How Immersive is Enough?: A Foundation for a Meta-analysis of the Effect of Immersive Technology on Measured Presence

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Abstract

A common assumption guiding research in virtual environments is that increased immersion (i.e., technological affordances) permits improvements in performance or engagement, with this effect mediated through user experience of "presence". However, the literature on the relationships between immersion and user presence is complex, with empirical studies focusing on different immersive system features, employing various designs, and yielding mixed results. In this paper we present the initial qualitative work required for conducting a subsequent quantitative meta-analysis investigating the relationship between immersion, presence, and performance. We first review the theoretical relationship, then present the rationale for such a meta-analysis. In the latter portion of the paper we offer a foundation on which this analysis can begin, initially focusing on the effects of various immersion components on self-reported levels of presence. We also provide a collection of previous studies that empirically examine the influence of various immersive system components on self-reported presence. Our future work will employ this list to conduct the quantitative phase of the meta-analysis.

Keywords--- **immersion, presence, meta-analysis**

1. Presence and Immersion

The concept of *presence*, or a sense of "being there," is a frequently emphasized factor when discussing virtual environments (VEs). Indeed, the assumption that achieving presence should be a goal of the design of VEs pervades both applied and academic work with such environments. An increased sense of presence is often thought to magnify user effects (e.g., the extent to which user responses to virtual stimuli and virtual interactions resemble parallel responses to "real world" counterparts) and, in turn, to increase the effectiveness of VE applications (e.g., the practical use of such environments as tools for learning, training, or therapy).

Over the last twenty years researchers have defined and explicated the concept of presence in a number of different ways (Heeter, 1992; Lee, 2004; Slater and Wilbur, 1997; Witmer and Singer, 1998; Lombard and Ditton, 1997; Steuer, 1992; McMahon, 2003). Notably, in their conceptualization of presence, Slater and Wilbur (1997) distinguish it from another related concept – immersion. Slater and Wilbur suggest that presence in a VE is inherently a quality of the *user's psychology*, representing the extent to which an individual experiences the virtual setting as the one in which they are consciously present. On the other hand, *immersion* can be regarded as a quality of the *system's technology*, an objective measure of the extent to which the system presents a vivid virtual environment while shutting out physical reality. By this account, the technological level of immersion afforded by the VE system facilitates the level of psychological presence. This relationship has implications, then, for how one might operationally design for increased presence.

Slater and Wilbur note that a system is more likely to be immersive – or to shut out physical reality – if it (1) offers high fidelity simulations through multiple sensory modalities, (2)

finely maps a user's virtual bodily actions to their physical body's counterparts, and (3) removes the participant from the external world through self-contained plots and narratives. Such features are thought to make the interface of the system more transparent, permitting the user to then become psychologically engaged in the virtual task at hand rather than attending to the input mechanisms themselves. That is, the more immersive the system, the more likely an individual will feel present within the *virtual* environment, and the more likely that the virtual setting will dominate over physical reality in determining user responses.

2. How Immersive is Enough?

The rationale provided by Slater and Wilbur would suggests that systems of higher immersive quality may elicit greater psychological presence and, in turn, generate stronger effects across a number of secondary user measures, including performance on various tasks (Slater, Linakis, Usoh, & Kooper, 1996; Bowman and McMahan, 2007). As such, we might conclude that a designer seeking to maximize the applied effectiveness of a VE simulation should construct the most advanced, technologically immersive system possible. Processors with faster update rates; tracking devices with finer scales and less cumbersome instruments; head mounted displays (HMDs) with wider fields of view (FOV); stereoscopic visuals and surround-sound; avatars with photo-realistic faces, expressions and clothing – all of these features are expected to cause, under this model of presence, matching gains in a user's performance on virtual tasks.

Inclusion of all of the above features can, however, also come with certain costs. First there is the very real financial expense, as such features can cost a considerable amount of money – money that may seem wasted when new technologies come out an increasingly short time later, with finer tracking, faster updates, or wider fields of view. Second, there is the pragmatic issue of usability (Blascovich & Bailenson, 2011) – high immersion hardware often correlates with higher cumbersomeness and calibration requirements, for both the user (e.g., heavy equipment, placement of body markers) and the researcher (e.g., acquiring and arranging dedicated spaces). As such, the theoretically-driven push for the most advanced system is often balanced by practical restriction (Bowman & McMahan, 2007). Individuals constructing virtual environments and wishing to get the biggest "bang for their buck" may find themselves asking "How immersive is enough?" Does the return on investment plateau after a particular FOV angle or with a particular update rate? Does the immersion conferred by a system with both stereoscopic visuals and surround sound lead to significantly greater effects than that of a system with only one or the other? In other words, how much benefit does the newer or additional technology really add to your VE's effectiveness?

3. Quantifying the Benefits of Immersive Quality

The literature on VEs does not readily provide a straight-forward answer to the questions posed above. First, the empirical literature contains conflicting results. A number of studies have empirically demonstrated a positive relationship between immersion and various performance measures, including of search ability (Pausch, Proffitt, & Williams, 1997), recall (Lin, Duh, Parker, Abi-Rached, & Furness, 2002), and spatial judgments (Slater, Linakis, Usoh, & Kooper, 1996). However, there are indeed also cases that fail to find a positive relationship between immersion and performance(e.g., Narayan et al., 2005; McMahan, Gorton, Gresock, McConnell, & Bowman, 2006; Polys, Kim & Bowman, 2006). Again, the underlying assumption is that immersion begets presence, which in turn begets performance gains. Interrogating this process in which immersive quality indirectly influences performance, Slater and colleagues (1996) suggested that immersion's effect on performance is indeed due to relative increases in experienced presence, but they also note that this effect should only be expected for virtual tasks in which more "natural" reactions are advantageous. This proposed moderation may explain some of the varied results in the literature. Such a theoretical framework is similar to that offered by Bowman and McMahan (2007), who suggest that multiple "immersion component" technologies independently influence a variety of potential "immersion benefits," including presence, which in turn independently influence application effectiveness and performance.

Second, in cases where the data *do* suggest that better technology leads to greater presence and stronger user effects, the findings are often not contextualized by fine gradients of immersion. For example, a given study may include "High" and "Low/No" immersion conditions operationalized in terms of whole systems, for instance, an IVE vs. a desktop. Although this is helpful for comparing the relative immersive quality of a system as a whole, it does not lend itself to isolating and examining a specific feature or dimension, such as tracking level or field of view. Further, when studies do explicitly test the relative contribution of a given immersive technology, they often use binary levels of that feature (again, high and low states) rather than multiple gradients. Notable but rare exceptions include Lin et al. (2002), and Duh et al.(2002), in which the authors considered four and six different fields of view, respectively. Given these trends, many feature-specific studies still do not tell us whether a "medium" level of that feature would yield the same effect as a higher level, or if a "high+" level would grant an even stronger effect. That is, though the operationalizations of a single study may allow the researchers to conclude that *something* is better than *nothing*, they often lack the degree of granularity needed to provide more precise conclusions about the nature of the effect. What we find then is that the existing literature as a whole does not clearly provide a picture of the relative impact of different immersive technologies on presence and performance. Some studies find statistically significant effects while others do not. Further, when an effect *is* observed, its magnitude may vary across different studies or different dependent variables. Moreover, the nature of such an effect (linear, exponential, quadratic, etc.) may be difficult to ascertain through the operationalizations of a single study. Simply put, a basic review of the existing literature does not itself permit researchers to confidently conclude that newer, faster, multi-modal immersive systems are always significantly more effective than older, slower, simpler ones.

Again, a review of the literature on immersion, its direct effects on presence and its indirect effects on performance indicates there to be some variety in the effects observed, the particular immersive components examined, and the designs in which they were investigated. In such a situation, a formal meta-analysis can lend insight into the general direction and size of any actual effect. Indeed, the procedures comprising a meta-analysis can help to "address the challenges introduced by the existence of multiple answers to a given question" (Rosenthal & DiMatteo, 2001, p.61). The quantitative steps for combining results across a corpus of studies not only permit researchers to gain a more holistic estimate of the effect in question, but can also provide insights into inconsistencies through the discovery of potential moderators and mediators (Rosenthal & DiMatteo, 2001; Rosenthal, 1991). Such an analysis would permit researchers a more nuanced characterization of the effects of immersive technology components, allowing us to tease out the relative added value of a given feature and to examine if that value added is a linear function or one of diminishing returns. In other words, by compiling the various operationalizations of immersion and their observed effects on different dependent measures, a meta-analysis can better inform researchers and others investing in VEs as to what technology is enough for their particular projects and for optimizing return on investment.

As noted above, in investigating the relationship between immersion and virtual task performance, a number of researchers have suggested the effect is composed of two component causalities: 1) increases in immersion components leading to greater presence and 2) increases in presence in turn leading to improvements in performance. For the purpose of our proposed meta-analysis, we intend to gauge the overall effect size of the first of these – the effect of immersion on presence. That is, in Bowman & McMahan's terms, we seek to see how various components influence one particular immersion benefit, presence. We have selected this initial focus on just one of the two general causalities outlined above for pragmatic reasons. First, determining the relative effect of individual immersion components (FOV, tracking level, etc.) on presence requires *a separate meta-analysis* for each independent variable of interest. Second, for our purposes, the need to investigate the effect of presence on performance is contingent upon whether immersion components are found to predict levels of presence. That is, if a significant effect size is found for the first link in the causal chain (the influence of immersion on presence), it would then be appropriate to consider the second link (the influence of presence on performance). If a significant effect size for the first link is not observed, future efforts might be better allocated towards reconsidering the presumed relationships between immersion, presence, and performance.

4. Basic Steps in a Meta-Analysis

Rosenthal & Dimatteo (2001) outline six general steps to performing a meta-analysis:

1. Define the independent and dependent variables of interest.
2. Systematically collect relevant studies.
3. Examine the variability among obtained effect sizes.
4. Combine the effects using several measures of their central tendency.
5. Examine the significance level of the indices of central tendency.
6. Evaluate the importance of the obtained effect size.

With these steps in mind, a meta-analysis can be considered to have two general phases. The first phase (steps 1 and 2) is essentially qualitative and descriptive, in which pertinent studies and results and collected and organized in light of variables of interest. The second (steps 3-6) is fully quantitative, in which all actual statistical procedures are conducted to produce overall findings. At present, our project is confined to the first, more qualitative phase. The purpose of this paper, in additional to outlining the need and rationale for a meta-analytic approach to investigating "how immersive is enough," is to share our collected list of candidate studies as a platform from which other researchers may draw or to which they may further contribute and refine. Below we describe the process by which we defined variables of interest and gathered candidate studies.

5. Variables of Interest

A meta-analysis of the effect of immersion components on presence first requires identifying the various technology features or manipulations thought to add to a system's immersive character. To compile such a list, we conducted a literature review to identify the most commonly investigated features. This review included a search through the full journal archives of *Presence: Teleoperators: and Virtual Environments* and *CyberPsychology & Behavior*, as well as the full proceedings archives of the International Society for Presence Researchers annual conference. A primary list of candidate studies included those that investigated the manipulation of at least one component of immersive system technology and any dependent measure of presence (including "presence", "telepresence", "spatial presence", or "social presence"). Additional candidate studies – spanning proceedings for the Institute of Electrical and Electronics Engineers (IEEE), the Association for Computing Machinery (ACM), and ACM's Special Interest Group on Graphics and Interactive Techniques (SIGGRAPH) conferences; various journals related to human-computer interaction, human factors design, and communication science; and unpublished manuscripts – were then identified by back-referencing the citations included in studies from the primary list. We also completed a search via Google Scholar of all authors of studies included on the primary list. Additionally, we attempted to contact all authors (whenever a current email address was available) with requests for any additional relevant works, published or unpublished.

For the sake of internal validity, we decided that initial analyses should be restricted to studies in which presence was measured through self-report. Although there is compelling reason to suspect the most promising measures of presence are not self report (e.g., Slater, 2004; Bailenson, Aharoni, Beall, Guadagno, Dimov, & Blascovich, 2004), an initial assimilation of the behavioral, cognitive, and physiological measures were too disparate to meet the standards of a meta-analysis which combines like dependent variables. However, in future work we plan to attempt qualitative assimilation of these other constructs. Reducing the pool of candidate studies in this manner has resulted in the list of studies included in Table 1. The common, modal independent variables from these studies permit us to examine the relative effect of a number of common immersive technology features, primarily related to hardware and, to a lesser extent, software. These studies are presented in Table 1, clustered within particular immersive features (represented by shaded groupings within table). These features include[1]:

- *Tracking level.* Tracking level refers to the number and types of degrees of freedom with which user input is tracked by an immersive system. Manipulations of this feature include the input method (natural movement-tracking vs. abstract controller of some type), and the relative level of tracking included (relative number of degrees of freedom [DOF]).
- *Stereoscopic vision.* A commonly discussed feature, this refers to whether a given system provides the user with monoscopic or stereoscopic visuals.
- *Image quality.* This composite variable considers a number of elements that influence the general quality, realism, and fidelity of visuals provided by an immersive system. Manipulations of this feature include high vs. standard definition resolution, flickering rates, lighting types, texture mapping quality, and general level of detail.
- *Field of view.* Another feature often presumed to relate to presence, field of view (FOV) refers to the relative field of the user's view within which the environment's visuals extend. This feature is commonly manipulated through blinders or the screen size of a head-mounted display (HMD). It is worth noting that, for the sake of our analyses, this variable will also include studies in which television or computer screen sizes were manipulated yet screen resolution and viewing distance were held constant (in effect actually altering the relative field of view of the user).

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[1] Studies manipulating the use of tactile feedback were also originally considered, but many of those on our initial list either focused on performance measures rather than presence or did not include a self-reported level of presence. Pending further review we still hope to include immersive haptic technologies as an independent variable within our quantitative analysis.

- *Sound quality.* A number of studies have investigated how the relative presence of sound may influence user ratings of presence. Manipulations of this feature include the relative use of any sound, ambient sound, diegetic sound, and spatialized sound, as well as the number of sound channels used.
- *Display type.* This feature refers to the form in which a virtual environment is displayed (HMD, projection, PC monitor, etc.). While this variable confounds other ones, (e.g., field of view, image quality, etc.), given what a popular manipulation it was we include it as an independent variable (not to be examined simultaneously with the confounding variables).
- *Emotional content.* Emotional content was one of the few content manipulations to be commonly found in the primary list of studies. For our purpose, emotional content refers to whether or not the immersive experience includes emotionally relevant content within the virtual space. This often includes the relative use of emotion-inducing scenes or violent content. Though at times focusing on different emotional valence, what bounds these studies is their comparison of the impact of different levels of arousing content (relaxing, neutral, arousing) on user presence.
- *Update rate*. A few studies have empirically examined how the rate at which the virtual environment is rendered may influence user presence.
- *User perspective.* This feature refers to the manipulation of the perspective – 1st vs. 3rd person – through which the user views the virtual environment.
- *Overall High vs. Low.* Finally, this category applies to studies in which multiple features were manipulated across conditions, thereby producing confounds (for our purpose), preventing us from teasing apart the relative contribution of a given feature. For example, a study which compares presence experienced while using an HMD with head-tracking to that experienced while using a desktop PC without any such tracking falls into this category, as both tracking level and display type were manipulated. However, note, in that same example, if the HMD condition did not include head-tracking, such a study would instead be considered a manipulation of display type, as discussed above.

Although the validity of some of these manipulations as immersion components is particularly apparent (e.g., manipulations of stereoscopic vision or update rate) and corroborated by similar lists (Bowman & McMahan, 2007), others are a bit more subjectively defined (e.g., image quality or emotional content). However, we attempted many taxonomies of features and consider the above set to represent a natural clustering of the studies included, as we believe any group of studies combined into a single category includes manipulations of the same fundamental, underlying concept. For example, the concept of "image quality" is multi-dimensional in nature, often discussed in terms of resolution, lighting, and realism, all of which together comprise an image's relative quality. Further, all studies that considered manipulations of "emotional content" investigate how the relative levels of an environment's arousing content can influence presence.

6. Intended Analyses

Our meta-analysis will technically consist of a series of meta-analyses, one for each immersive component to be considered. This will allow us to examine the relative effect size of each system feature. Further, in addition to completing a separate meta-analysis for each independent variable feature, we will, if permitted the statistical power, seek to differentiate effects on self-presence, spatial presence, and social presence. The ability to do this depends on the number of studies that independently gauge each of these constructs, as opposed to simply capturing a general measure of presence.

Additionally, the candidate studies span a wide range of designs and time. In turn, two studies empirically examining the same feature may include different relative magnitudes of that feature. Indeed, what may have been a relatively wide FOV level in the early 1990s may be fairly narrow by today's standards. An empirical question to be considered is whether we should examine the relative difference between conditions of high and low as an effect size (even if the high from one study is lower than the low from another), or alternatively if we should seek to place boundaries on the absolute levels of the ranges of immersion. We will continue to examine this issue as we assimilate the studies. Further, if a given study offers more than two levels of a given feature, for the sake including the effect into our analyses, we will simply note the general linear effect by comparing the means and standard deviations of the two most extreme levels.

Finally, the existing literature has more thoroughly investigated the relative impact of some of these immersive features (e.g., stereoscopic vision, field of view) than others (e.g., update rate, user perspective), as demonstrated in Table 1. This situation may have repercussions for the subsequent quantitative analysis – in particular, meta-analyses of features with greater numbers of candidate studies may offer greater insight into actual effect sizes than those with fewer candidate studies. However, we still intend to conduct analyses on the smaller groups, as any results may be potentially offer actionable insights for system construction

7. Closing Remarks

The purpose of this paper is two-fold. First, in light of current theoretical frameworks, as well as the mixed results and various operationalizations of immersion and presence found in the literature, we argue the need for a proper meta-analytical approach to investigating the relationship between immersion, presence, and performance. Second, focusing on the first link in this presumed causal chain, we've proposed a series of meta-analyses for investigating the overall effects of various immersive system component technologies on self-reported levels of presence. In so doing, we wish to share a fairly composite list of relevant studies. Considering the vast field of work of be factored into such a project, not only may this collection be of potential use to others, but it likely stands to be made more replete with contributions from other scholars. With this list examined and secured, we will soon move into the quantitative phase of these meta-analyses, which, should they provide significant and noteworthy effect sizes, may call for a second series of analyses investigating the effect of presence on performance across various types of tasks. Together, two such meta-analytic efforts would permit a much more holistic estimate of the effects of immersion on presence and of presence on performance, and in turn may provide a better, more quantifiably discerned answer to the question of "how immersive is enough."

Table 1. Primary List of Studies Investigating the Effect of Immersive System Quality on Self-reported Levels of Presence

Author(s)	Year	Immersive Quality	Manipulation Operationalization
Ahn	2011	High vs. Low	HMD (with head-tracking) vs. desktop
Axelson et al.	2001	High vs. Low	CAVE-like system vs. desktop
Banos et al.	2004	High vs. Low	HMD (with head-tracking) vs. desktop
Botella et al.	1999	High vs. Low	"high impact workstation" vs. PC with lower quality HMD & graphics cards, and 2D mouse
Gorini et al.	2011	High vs. Low	HMD, motion-tracker, 640x480 resolution vs. external monitor, 1600x1200 resolution
Juan & Perez	2009	High vs. Low	CAVE vs. HMD (with headtracking)
Larsson et al.	2001	High vs. Low	HMD (with head-tracking) and stereoscopic video vs. projection with monoscopic video
Lo Priore et al.	2003	High vs. Low	HMD (with head-tracking) vs. flatscreen with joystick
Patel et al.	2006	High vs. Low	3D immersive environment vs. 2D video projection
Peer et al.	2010	High vs. Low	HMD (with head-tracking) vs. stereoscopic projection
Perksy & Blascovich	2008	High vs. Low	Immersive VE vs. Desktop VE
Rand et al.	2005	High vs. Low	GX-HMD vs. GX-monitor
Rand et al.	2005	High vs. Low	GX-HMD vs. GX Monitor
Sallnäs	2005	High vs. Low	CVE vs. video-audio conference

Author(s)	Year	Immersive Quality	Manipulation Operationalization
Sallnäs	2005	High vs. Low	Collaborative web environment vs. video-audio conference
Tamborini et al.	2000	High vs. Low	Immersive VE vs. Desktop VE
Ahn	2011	Tracking level	“Self-move” vs. “other-move”
Aymerich-Franch	2009	Tracking level	Body-tracking vs. joystick
Broek	2008	Tracking level	Active exposure (play game) vs. passive exposure (watch game)
Bystrom & Barfield	1999	Tracking level	Control of movement & navigation vs. none
Bystrom & Barfield	1999	Tracking level	Head-tracking vs. no head-tracking
Hendrix & Barfield	1996	Tracking level	Head-tracking vs. no head-tracking
Hoshi & Waterworth	2009	Tracking level	Tool (racquet or mazeboard glove) vs. regular glove
McGloin et al.	2011	Tracking level	Wiimote vs. Playstation 3 controller
Nordahl	2005	Tracking level	Footstep-tracking audio feedback vs. no audio
Peer et al.	2010	Tracking level	3 DOF vs. 6 DOF
Petzold et al.	2004	Tracking level	Presence vs. absence of auditory feedback
Regenbrecht et al.	2002	Tracking level	Free movement vs. view pre-recorded sequence
Snow & Williges	1998	Tracking level	Head-tracking vs. no head-tracking
Welch et al.	1996	Tracking level	Active exposure (driver) vs. passive exposure (passenger)
Witmer & Kline	1998	Tracking level	Treadmill-based movement vs. “teleportation”
Zelenkauskaite & Bucy	2009	Tracking level	Type/respond vs. read only
Banos et al.	2008	Stereoscopic vision	Stereoscopic vs. monoscopic
Davis & Hodges	1995	Stereoscopic vision	Stereoscopic vs. monoscopic
Freeman et al.	2000	Stereoscopic vision	Stereoscopic vs. monoscopic
Hauber et al.	2005	Stereoscopic vision	3D vs. 2D videoconferencing
Hendrix & Barfield	1996	Stereoscopic vision	Stereoscopic vs. monoscopic
IJsselsteijn et al.	2001	Stereoscopic vision	Stereoscopic vs. monoscopic
Mulbach et al.	1995	Stereoscopic vision	Stereoscopic vs. monoscopic
Snow & Williges	1998	Stereoscopic vision	Stereoscopic vs. monoscopic

Author(s)	Year	Immersive Quality	Manipulation Operationalization
Takatalo et al.	2011	Stereoscopic vision	Stereoscopic vs. monoscopic
Bracken	2005	Image quality	High definition vs. standard definition
Bracken & Botta	2002	Image quality	High definition vs. standard definition
Bracken & Skalski	2009	Image quality	High definition vs. standard definition
Ççiflikli & Güüdüükbay	2010	Image quality	High vs. low flickering
Dinh et al.	1999	Image quality	Localized lighting & high resolution textures vs. ambient lighting & low resolution textures
Skalski & Whitbred	2010	Image quality	High definition vs. standard definition
Snow & Williges	1998	Image quality	Texture mapping vs. no texture mapping
Snow & Williges	1998	Image quality	High vs. low environmental detail
Welch et al.	1996	Image quality	High vs. low pictorial realism (objects, colors, complexity)
Bracken & Botta	2002	Field of view	65” vs. 32” screen (holding resolution and distance constant)
Hendrix & Barfield	1996	Field of view	Geometric field of view – 90° vs. 10°
Hou et al.	2012	Field of view	81” screen (76°) vs. 12” screen (18°)
IJsselsteijn et al.	2001	Field of view	50° vs.28° (resolution and distance held constant, screen size changed)
Lin et al.	2002	Field of view	180° vs. 60°
Lombard et al.	2000	Field of view	46” screen vs. 12” screen (holding resolution and distance constant)
Prothero & Hoffman	1995	Field of view	Unmasked screen (105°) vs. scene mask (60°)
Shim & Kim	2003	Field of view	180° vs. 120°
Snow & Williges	1998	Field of view	High (48°x36°) vs. Low (24°x18°)
Dinh et al.	1999	Sound quality	Presence vs. absence of ambient sound
Hendrix & Barfield	1996b	Sound quality	Spatialized vs. no sound
Hendrix & Barfield	1996b	Sound quality	Spatialized vs. non-spatialized sound
Jeong et al.	2009	Sound quality	Presence vs. absence of diegetic sound (screams)
Jeong et al.	2008	Sound quality	Presence vs. absence of diegetic sound (screams)
Larsson et al.	2007	Sound quality	Sound vs. no sound
Lessiter & Freeman	2001	Sound quality	5.1 channel vs. mono sound
Lessiter & Freeman	2001	Sound quality	5.1 channel vs. 2.0 channel sound

Author(s)	Year	Immersive Quality	Manipulation Operationalization
Nunez	2007	Sound quality	Presence vs. absence of diegetic sound
Petzold et al.	2004	Sound quality	Presence vs. absence of auditory feedback
Skalski & Whitbred	2010	Sound quality	5.1 surround vs. 2 channel Dolby digital sound
Snow & Williges	1998	Sound quality	Sound vs. no sound
Västfjäll	2003	Sound quality	6 channel vs. mono sound
Grassi et al.	2008	Display type	HMD vs. desktop
Lott et al.	2003	Display type	HMD (no head-tracking) vs. flatscreen
Takatalo et al.	2006	Display type	Near-eye display vs. external monitor
Banos et al.	2004	Emotional content	Emotion-inducing VE (sad vs. neutral)
Banos et al.	2008	Emotional content	Emotion-inducing VE (joy vs. relaxed)
Ivory & Kalyanaraman	2007	Emotional content	Violent vs. non-violent game
Nowak et al.	2008	Emotional content	Violent vs. non-violent game context
Riva et al.	2007	Emotional content	Emotion-inducing VE (anxious vs. neutral)
Riva et al.	2007	Emotional content	Emotion-inducing VE (relaxed vs. neutral)
Barfield & Hendrix	1995	Update rate	5 vs. 25 hz
Snow & Williges	1998	Update rate	8 vs. 16 hz
Hoshi & Waterworth	2009	User perspective	1st person (maze game) vs. 3rd person (tennis game)
Jeong et al.	2008	User perspective	1st vs. 3rd person views in same video game
Kallinen et al.	2007	User perspective	1st vs. 3rd person views in same video game

References

Ahn, S. J. (2011). *Embodied experiences in immersive virtual environments: Effects on pro-environmental attitude and behavior*. Unpublished doctoral dissertation. Stanford University. Palo Alto, CA.

Axelsson, A. S., Abelin, Å., Heldal, I., Schroeder, R. & Wideström, J.(2001). Cubes in the cube: A comparison of a puzzle-solving task in a virtual and a real environment. *CyberPsychology & Behavior*, *4*(2 April), 279-286.

Aymerich-Franch, L. (2010). Presence and emotions in playing a group game in a virtual environment: The influence of body participation. *Cyberpsychology, Behavior, and Social Networking*, *13*(6), 649-654.

Bailenson, J. N., Aharoni, E. Beall, A. C., Guadagno, R. E., Dimov, A., & Blascovich, J. (2004). Comparing behavioral and self-report measures of embodied agents' social presence in immersive virtual environments. *Proceedings of the 7th Annual International Workshop on PRESENCE*, October 13 - 15, Valencia, Spain.

Banos, R. M., Botella, C., Alcaniz, M., Liano, B. A., Guerrero, B., & Rey, B. (2004). Immersion and emotion: Their impact on the sense of presence. *CyberPsychology & Behavior, 7*(6), 734-741.

Banos, R. M., Botella, C., Rubio, I., Quero, S., Garcia-Palacious, A., & Alcaniz, M. (2008). Presence and emotions in virtual environments: The influence of stereoscopy. *CyberPsychology & Behavior, 11*(1), 1-8.

Barfield, W., & Hendrix, C. (1995). The effect of update rate on the sense of presence within virtual environments. Virtual Reality: The Journal of the Virtual Reality Society, 1(1) 3–16.

Blascovich, J., & Bailenson, J. N. (2001). Infinite reality: Avatars, eternal life, new worlds, and the dawn of the virtual revolution. New York: William Morrow.

Botella, C., Rey, A., Perpina, C., Banos, R., Alcaniz, M., Garcia-Palacios, A., Villa, H., & Alozano, J. (1999). Differences on presence and reality judgment using a high impact workstation and a PC workstation. *CyberPsychology & Behavior, 2*(1), 49-52.

Bowman, D. & McMahan, R. (2007).Virtual reality: How much immersion is enough? *IEEE Computer, 40*(7), 36-43.

Bracken, C. C. (2005). Presence and image quality: The case of high-definition television. *Media Psychology, 7*(2), 191-205.

Bracken, C. C. & Botta, R. A. (2002). Presence and television: Form versus Content. *Proceedings of the 5th Annual International Workshop on PRESENCE*, October 9-11, Porto, Portugal.

Bracken, C.C. & Skalski, P. (2009). Telepresence and video games: The impact of image quality. *PsychNology Journal, 7*(1), 101-112.

Broek, P. (2008). *To game or not to game: Examining differences in presence, arousal and intended aggression after playing or observing a violent videogame*. Unpublished manuscript. Department of Psychology, University of Twente, Netherlands..

Bystrom, K. & Barfield, W. (1999). Collaborative task performance for education using a virtual environment. *Presence: Teleoperators and Virtual Environments, 8*(4), 435-448.

Ççiflikli, B. & Güüdüükbay, U. (2010). Increasing the sense of presence in a simulation environment using image generators based on visual attention. *Presence: Teleoperators and Virtual Environments, 19*(6), 557-568.

Davis, E. T. & Hodges, L. F. (1995). Human stereopsis, fusion, and stereoscopic virtual environments. In W. Barfield & T.A. Furness (Eds.), *Virtual environments and advanced interface design* (pp. 145–174). Oxford, England: Oxford University Press.

Dinh, H. Q., Walker, N., Hodges, L. F., Chang, S., & Kobayashi, A. (1999). Evaluating the importance of multi-sensory input on memory and the sense of presence in virtual environments. *Proceedings of the IEE Virtual Reality Conference 1999, 222-228.*

Duh, H. B. L., Lin, J. J. W., Kenyon, R.V., Parker, D. E., & Furness, T. A. (2002). Effects of characteristics of image quality in an immersive environment. *Presence: Teleoperators and Virtual Environments, 11*(3), 324-332.

Freeman, J., Avons, S. E., Meddis, R., Pearson, D.E. & IJsselsteijn, W. A. (2000). Using behavioral realism to estimate presence: A study of the utility of postural responses to motion-stimuli. *Presence: Teleoperators and Virtual Environments, 9*(2), 149-164.

Gorini, A., Capideville, C. S., De Leo, G., Mantovani, F., & Riva, G. (2011). The role of immersion and narrative in mediated presence: The virtual hospital experience. *Cyberpsychology, Behavior & Social Networking,14*(3), 99-105.

Grassi, A., Giaggioli, A., & Riva, G. (2008). The influence of media content and media form in sense of presence: A preliminary study. *Proceedings of the 11th Annual International Workshop on PRESENCE,* October 16-18, Padua, Italy.

Hauber, J., Regenbrecht, H., Hills, A., Cockburn, A., & Billinghurst, M. (2005). Social presence in twp- and three-dimensional videoconferencing. *Proceedings of the 8th Annual International Workshop on PRESENCE*, September 21-23, London, U.K..

Heeter, C. (1992). Being there: The subjective experience of presence. *Presence: Teleoperators and Virtual Environments, 1*, 262–271.

Hendrix, C. M. & Barfield, W. (1996). Presence within virtual environments as a function of visual display parameters. *Presence: Teleoperators and Virtual Environments, 5*(3), 274-289.

Hendrix, C. M. & Barfield, W. (1996b). The sense of presence within auditory virtual environments. *Presence: Teleoperators and Virtual Environments, 5*(3), 290-301.

Hoshi, K. & Waterworth, J.A. (2009). Tangible presence in blended reality space. *Proceedings of the 12th Annual International Workshop on PRESENCE*, November 11-13, Los Angeles, California, USA.

Hou, J., Nam, Y., Peng, W., & Lee, K. M. (2012). Effects of screen size, viewing angle, and players' immersion tendencies on game experience. *Computers in Human Behavior, 28*, 617-623.

IJsselsteijn, W., de Ridder, H., Freeman, J., Avons, S.E., & Bouwwhuis, D. (2001). Effects of stereoscopic presentation, image motion, and screen size on subjective and objective corroborative measures of presence. *Presence: Teleoperators and Virtual Environments, 10*(3), 298-311.

Ivory, J. D., & Kalyanaraman, S. (2007). The effects of technological advancement and violent content in video games on players' feelings of presence, involvement, physiological arousal, and aggression. *Journal of Communication, 57*, 532-555.

Jeong, E. J., Biocca, F. A., & Bohil, C. J. (2009). Advertising effects through violent virtual experience - Presence, arousal, brand memory and attitude in 3D violent games. *Proceedings of the 12th Annual International Workshop on PRESENCE*, November 11-13, Los Angeles, California, USA.

Jeong, E. J., Biocca, F. A., & Bohil, C. J. (2008). Effects of representational realism in 3D violent games. *Proceedings of the 11th Annual International Workshop on PRESENCE*, October 16-18, Padua, Italy.

Juan, M. C. & Perez, D. (2009). Comparison of levels of presence and anxiety in an acrophobic environment viewed via HMD or CAVE. Presence: Teleoperators and Virtual Environments, 18(3), 232-248.

Kallinen, K., Salminen, M., Ravaja, N., Kedzior, R., & Saaksjarvi, M. (2007). Presence and emotion in computer game players during 1st person vs. 3rd person playing view: Evidence from self-report, eye-tracking, and facial muscle activity data. *Proceedings of the 10th Annual International Workshop on PRESENCE,* October 25-27, Barcelona, Spain.

Larsson, P., Västfjäll, D., Olsson, P., & Kleiner, M. (2007). When what you hear is what you see: Presence and auditory-visual integration in virtual environments. *Proceedings of the 10th Annual International Workshop on PRESENCE,* October 25-27, Barcelona, Spain.

Larsson, P., Västfjäll, D., & Kleiner, M. (2001). The actor-observer effect in virtual reality presentations. *CyberPsychology & Behavior, 4*(2), 239-246.

Lee, K. M. (2004). Presence, explicated. *Communication Theory, 14*(1), 27-50.

Lessiter, J. & Freeman, J. (2001). Really hear? The effects of audio quality on presence. *Proceedings of the 4th Annual International Workshop on PRESENCE*, May 21-23, Philadelphia, Pennsylvania, USA.

Lin, J. J., Duh, H. B. L., Parker, D. E., Abi-Rached, H., & Furness, T. A. (2002). Effects of field of view on presence, enjoyment, memory and simulator sickness in a virtual environment. *Proceedings of the IEEE Virtual Reality Conference 2002, 164-171.*

Lombard, M., & Ditton, T. (1997) At the heart of it all: The concept of presence. *Journal of Computer-Mediated Communication, 3*(2).

Lombard, M., Reich, R., Grabe, M. E., Bracken, C. & Ditton, T. (2000). Presence and television: The role of screen size. *Human Communication Research, 26*(1). 75–98.

Lott, A., Bisson, E., Lajoie, Y., McComas, J., & Sviestrup, H. (2003). The effect of two types of virtual reality on voluntary center of pressure displacement. *CyberPsychology & Behavior, 6*(5), 477-485.

Lo Priore, C., Castelnuova, G., Liccione, D., & Liccione, D., (2003). Experience with V-STORE: Considerations on presence in virtual environments for effective neuropsychological rehabilitation of executive functions. *CyberPsychology & Behavior, 6*(3), 281-287.

McMahan, A. (2003). Immersion, engagement, and presence: A method for analyzing 3-D video games. In M.J.P. Wolf & P. Bernard (eds.) *The Video Game Theory Reader* (pp.67-86). New York: Routledge.

McMahan, R. P., Gorton, D., Gresock, J., McConnell, W., & Bowman, D. A. (2006). Separating the effects of level of immersions and 3D interaction techniques. *Proceedings from the ACM Virtual Reality Software and Technology Conference*.

McGloin, R., Farrar, K.M., & Krcmar, M. (2011). The impact of controller naturalness on spatial presence, gamer enjoyment, and perceived realism in a tennis simulation video game. *Presence: Teleoperators and Virtual Environments, 20*(4), 309-324.

Mulbach, L., Bocker, M. & Prussog, A. (1995). Telepresence in videocommunications: A study on stereoscopy and individual eye contact. *Human Factors, 37*(2), 290-305.

Narayan, M., Waugh, L., Zhang, X., Bafna, P., & Bowman, D.A. (2005). Quantifying the benefits of immersion for collaboration in virtual environments. *Proceedings from the ACM Virtual Reality Software and Technology Conference*.

Nordahl, R. (2005). Self-induced footsteps sounds in virtual reality: Latency, recognition, quality and presence. *Proceedings of the 8th Annual International Workshop on PRESENCE*, September 21-23, London, U.K..

Nowak, K.L., Krcmar, M., & Farrar, K. (2008). The causes and consequences of presence: Considering the influence of violent video games on presence and aggression. *Presence: Teleoperators and Virtual Environments, 17*(3), 256-268.

Nunez, D. (2007). Effects of non-diegetic information on presence: A content manipulation experiment. *Proceedings of the 10th Annual International Workshop on PRESENCE*, October 25-27, Barcelona, Spain.

Patel, K., Bailenson, J.N., Hack-Jung, S., Diankov, R., & Bajcsy, R. (2006). The effects of fully immersive virtual reality on the learning of physical tasks. *Proceedings of the 10th Annual International Workshop on PRESENCE,* August 24-26, Cleveland, Ohio, USA.

Pausch, R., Proffitt, D., & Williams, G. (1997). Quantifying immersion in virtual reality. *Proceedings from the Annual ACM SIGGRAPH Conference, Computer Graphics*, 13–18.

Peer, A., Pongrac, H., & Buss, M. (2010). Influence of varied human movement control on task performance and feeling of telepresence. *Presence: Teleoperators and Virtual Environments, 19*(5), 463-481.

Persky, S. & Blascovich, J. (2008). Immersive virtual video game play and presence: Influences on aggressive feelings and behavior. *Presence: Teleoperators and Virtual Environments, 17*(1), 57-72.

Petzold, B., Zaeh, M. F., Färber, B., Deml, B., Egermeier, H., Schilp, J. & Clarke, S. M. (2004). A study on visual, auditory and haptic feedback for assembly tasks. *Presence: Teleoperators and Virtual Environments, 13*(1), 16-21.

Polys, N. F., Kim, S., & Bowman, D. A. (2007). Effects of information layout, screen size, and field of view on user performance in information-rich virtual environments. *Computer Animation and Virtual Worlds, 18*, 19-38.

Prothero, J. D., & Hoffman, H. G. (1995). *Widening the field-of-view increases the sense of presence in immersive virtual environments*. Human Interface Technology Laboratory Technical Report TR-95-2.

Rand, D., Kizony, R., Feintuch, U., Katz, N., Josman, N., Rizzo, A. A. & Weiss, P. L. (2005). Comparison of two VR platforms for virtual reality rehabilitation: Video capture versus HMD. *Presence: Teleoperators and Virtual Environments*, *14*(2), 147-160.

Regenbrecht, H. & Schubert, E. T. (2002). Real and illusory interactions enhance presence in virtual environments. *Presence: Teleoperators and Virtual Environments, 11*(4), 425-434.

Riva, G., Mantovani, F., Capideville, C. S., Preziosa, A., Morganti, F., Villani, D., Gaggioli, A., Botella, C., & Alcañiz, M. (2007). Affective interactions using virtual reality: The link between presence and emotions. *CyberPsyschology & Behavior, 10*(1), 45-56.

Rosenthal, R. (1991). Meta-analysis: A review. *Psychosomatic Medicine, 53*, 247-271.

Rosenthal, R., & DiMatteo, M. R. (2001). Meta-analysis: Recent developments in quantitative methods for literature reviews. *Annual Review of Psychology, 52*, 59-82.

Sallnäs, Eva-Lotta (2005). Effects of communication mode on social presence, virtual presence, and performance in collaborative virtual environments. *Presence: Teleoperators and Virtual Environments, 14*(4), 434-449.

Shim, W. & Kim, G. J. (2003). Designing for presence and performance: The case of the virtual fish tank. *Presence: Teleoperators and Virtual Environments, 12*(4), 374-386.

Slater, M. (2004). How colorful was your day? Why questionnaires cannot assess presence in virtual environments. *Presence: Teleoperators and Virtual Environments, 13*(4), 484-493.

Slater, Linakis, V., Usoh, M., & Kooper, R. (1996, July). Immersion, presence, and performance in virtual environments: An experiment in tri-dimensional chess. *Proceedings from the ACM Virtual Reality Software and Technology Conference,* July, Hong Kong.

Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators and Virtual Environments, 6*, 603-616.

Snow, M. P. & Williges, R. C. (2008). Empirical models based on free-modulus magnitude estimation of perceived presence in virtual environments. *Human Factors, 40*(3), 386-402.

Skalski, P., & Whitbred, R. (2010). Image versus Sound: A Comparison of Formal Feature Effects on Presence and Video Game Enjoyment. *PsychNology Journal, 8*(1), 67-84.

Steuer, J. (1992). Defining virtual reality: Dimensions determining telepresence. *Journal of Communication, 42*(4), 73–93.

Takatalo, J., Kawai, T., Kaistinen, J., Nyman, G., and Hakkinen, J. (2011). User experience in 3D stereoscopic games. *Media Psychology, 14*, 387-414.

Takatalo, J., Häkkinen, J., Komulainen, J., Särkelä, H. & Nyman, G. (2006). The impact of the display type and content to a game adaptation. *Proceedings of the 8th International Conference on Human-Computer Interaction with Mobile Devices and Services*, September 12-15, Otaniemi, Finland.

Tamborini, R., Eastin, M., Lachlan, K., Fediuk, T., Brady, R., & Skalski, P. (2000). The effects of violent virtual video games on aggressive thoughts and behaviors. *Paper presented at the 86th Annual Convention of the National Communication Association*. November 9-12, Seattle, Washington, USA.

Västfjäll, D. (2003). The subjective sense of presence, emotion recognition, and experienced emotions in auditory virtual environments. *CyberPsychology & Behavior, 6*(2), 181-188.

Welch, R., Blackmon, T. T., Liu, A., Mellers, B. A. & Stark, L. W. (1996). The effects of pictorial realism, Delay of visual feedback, and observer interactivity on the subjective sense of presence. *Presence: Teleoperators and Virtual Environments, 5*(3), 263-273

Witmer, B. G. & Kline, B. P. (1998). Judging perceived and traversed distance in virtual environment. *Presence: Teleoperators and Virtual Environments, 7*(2), 144-167.

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments, 7*, 225–240.

Zelenkauskaite, A & Bucy, E. (2009). Presence, participation, and political text-on-television: Testing a converged technology. *Proceedings of the 12th Annual International Workshop on PRESENCE*, November 11-13, Los Angeles, California, USA.