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From Being There To Feeling Real: The Effect Of Real World Expertise On Presence In Virtual Environments

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Abstract

The emergence of VR as a broadly available consumer technology is driving a renewed need for knowledge on how to enhance presence and design virtual experiences for a broader range of users and use cases that come with VR ubiquity. In prior work, we established an integrative framework for presence expanding the definition from a "sense of being there" to a “sense of feeling real,” which can encompass multiple dimensions of presence and interactions amongst them. Here we investigate the role of variations in three variables on the experience of presence in virtual reality: expertise in real-world activities, interaction ability, and the virtual hand ownership illusion. Through immersing users in a commercially available VR environment that simulates rock climbing and utilizing a mixed methods approach, we provide insight into how individual differences in felt presence arise between users. This new work supports our integrative framework and provides methods by which a broader research and design community can extend it and assess differences in users to support the design of immersive experiences which address the components and underlying determinants of individual differences in felt presence in VR. Our results indicate that there exist relationships between expertise in real world tasks and corresponding activity within virtual environments and underlying components of presence including interaction ability and a virtual hand ownership illusion.

Towards Feeling Real

The ongoing renaissance in consumer-grade virtual reality technologies is expanding the potential scope of use cases for virtual experiences and broadening the range of users that interact with the systems via large-scale availability. This expansion of the VR landscape combined with the proliferation of Internet of Things (IoT) devices, and emerging next generation network standards (e.g. 5G), advance the embedding of virtual and augmented reality into everyday professional, social, and personal contexts. In relation to embodied information behavior, these technologies and their evolving form factors portend a combination of immersion on-demand, immersion on-the go, sensorial augmentation beyond individual physical characteristics, and blended physical/virtual spaces [1]. This embedding of virtuality within contexts ranging from entertainment, gaming, science and medicine, psychology, the arts, news services, education and training, to shopping, dating or other social experiences is transforming everyday activities across cultures and driving a renewed exploration of the nature of presence in virtual environments.

In prior work [2] we established an integrative framework and predictive theory of presence, expanding the definition from a "sense of being there" to a “sense of feeling real,” which can encompass multiple dimensions of presence and interactions amongst them. Recently, Skarbez et al similarly derived a definition of presence as the “perceived realness” of an environment [3], a definition in alignment with our predictive framework. Our model integrates media schemata (MS), described by Ijsselsteijn as “knowledge representations of what media are, and are capable of,” [4] into a predictive processing framework of presence in instances where experience is at least partially mediated. There is evidence to support the positive effect of experience with the mediating technology on presence in virtual environments [5]. As a counterpart to media schemata our framework proposes reality schemata (RS), theorized as mental models of the world that are used to make predictions of the environment. In this “feeling real” framework, it is hypothesized that presence arises from the alignment of these predictions with the attended stimuli in the world. The new work presented here is part of a broader effort to understand the effect of individual characteristics which result in differences in user’s sense of presence.

Related Work

Interaction and Embodiment

Across embodied cognition theories, perceived affordances, as learned through embodied interaction with the world, are embedded within cognitive processes [6]. Perception and presence in effect come about through learning the relationship between actions and outcomes in the form of learned sensorimotor contingencies [7], [8] which align with reality schemata, but are restricted to action. The positive relationship between embodiment within virtual environments and presence has been established in theory [7] and supported empirically)[8]. Supporting intended actions by allowing users to fulfill their intentions as they are informed by the context of the environment is critical to establishing both embodiment [9] and presence [10]–[12]. Part of embodiment within virtual environments is the body ownership illusion [7], which has been shown to affect physical and social behaviors [13] in virtual experiences. Additionally, perceived and experienced interactions within virtual environments are particularly important for spatial presence in virtual environments [14].

Fidelity of Mediated Environments

Fidelity is a construct which describes a virtual environments replication of an operational environment [15]. This is similar to immersion as defined by Slater, as the objective attributes of a virtual reality system in replicating equivalent real-world stimuli [16]. Both of these constructs are objective qualities of virtual environments, separate from user perception of the environment. Unlike immersion, fidelity has many different conceptualizations with nonequivalent, yet related, subcategories [15], [17], [18]. Alexander et al., describe *physical fidelity* as the extent to which a virtual environment replicates the sensorial stimuli of its real-world counterpart and *functional fidelity* as the virtual environment’s ability to replicate the functionality of an equivalent real-world counterpart [15](Alexander, 2005). Physical fidelity is a characteristic of the virtual environment itself, while functional fidelity is the objective replication of the possible interactions within the environment. Functional fidelity is similar to Gibsonian notions of affordance, which describes the possible interactions with an object or environment without conceptual ties to comparisons to real-world equivalences [20].

Not all elements of physical and functional fidelity can be assumed to have equal effects on presence. In a meta-analysis performed by Cummings and Bailenson, stereoscopy and motion tracking were reported as having a greater effect on presence than the quality of visual display [20]. Measuring fidelity is problematic because of the complexity involved in identifying all perceivable elements and interactions within a real-world environment as well as the lack of a comparative real-world environment to measure fidelity to in fictitious environments. Because of this difficulty involved in developing a measure of fidelity, many studies rank the fidelity of multiple virtual environments rather than formulate an objective measure [18], [21], [22]. For example, a monoscopic virtual environment has lower physical fidelity than the same virtual environment with a stereoscopic display, where everything else is held constant; an interaction where a user pushes a button to grab an object has lower functional fidelity than a virtual environment that requires the user to reach out and grab an object, all else held constant. Ranking virtual environments in this way allows researchers to study the effects of fidelity without having to categorize and measure the complexities of visual stimuli and affordances within both virtual environments and their real-world counterparts.

Given the learning component of sensorimotor contingencies and the combined contributions of action, embodiment, and fidelity of mediated environments, the resulting possible interactions upon presence are myriad, complex and potentially difficult to surface and disambiguate. Below we report phase one results from an ongoing study exploring the mediating relationship of interaction, body ownership illusion, and previous experience on presence in virtual environments. These results align with previous studies in the field which demonstrate a positive relationship between the ability to interact within virtual environments [14] and the body ownership illusion on presence [8]. Here we contribute new insights in support of the mediating effect of *expertise* on the effects of the ability to interact and the body ownership illusion. This observational study presents a novel hybrid protocol/method for elucidating the effects of individual user characteristics on presence wherein modifying functional fidelity can act as an intervention that highlights the interactions between experimental conditions and variables.

Methods

To investigate the role of variation in three user characteristics on the experience of presence in virtual reality: expertise in real-world activities, familiarity with mediating technologies, and perceived affordances of user interaction interfaces, we design and implement a mixed methods protocol involving elements for quantitative and qualitative analysis. In this paper we report the preliminary findings from our statistical analysis.

Rock climbing was chosen as the simulated task because the underlying elements of expertise are more readily externalized due to an explicit and generally accepted difficulty scoring system described below. The explicit scoring system in rock climbing offers a proxy measure for participant experience and ability in rock climbing without having to perform controlled training in multiple sessions or complex real-world tasks to measure skill/aptitude. Climbing routes are graded by the difficulty of the physical and technical abilities needed to complete the route. In order to estimate the experience of our participants two North American rock climb grading systems were made commensurate on a similar scale via similarities in the physical and technical abilities required to complete a climb (MEC Cite): the Yosemite Decimal System [23] and the Hueco scale [24] (Table 1). We utilize the highest graded route that our participants report having climbed as an estimate of their expertise with rock climbing.

Grading Equivalency	Yosemite Grading System	Hueco Grading System
0	"Has not climbed/does not know highest climb rating"	
1	<5.9	V0, V1
2	5.10	No equivalent
3	5.11	V2, V3
4	5.12	V4, V5, V6
5	5.13	V7, V8, V9
6	5.14	V10, V11, V12

Table 1: Climb grade equivalency

Participants

This study's sample consisted of 52 participants, ages ranging from 18 to 55 (M=24.10; SD=7.75), of both genders (X=36; Y=16). Recruiting took place over face to face contacts, group announcements, email and flyers posted at a local climbing gym. 27 participants had never climbed before, while 25 had varying levels of climbing experience.

Virtual Environment

The usability of commercial video games in research [25] encouraged us to select the Oculus Rift video game "The Climb" for this study [26]. "The Climb" was chosen because it allows us to use both the Xbox and motion-tracked Oculus Touch controllers in similar virtual environments with similar interactions which form the basis of a low functional fidelity environment (Xbox controller) and a high functional fidelity environment (Oculus Touch controller). Grabbing onto rocks that form holds and alternating hand holds sequentially in order to ascend is the main interaction within the game. Users can also jump, show a suggested path overlay, and revert to the location of the last checkpoint they had reached in the environment in the form of carabiners placed upon the climbing route that trigger an audio signal once reached.

In real-world rock climbing, there are a multitude of techniques that experts use in order to efficiently climb beyond just physical strength. Rock climbing requires as much strength as it does technique, planning/strategy, and balance [27]. Real world climbing also engages the full body - hands are a main part of the activity of climbing, yet feet and body are also significantly engaged. Virtual hands are the conduit for all of the embodied interaction within The Climb, and while hands are an integral part of the real-world climbing experience, virtual feet and body are conspicuously missing in the virtual experience. On a surface level, the game supports the activity of rock climbing, however it does not support some of the more advanced techniques that experts utilize including body movements and grip types [28]. The Oculus Touch controller affords more of these advanced interactions instantiating environments with its use as higher functional fidelity environments.

In condition 1 (C1), the low functional fidelity virtual environment, when using the Xbox controller, users' control the location of their hands and the direction of their jumps with their head position and a series of button presses. In condition 2 (C2), using the Oculus Touch, hand location is determined by motion tracking of the hand-held controllers, and jumping can be performed either by quickly moving hands or through a series of button presses similar to those on the Xbox One controller. Other interactions are the same as the Xbox controller.

Materials

A workstation with an NVIDIA GTX 970, Intel I7-6700K CPU, 16GB of RAM and Windows 10 operating system was used to drive the virtual experience. Screen recording of participants experience in the virtual environment was completed via a Razer Ripsaw capture card. External video and audio was captured using a Logitech HD Webcam C615 throughout the virtual experiences and the semi-structured interview. The participants experience in the virtual environment and video recording was synchronized within OBS [Open Broadcaster Software https://obsproject.com/]. Participants completed questionnaires digitally via mouse and keyboard within Qualtrics.

Measures

Presence was measured using two self-report questionnaires: the IGroup Presence Questionnaire [29] and the Slater-Usoh-Steed Presence Questionnaire [30]. The IGroup Presence Questionnaire (IPQ) is based in the embodied cognition framework of presence wherein 14 items are scored on an anchored 0- to 6-point scale with a maximum value of 84 indicating high presence and a minimum value of 0 indicating low presence. The IPQ also has 3 subscales: Spatial Presence, Involvement, and Realness, as well as a single general question (G1) which load into the total IPQ score. The Slater, Usoh, & Steed (SUS) presence questionnaire is based in Slater's concept of place illusion, the illusion of being located in the virtual environment [30]. The questionnaire contains 6 items rated on an anchored 1- to 7-point Likert scale with a maximum score of 42 indicating high presence and a minimum score of 6 indicating low presence.

Two previously established covariates of presence where measured to control for extraneous factors. The Simulator Sickness Questionnaire (SS) was used to measure simulator sickness due to its negative correlation with presence [31]. The questionnaire contains 16 items rated on a 4 point scale with a maximum score of 64, indicating high simulator sickness, and a minimum of 16, indicting low simulator sickness. The Immersive Tendencies Questionnaire (ITQ) measures the tendency of individuals to become immersed in media [32], and has been shown to be positively correlated with presence in immersive virtual environments [33]. The ITQ contains x items rated on a 7 point scale, with a maximum score of 120 indicating a higher tendency to feel presence.

Additionally, we created an interaction ability questionnaire (InQ), climbing experience survey (CES), and technology experience survey (TES). The InQ assesses participants perceived ability to interact in the virtual environment. The CES is a self-report of real-world climbing expertise and the TES is a self-report of experience with virtual and gaming technology prior to participation in the study. The InQ is designed to measure how participants feel about their ability to interact with the environment. It contains 5 items scored on a 1- to 7-point scale with a maximum score of 35, indicating high interaction ability, and a minimum score of 5 indicating low interaction ability. Additionally, a single question about virtual hand ownership was administered with the InQ, scored in the same manner, but identified as a Virtual Hand Ownership (VHO). Table 2 contains the from questions from the InQ. The technology experience survey is designed to capture the breadth of experience users had had with related devices to the ones used within the experiment. This survey contains 6 questions, about participants prior experience with related controllers, VR devices, and a self-report indicator of knowledge about VR devices. The climbing experience survey measures users prior experience climbing, their climbing confidence, types of climbing they have done in the past, and the highest rated climb they had completed in each climb type prior to participating in the study. The highest rated climb was the only variable used within our analysis (Cexp).

Questionnaire	Question
InQ	I felt like I could adequately interact within the environment.
InQ	In the virtual environment, what I intended to do resulted in an outcome that I expected.
InQ	By the end of the experience, I was confused with how to act within the environment.
InQ	I know how to interact with the virtual environment.
InQ	My intentions aligned with what actually happened within the environment.
VHO	I felt like the virtual hands in the environment were my hands.

Table 2: Interaction ability questionnaire (InQ)

Hybrid Protocol

The experimental procedure did not vary, and was not counterbalanced due to concerns about low power from a reduced sample size. Additionally, providing participants with different orderings of the virtual environments can cause methodological problems because of previous evidence that has shown the relational manner in which participants respond to presence questionnaires, using previous experiences within an experimental design as the basis for answers to questions on presence questionnaires [34].

The experimental design consisted of three parts: in the first section, participants used an Xbox controller to interact with the virtual environment; in the second section, participants used motion-tracked Oculus Touch controllers to interact with the virtual environment; in the third section, the researcher led a semi-structured interview with the participant. The protocol of the first section with the Xbox controller was repeated for the second section with the Oculus Touch controller. For these two sections, the researcher briefed the participant over the interactions with the controller and the Oculus Rift was calibrated for the participant. After calibration was complete, the participant was put in a tutorial environment with the Oculus Rift and the controller type for that section which trained them on the basic interactions that would be used in the experimental virtual environment (T1, T2). A short questionnaire was administered upon completion of the tutorial that included the Simulator Sickness Questionnaire and the Interaction Questionnaire. After the tutorial questionnaire was completed, the participant was then put in the experimental virtual environment for 8 minutes with the controller type for the tutorial they had just completed (C1, C2). After the 8-minute duration had passed, participants were administered a questionnaire consisting of the SS, the IPQ, the SUS, and the InQ. An additional questionnaire was administered at the end of the second section which included the ITQ, the CES and the TES.

Methods for Analysis

Difference score regression can be used as an alternative to panel designs (or mixed effects regression model [35]. There are some necessary conditions that would allow difference scores to be used as outcomes and as predictors in a regression model. The most importance of these conditions are that: 1) The change scores should have low measurement errors; and 2) The correlations of the predictor scores X_{ij} at period one (i.e. T1, C1) are correlated with ΔY_{ij}outcomes in a consistent fashion, as compared to the predictor score correlations $X_{ij}$with the ΔY_{ij}outcomes at period two (T2, C2). In other words, if the correlation of $\Delta Y_{ij}$with X_{ij} is statistically significant and positive at period C2, then the correlations of$\Delta Y_{ij}$with X_{ij}should not be statistically significant and negative at period C1 (and vice-versa). A benefit of the difference score (also called change or gain score) is the relative conceptual simplicity of the design as compared to a mixed effects regression approaches, while inheriting some benefits of a within-subject repeated measures design: i) consistent unmeasured and unchanging explanatory confounder bias is controlled; and ii) instances where errors in the explanatory variables are unchanging and persist over time, drop out [35]. In the present study, the tutorial conditions (T1, T2), climbing conditions (C1, C2), and the two controller types, are experienced by all subjects in a specific sequence (T1-C1-T2-C2). Accordingly, there is a need to account for potential confounding of controller type and the effect of baseline conditions on subsequent change. Some researchers have taken the position that adjustments should be made for baseline scores (or initial status) by including baseline scores as covariates in conjunction with change score predictors. However this approach is not without drawbacks, and can be problematic in practice [35]. As an alternative, we use a "proxy variables" approach to account for the potential confounding of controller type and VR experience on change scores. Proxy variables are measured predictor variables that can be used in place of an unmeasured confounder variable(s). The original confounder variable may unavailable because it is either logically impossible to measure the variable, or is impractical to measure the variable. There are reasonable motivations for not including initial status (T1 and C1 for Y outcomes) as covariates (for in depth discussions [35]). Alternatively, we can include proxy variable(s) in a regression model that controls for increments in change scores, that are correlated with initial status (i.e. C1, T1). This proxy variable should be be correlated with initial status on the Youtcomes, but should not be correlated with the disturbance term in the regression model (error term). For our purposes we use two proxy variables which measure the level of familiarity to controller hardware and virtual reality technology from the technology experience survey (i.e. the variables Controller Sum and VR Sum).

Generalized Additive Regression Models (GAM)

A non-parametric regression approach is used to model ΔYoutcome change scores in relation to ΔX predictor change scores (i.e. an additive regression model using smoothing splines). An important goal in regression modeling is to build a model that predicts the outcome variable with high accuracy, and which has been validated by cross-validation, generalized cross-validation, or an information criterion model selection metric (e.g. AIC or BIC). We use the R package mgcv [36] to fit generalized additive regression models using a generalized cross-validation (GCV) metric to compare and select competing models.

Using first differences in the Y outcomes and X outcomes, a “first differences" (or change score) generalized additive regression model is used to model ΔYoutcomes in relation to ΔX predictors.

The Generalized Additive Model (GAM) with link function g,

$$g[E(\Delta Y|\Delta X)] = \alpha + \sum_j f_j(\Delta X_j)$$

is used to model our ΔYoutcomes as a function of our ΔX predictors. Using smoothing splines with additive models provides a great degree of flexibility in accounting for nonlinear trends in predictors terms and corresponding interaction effects. Smoothing splines allow models to conform to data while balancing the accuracy of the model against potential overfitting on the observed data.

Tensor product spline smoothing of the predictor variables were used to create two variable interaction terms for the regression model. Advantages of tensor product smooths - the different scaling units of the variables that produce the interaction product are taken into account.

We use random forest as an ensemble modeling technique for purposes of variable selection. Random forest regression can be suboptimal when the goal is to estimate and smooth the boundaries of non-linear continuous outcomes. Additive regression modeling with smoothing spline, in comparison to random forest regression, are ideally suited for estimating continuous outcomes predicted by smooth nonlinear functions of continuous predictors. Consequently, we use the random forest ensemble regression method for purpose of variable importance estimation and variable reduction; however, we use the generalized additive model (GAM) regression approach for estimating nonlinear interactions of spline smoothed predictors in predicting the ΔY outcomes. We use the R package randomForestSRC to perform random forest regression [37].

The primary output of nonparametric regression using smoothing splines are: i) the estimates of the predicted $\hat{Y}$ spline-smoothed functions which are conditional on the predictor values (the X_js); ii) the partialed Y-predictions (and partial plots) as a function of the X_js; iii) F-values and their corresponding probabilities values to indicate the statistical significance for the set of spline smoother coefficients which correspond to a given predictor term; iv) the adjusted R-squared, which indicates the degree of fit (or variance accounted for in Y given the predictor set); and v) a generalized cross-validation index which can be used for comparing across candidate models, similar to the use of AIC in other model comparison settings). Unlike parametric regression models (e.g. classical regression), smoothing-spline coefficients are not readily interpretable, and the bulk of the interpretation lies in interpreting the qualitative changes in the regression surface for the Y-partialed predicted values. Our modeling strategy in the present study is to find good two-term interaction predictors that can account for substantial variance in the ΔY outcomes. Interpretation of these interactions are best accomplished by examining the partialed $\widehat{\Delta Y}$ predicted values in a three-dimensional perspective plot, or a multi-panel conditioning plot. These partialed interaction plots represent the partial contribution of the two-term interaction on the ΔY outcome.

Results

The Random Forest variable selection results are presented to the right in Table 3 as well as the GAM results for each outcome variable (Table 4). In this preliminary analysis, we focus on a sampling of patterned significant interactions across these models with a focus on interactions involving climbing experience (Cexp), interaction ability (InQ), virtual hand ownership (VHO), and immersive tendencies (ITQ). Qualitative interpretation of the 3D surface plots of partialed interaction and X with confidence intervals when necessary is performed below.

Relationship between Interaction Ability and Virtual Hand Ownership

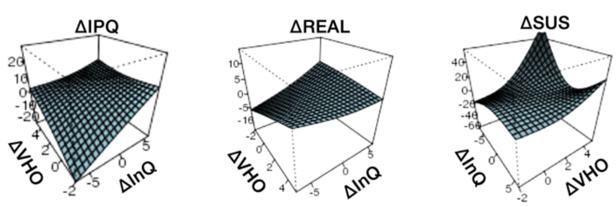

Figure 1: 3D plots of interactions within models (VHO and InQ)

A significant interaction between interaction ability and virtual hand ownership occurred within the GAM models for the IPQ ($p<.01$), the Real subscale ($p<.01$) and the SUS ($p<.01$) The interaction between these two predictor variables is similar between the IPQ (fig x) and Real subscale (fig x) models. The positive correlation between these two predictor variables and the presence score outcomes is strong when scores on the predictor variables is low; however, when a maximal level of either variable is met, the strength of the correlation weakens. When able to interact very well, increasing virtual hand ownership has diminishing returns on increases in presence and vice-versa. The IPQ and Real subscale models differ in the way the correlation changes when maximal levels of either variable is achieved. In the IPQ model, the positive correlation is weakened, while in the Real model, the correlation becomes weakly negative, though the effects of this section of the correlation are marginal. The similarities between these models is sensible because the Real subscale is included within the scoring of the IPQ. Effects within the Real subscale should carry over to some extent if they are not adversely affected by the additional subscales included within the IPQ. The differences in the change in the correlation when maximal levels of either predictor variable is achieved suggests that latent effects may exist within the other subscales included within the IPQ (Spatial Presence and Involvement).

	Δ IPQ	Δ IPQ: G1	Δ IPQ: SP	Δ IPQ: INV	Δ IPQ: REAL	Δ SUS
Climber Expertise	**2.75**	-0.01	**0.00**	**0.16**	-0.30	-0.09
Immersive Tendencies Questionnaire	**3.30**	**0.08**	**0.11**	**2.42**	**0.22**	**0.18**
Controller Sum	**3.29**	**0.06**	**0.77**	-0.11	**0.41**	**0.39**
VR Sum	-0.19	**0.03**	-0.10	**-0.02**	0.00	**0.04**
VR Knowledge	-0.23	-0.01	-0.16	**-0.02**	-0.04	**0.13**
ΔInteraction Questionnaire	**4.74**	**0.13**	**1.78**	-0.07	**0.42**	**4.31**
Δ Virtual Hand Ownership	**5.78**	**0.02**	**2.33**	-0.03	**0.32**	**1.60**
Δ Simulator Sickness	-0.23	-0.01	-0.05	**0.00**	**0.36**	**2.04**
Δ Interaction Questionnaire - Tutorial	-0.73	0.00	**0.10**	-0.22	-0.04	-0.51
Δ Virtual Hand Ownership - Tutorial	**0.92**	-0.01	**0.51**	**0.01**	-0.05	-0.33
Δ Simulator Sickness - Tutorial	-0.99	-0.02	-0.27	-0.12	-0.09	-1.92
% variance explained	13.84	7.36	14.39	5	7.42	11.31
Error Rate	81.94	1.29	16.9	16.61	9.6	27.93

Table3: Random forest variable importances

Within the SUS GAM model, the interaction between interaction ability and virtual hand ownership is quite different from the IPQ and Real subscale. Consistent with the IPQ and Real subscale, the SUS model shows the least amount of presence at the lowest levels of interaction ability and virtual hand ownership. Unlike the other models with this interaction, the SUS model indicates that participants feel most present when interaction ability is low and virtual hand ownership is high. Additionally, at low virtual hand ownership there is a weak positive correlation with interaction ability and when virtual hand ownership is high there is a strong negative correlation with interaction ability that turns into a weaker positive correlation with interaction ability at middling levels of interaction ability. This could be an artifact of utilizing change scores in this specific interaction. From this perspective, it is possible that within the SUS, barring the negative correlation with interaction ability at high levels of virtual hand ownership, the SUS model would align with the models generated for the IPQ and Real subscale. However, this interaction cannot be ignored and does merit future research to further explain these results.

Model	Variable 1	Variable 2	edf	Ref.df	F	p-value
IPQ	Climber Expertise	ΔInteraction Questionnaire	4.17	5.64	5.64	<.01*
	Climber Expertise	Immersive Tendencies Questionnaire	1.75	2.07	5.28	<.01*
	Controller Use	-	1.00	1.00	5.18	<0.05*
	Immersive Tendencies Questionnaire	Δ Virtual Hand	2.70	2.91	2.73	0.07
	ΔInteraction Questionnaire	Δ Virtual Hand	2.03	4.00	2.46	<.01*
	VR Use	-	1.47	1.71	0.39	0.69
	Climber Expertise	Δ Virtual Hand	1.00	1.00	0.18	0.68
	R-sq. (adj)	.623				
IPQ: G1	Immersive Tendencies Questionnaire	ΔInteraction Questionnaire	1.00	1.00	4.85	<0.05*
	Immersive Tendencies Questionnaire	Δ Virtual Hand	2.87	4.00	3.59	<.01*
	Controller Use	-	1.00	1.00	2.51	0.12
	Climber Expertise	Δ Virtual Hand	3.43	3.72	2.12	0.09
	Climber Expertise	ΔInteraction Questionnaire	1.67	1.97	0.58	0.52
	VR Use	1	1.00	1.00	0.35	0.56
	Climber Expertise	Immersive Tendencies Questionnaire	1.00	1.00	0.03	0.87
	R-sq (adj)	.391				
IPQ: SP	ΔInteraction Questionnaire	Δ Virtual Hand - Tutorial	5.00	5.00	9.84	<.01*
	Climber Expertise	ΔInteraction Questionnaire	1.00	1.00	7.61	<.01*
	Climber Expertise	Δ Virtual Hand	3.79	3.95	6.88	<.01*
	Controller Sum		1.89	1.99	5.66	<.01*
	Δ Virtual Hand	Δ Virtual Hand - Tutorial	5.65	5.91	4.97	<.01*
	VR Use	-	1.00	1.00	0.21	0.65
	R-sq (adj)	.753				
IPQ: INV	Climber Expertise	Immersive Tendencies Questionnaire	4.37	4.76	4.04	<.01*
	Controller Use	-	1.00	1.00	3.19	0.08
	VR Use	-	1.17	1.31	0.07	0.88
	R-sq (adj)	.225				
IPQ: REAL	Δ Virtual Hand	ΔInteraction Questionnaire	3.21	3.38	5.02	<.01*
	Controller Use	-	1.00	1.00	4.53	<0.05*
	Immersive Tendencies Questionnaire	Δ Simulator Sickness	4.39	4.75	3.36	<.01*
	Immersive Tendencies Questionnaire	ΔInteraction Questionnaire	1.34	4.00	1.84	<.01*
	VR Use	-	1.12	1.23	0.36	0.53
	R-sq (adj)	.521				
SUS	ΔInteraction Questionnaire	Δ Simulator Sickness	5.00	5.00	8.01	<.01*
	Controller Use	-	1.00	1.00	7.61	<.01*
	Δ Virtual Hand	VR Knowledge	4.13	4.55	6.16	<.01*
	Δ Virtual Hand	Δ Simulator Sickness	2.89	2.98	3.90	<.01*
	VR Knowledge	Δ Simulator Sickness	1.26	4.00	2.01	<.01*
	VR Use	-	1.00	1.00	1.60	0.21
	ΔInteraction Questionnaire	Δ Virtual Hand	3.79	4.00	13.38	<.01*
	R-sq (adj)	.783				

Table 4: All GAM interactions. Green interactions covered below.

Relationship between Climbing Experience and Interaction Ability

There was a significant interaction between the Igroup presence questionnaire (p<.01) and the spatial presence subscale (p<.01). The interaction between climbing experience and interaction ability is similar in the GAM models for both the IPQ and the SP. The strength of the positive correlation between interaction ability and the outcome variable was dependent on climbing experience. The positive correlation between interaction ability and the outcome variable strengthens as a function of increases in climbing experience. However, in the IPQ, the constant of this correlation is also altered as a function of climbing experience so that at maximal levels of interaction ability outcome variable scores are approximately equivalent. In effect, climbers are only discernibly different from non-climbers in IPQ scores when interaction ability is low wherein we predict experts would be more adversely affected in presence scores on the IPQ.

providing evidence that as experience grows the functional fidelity of the environment becomes more important to individuals with experience in the specialized task.

There are many possible explanations to the differences in the effect of climbing experience on the correlation between interaction ability and presence score outcomes on the IPQ and the Spatial presence subscale. This difference might be attributable to the differences in sensitivity of the IPQ and the Spatial presence subscale. Since the spatial presence subscale is included within the calculation of the IPQ, latent factors on this relationship in the other subscales included within the IPQ might be affecting this relationship.

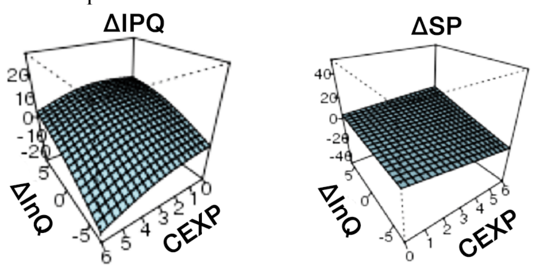

Figure 2: 3D plots of interactions within models (InQ and CEXP)

Relationship between Climbing Experience and Virtual Hand Ownership

A significant interaction between climbing experience and virtual hand ownership existed amongst both the single general question for the "sense of being there" (p<.07) and the Spatial Presence (p<.01) subscales of the IPQ. For the "sense of being there" (G1), at low levels of climbing experience, virtual hand ownership has little effect on presence score outcomes, while at increasing levels of climbing experience a strong positive correlation arises between interaction ability and presence score outcomes. This suggests that for people with less experience within the simulated task, virtual hand ownership is less important in establishing a sense of being there, while for those with experience in the simulated task, feeling as though the virtual hands presented to them were there hands was integral to the feeling of "being there."

In SP the relationship between climbing experience and virtual hand ownership, climbing experience seems to be a less effective determinant in the strength of the correlation between virtual hand ownership and spatial presence. Across all levels of climbing experience there is a strong positive correlation between virtual hand ownership and spatial presence score outcomes. This positive correlation is relatively unchanged by climbing experience unlike G1, suggesting that virtual hand ownership is equally important in establishing Spatial Presence regardless of experience in the simulated task.

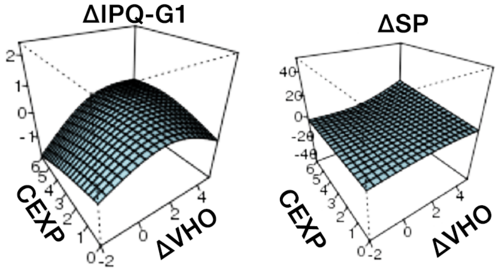

Figure 3: 3D plots of interactions within models (VHO and CEXP)

Immersive Tendencies and Climbing Expertise

The GAM models for the IPQ (p<.01) and its Involvement subscale (p<.01) show inverted interactions between immersive tendencies and climbing experience. In the Involvement subscale, at higher levels of immersive tendencies, involvement is negatively correlated with climbing experience. This negative correlation with climbing experience is mirrored in the IPQ were the interaction occurs at low levels of the ITQ. In the involvement subscale, there are clear differences at every level of climbing experience between the high ITQ and the low ITQ group, while in the IPQ model, similar scores were achieved across the IPQ at low levels of climbing experience

In the Involvement subscale at higher immersive tendencies, climbing experience are correlated with higher presence scores. As climbing experience increases while having high immersive tendencies, presence is reduced. As climbing experience increases and immersive tendencies are low, presence slightly increased, though the effect is negligible relative to the negative correlation between high immersive tendencies and climbing experience in involvement outcomes.

In the IPQ GAM model we see a different relationship between immersive tendencies and climbing experience. At high immersive tendencies, climbing experience has little effect on presence score outcomes, while at low immersive tendencies, presence is negatively correlated with climbing experience. Put differently, while having high immersive tendencies, experience in the simulated task has little effect on presence. Conversely, having low immersive tendencies, greater experience in the simulated task adversely affects presence.

These models indicate that involvement is affected by immersive tendencies and at high levels of immersive tendencies, a negative correlation occurs between involvement and climbing experience. This effect seemingly does not carry over to the overall IPQ, which the Involvement subscale in factored into. Instead climbing experience is negatively correlated with presence for individuals with low immersive tendencies.

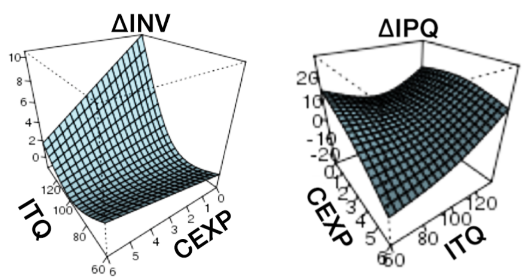

Figure 4: 3D plots of interactions within models (CEXP and ITQ)

Interpretation of Results

- Climbing experience (CEXP) increased the positive correlation between:
  - Interaction ability (InQ) and presence (IPQ)
  - Interaction ability (InQ) and spatial presence (SP)
  - Virtual hand ownership and the "sense of being there" (G1)
  - Virtual hand ownership and spatial presence (SP)

Our general hypothesis was that climbers would experience less presence within the virtual environments relative to non-climbers. Instead, when combined these results suggest that climbing experience shapes the way that *interaction ability* and *body ownership* (as indicated by virtual hand ownership) lead to felt presence. Across all modeled interactions involving climbing experience and virtual hand ownership or interaction ability, climbing experience strengthens the existing positive correlation with the corresponding presence measure, while reducing the constant. Individuals with more experience in the real-world equivalent to the simulated task are more negatively impacted by feeling an inability to interact or a lack of virtual body ownership relative to individuals with less or no experience in the real-world task. Put simply, our results suggest that interaction ability and felt virtual hand ownership are more important in establishing presence for experts, than for novices, within a simulated task of their field of expertise. When viewed in the context of theoretical conceptions of learned sensorimotor contingencies, the difference in the perception of the functional fidelity of the environment (according to degrees of expertise) may be the causal element that results in the difference in the effects of mediating factors on presence.

These results align with those of Regenbrecht & Schubert [14], which found that perceived and experienced interactions within virtual environments enhance a sense of spatial presence. In a practical sense, experience with the real-world counterpart to the simulated task should manage expectations, similar to the manipulation of expectations performed within the aforementioned study. Although interaction ability is not the same as perceived and experienced interactions, they fall within the same theoretical construct of sensorimotor contingencies. We found that the relationship between spatial presence and interaction was partially dependent upon prior experience with a real-world activity displayed within the virtual environment.

Previous research supports a positive relationship between the body ownership illusion and presence [8]. Our findings uphold this relationship between these variables as a positive correlation. They suggest that this association may be partially dependent on experience in real world activities when presented within a virtual environment. These also suggest a lack of virtual body ownership more negatively impacts individuals with greater degrees of expertise with the real-world counterpart of the activity in the virtual environment.

Discussion and Future Work

In this work, we present a hybrid protocol wherein the manipulation of functional fidelity and the IPQ measure are effective tools for uncovering relationships that exist with interaction ability and the body ownership illusion.–Specifically, the IPQ is based in embodied cognition frameworks, and functional fidelity can serve as an objective difference in the interactive affordances within a virtual environment, and therefore, combined they provide a hybrid method for elucidating the underlying contributions to presence.

Rock climbing is an activity with an embedded measure of expertise and ability that is widely used and accepted within the community. The externalized grading system in this activity allows effective and quick approximate quantification of expertise. Given the emerging increase in use scenarios for virtual reality technologies it is reasonable to anticipate that an ever-larger set of activities will be simulated within virtual environments. These activities will exist along a continuum of requirements for emulation of real world physical interaction - some activities may be more abstract than others. Measuring expertise is often difficult in activities that involve tacit expertise. To enhance the generalizability of our findings to this broader set of virtual user scenarios, and given that there are not universal measures of expertise for any and all real-world tasks, our future studies will integrate presence measures with physiological and behavioral analysis. Of particular interest is the effects of expertise in real-world activities that parallel abstract or fantastical activities in virtual environments to understand the potential applications of the findings presented in this study to a broader range of virtual reality use cases.

As a further step towards generalizability of our findings, we are working on a complete analysis of the behavioral observations and interviews of the participants within this study. Our goal is to contextualize our quantitative analysis of questionnaire data with information from participant observation videos and semi-structured interviews utilizing code schemas developed to represent both action-based and semantic content that enables us to model the relationship between expertise and presence. We are interested in how knowledge structures, in the form of reality schemata, are applied to the perception of the environment.

We believe that further understanding how individual characteristics lead to naturally appearing differences in felt presence within virtual and augmented environments is important for the ethical design and application of virtual and augmented reality into everyday life as proposed.

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