were identified between Total Agency and any of the ITC-SOPI scales in either condition. There were also no significant correlations identified between post simulation putting scores and any agency or presence scale in either condition. This same pattern of scores was obtained from a series of non-parametric Spearman's rho tests (seen in Tables 5 and 6).

Table 3. Correlations between ITC-SOPI scales, total agency and post simulation putting scores in the passive VR condition.

Empty Cell	SP	E	EV	NE	TA	PUTT
SP	-					
E	.56**	-				
EV	.57**	.35	-			
NE	-.15	-.04	-.20	-		
TA	-.12	.33	.24	-.23	-	
PUTT	-.11	.05	-.07	.001	-.19	-

**p < .01.

Note. N = 23. SP = Spatial Presence scale, E = Engagement scale, EV = Ecological Validity scale, NE = Negative Effect scale, TA = Total Agency Scale, PUTT = Post simulation putting scores.

Table 4. Correlations between ITC-SOPI scales, total agency and post simulation putting scores in the active VR condition.

Empty Cell	SP	E	EV	NE	TA	PUTT
SP	-					
E	.24	-				
EV	.41*	.23	-			
NE	.02	.08	-.43*	-		
TA	-.10	.18	.19	.13	-	
PUTT	-.27	.24	.001	-.06	.08	-

Note. N = 23. SP = Spatial Presence scale, E = Engagement scale, EV = Ecological Validity scale, NE = Negative Effect scale, TA = Total Agency Scale, PUTT = Post simulation putting scores.

*p < .05.

Table 5. Spearman's rho between ITC-SOPI scales, total agency and post simulation putting scores in the passive VR condition.

Empty Cell	SP	E	EV	NE	TA	PUTT
SP	-					
E	.54**	-				
EV	.49*	.30	-			
NE	-.22	-.001	-.43*	-		
TA	-.07	.29	.29	-.21	-	
PUTT	.04	.07	-.06	.04	.03	-

*p < .05. **p < .01.

Note. N = 23. SP = Spatial Presence scale, E = Engagement scale, EV = Ecological Validity scale, NE = Negative Effect scale, TA = Total Agency Scale, PUTT = Post simulation putting scores.

Table 6. Spearman's rho between ITC-SOPI scales, total agency and post simulation putting scores in the active VR condition.

Empty Cell	SP	E	EV	NE	TA	PUTT
SP	-					
E	.45*	-				
EV	.42*	.16	-			
NE	.09	.04	-.47*	-		
TA	-.04	.17	.23	.06	-	
PUTT	-.26	.20	.02	-.07	-.21	-

*p < .05.

Note. N = 23. SP = Spatial Presence scale, E = Engagement scale, EV = Ecological Validity scale, NE = Negative Effect scale, TA = Total Agency Scale, PUTT = Post simulation putting scores.

Practice order effects were examined by using independent samples t-tests to compare active-first and passive-first participants against active-second and passive second participants. These participants were compared on their post simulation putting scores, presence variable scores and agency scores. No significant differences were identified for any variable between participants who completed the active condition first or second. There were also no significant differences identified for any variable between participants who completed the passive condition first or second. A series of Mann-Whitney U tests show this pattern of scores to be the same for non-parametric tests.

Our study examined the association between presence, agency, and skill improvement in both active and passive VR simulations. The results showed that the active simulation induced higher feelings of presence and agency than the passive simulation, supporting the first hypothesis. The second and third hypotheses were not supported, with no significant change occurring in skill improvement following the active simulation, and no significant correlation between presence, agency, and skill improvement in either condition.

Based on prior research, it was expected that Spatial Presence, Engagement and Ecological Validity, and Total Agency would have higher scores in the active condition (Kong et al., 2017; Lessiter et al., 2001). However, the results showed that only Engagement, Negative Effects and Total Agency were significantly higher in the active simulation. As Engagement is an important influence on the overall experience of presence, higher scores during the active condition support our first hypothesis. Higher interactivity in the active simulation would have increased engagement as participants felt more involved (Lessiter et al., 2001). The increase in total agency in the active condition is in accord with past literature that found individuals who had control over their actions in VR developed a sense of agency (Kokkinara et al., 2016; Kong et al., 2017). In the active simulation participants were able to control the actions they performed, allowing a greater sense of agency to be developed than in the passive simulation.

An important finding contradicting the first hypothesis was that Ecological Validity was higher in the passive simulation. Ecological Validity was expected to be higher in the active simulation, reflecting a closer approximation of the process of navigating the real-world environment (Yu et al., 2012). Interestingly, it appears that in the present study, Ecological Validity was more influenced by the photorealistic environment of the passive condition, rather than the polygon-modelled environment of the active condition. This finding suggests that using recordings of real environments may contribute to greater feelings of presence and that animated simulations may restrict the experience of presence. Moving forward, a key challenge for VR technology will be to integrate higher photorealism into its polygonal environments. In these relatively early stages of VR processing power, mapping photographic textures on to the surface of polygons and environment backgrounds may have the capacity to increase presence without sacrificing interactivity.

Higher Negative Effects scores in the active simulation did not support the first hypothesis but were given precedent in existing literature. Prior research has shown negative effects in VR to decrease feelings of presence, presumably as participants are distracted from the virtual environment as their attention becomes focused on their discomfort (Lombard and Ditton, 1997). An obstacle to increasing VR realism is that more immersive VR technologies have been shown to produce greater negative effects (LaViola, 2000). This effect was replicated in the present study, as participants reported more dizziness, disorientation and nausea in the active condition. The negative influence of these variables may also have lowered the spatial presence scores in the active simulation.

The Spatial Presence scale initially showed no significant difference between the active and passive conditions. However, Spatial Presence was significantly higher in the active simulation when the other presence and agency variables were controlled for, providing support for the first hypothesis. This effect highlights the influence that condition alone can have on presence, supporting previous research showing that active VR simulations, with their higher levels of interactivity, allow greater feelings of presence (Freeman et al., 2005; Schuemie et al., 2001). The influence of the other variables on general presence was also noteworthy. Consistent with past research (Lessiter et al., 2001; Schuemie et al., 2001), participant engagement and perception of realism influenced their sense of presence. While increased engagement may have increased feelings of general presence in the active simulation, higher Ecological Validity scores are likely to have had a similar effect in the passive simulation.

The second hypothesis, proposing that the active simulation would allow greater levels of skill improvement, was not supported, as no difference was found between post-simulation putting scores following the active and passive simulations. There was also no difference found between the baseline scores and post-simulation scores for either condition. As participants completed the putting assessment three times it is likely any improvements seen are due to practice effects. Although the active VR condition allowed participants to practice their putting in the virtual environment, skill improvement was not evident. This may be attributable to a lack of realism in the VR (Kaber et al., 2014; Zhang et al., 2016). Discrepancies that may have prevented skill transfer from virtual to real environment include the Oculus controllers not being the same weight as a golf club, and participants not receiving force feedback when they hit the virtual golf ball. As both conditions showed no skill improvement, these findings do not support the argument proposed by Lammfromm and Gopher (2011) stating that VR can improve cognitive aspects of a skill, and that this can be a sufficient precondition for skill improvement. One possibility is that more time was necessary for skill improvement to be demonstrated, as skill improvement becomes more evident when training and observation take place over an extended time period.

Aside from the technologies-specific issues that may have inhibited skills development, the fact that participants only came in for a single session was likely a considerate factor (Gray, 2017). Due to the expensive nature of VR, participants were not able to practice their skills for a longer period due to the methodological limitations of this research. Interestingly, many modern VR studies are limited to single-session exposure due to similar research limitations. However, as newer VR headsets offer more portable options for training and learning, it would be worthwhile to investigate whether participants experience a marked increase in skills development when VR training is applied in the longer term, and with greater consistency (e.g., daily training across several weeks). With the advent of portable technologies, researchers ought to consider the possible benefits of outside-the-laboratory VR training; although researchers will need to carefully monitor any confounding variables and ensure habituation occurs within VR if such an approach is taken in future work.

The third hypothesis proposed that presence would be associated with agency and skill improvement. This hypothesis was not supported. No significant correlations were found between any of the presence variables and agency in either the active or passive conditions. While the Spatial Presence scale and Total Agency tended to be higher in the active simulation, this relationship did not achieve statistical significance. Perhaps the link between presence and agency is not as plausible as may be assumed. Presence items focus on the individual perceiving themselves within the virtual environment (Lessiter et al., 2001), while agency items focus on the perception of controlling one's own actions, and how difficult those actions are to perform (Polito et al., 2013). With this distinction in mind, it is conceivable that a participant may feel engaged and present in the virtual environment, without necessarily experiencing a high sense of agency over their actions. Agency may also be reduced by the participant's awareness that they are entering a manufactured environment, created with implicit expectations and parameters concerning participant actions and reactions. An emerging challenge for VR simulations in both entertainment and training will be to grow participant agency, perhaps by increasing the diversity of experiences and behaviours possible in the environment, even where these are tangential to the designers' expectations for the VR simulation.

Whilst no difference was noted in skills improvement between VR environments, the boarder issue of learning and behavioural entrainment is worth reemphasising here. As participants were immersed in a VR scenario (despite active v passive conditions), there may have been additional benefits gained from taking part in a VR simulation, which we did not measure here. For instance, we were not able to establish whether participants experienced an increase positive affect towards real-life experiences on a golf course after the VR experience, even though we would anticipate that VR immersion can facilitate increased self-confidence towards comparable real-world tasks (i.e., whether a tangible skills gain/loss is apparent). Such factors related to learning more broadly are worth investigating in future work that broadens the narrow band of investigation centred on quantitative skills acquisition and performance improvement.

In light of the findings here, limitations need to be considered. One limitation was that fundamental differences between the two VR simulations may have confounded results. The 360^{o} video was a recording of a real golf course, while “Cloudlands VR Minigolf” was an animated simulation. The simulations also differed in length. These differences between the simulations likely affected participant perception of the two virtual experiences. In order to fully account for these variables, two parallel-form simulations with identical, or at least similar, appearance and duration would need to be created to avoid inconsistent outcomes and possible priming. An additional limitation results from the time participants could practice. Had participants been given an opportunity to take part in numerous trials across a period of weeks, the impact across conditions may have been more evident. On that point, some participants could have been experienced golfers prior to partaking in the experiment, which may have created unnecessary confounding of variables. The inverse is also possible, that participants had never attempted to play golf or minigolf in the past, which may have led to wide individual differences in the data. Future work can address these issues by examining standardised VR scenarios, by implementing a repeat-session design, and by screening participants for skill level during recruitment.

The ability to generalise the VR skills training results must also be considered. While this study's findings show that VR was unable to improve the skill of putting a golf ball, these same findings may not apply to all virtual skills training. Several things must be taken into account including the VR platform used, the skill trained, and length of the training period. Studies that use different VR interfaces or navigation methods or have training periods of a different length may find different results. VR may also be more suitable for training specific skills as these can be performed more realistically in a virtual environment. Due to these inconsistencies in can be difficult to compare VR skills training across studies, and with VR technology and research both in their infancy, it is possible that there are important parameters influencing presence, agency, and training that have yet to even be identified.

The open-ended, generative findings of the present study make it clear that future research is necessary to further understand how presence and agency can enhance skill training within a VR environment. This study's findings add to the existing knowledge base concerning factors influencing presence and agency in VR, and supports previous literature showing that eliciting active participation in VR has the capacity to increase these important elements of the virtual experience. Exploring the relationships between agency, presence, and skills acquisition will become ever more important as the complexity of VR software and hardware evolves to closer meet the demands of real-world performance-graded tasks found in sports psychology and beyond.

Declarations

Author contribution statement

J. Piccione: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

J. Collett: Analyzed and interpreted the data.

A. De Foe: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

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The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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