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How Immersive Is Enough? A Meta-Analysis of the Effect of Immersive Technology on User Presence

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The concept of presence, or "being there" is a frequently emphasized factor in immersive mediated environments. It is often assumed that greater levels of immersive quality elicit higher levels of presence, in turn enhancing the effectiveness of a mediated experience. To investigate this assumption the current meta-analysis synthesizes decades of empirical research examining the effect of immersive system technology on user experiences of presence. Aggregating 115 effect sizes from 83 studies, it finds that technological immersion has a medium-sized effect on presence. Additionally, results show that increased levels of user-tracking, the use of stereoscopic visuals, and wider fields of view of visual displays are significantly more impactful than improvements to most other immersive system features, including quality of visual and auditory content. These findings are discussed in light of theoretical accounts of the presence construct as well as practical implications for design.

MEDIATED ENVIRONMENTS, PRESENCE, AND IMMERSION

Even though Ivan Sutherland (1965) published his seminal essay, "The Ultimate Display," almost 50 years ago, the technology that is able to produce a "looking glass into the mathematical wonderland" has only become widely available in the past few years (see Blascovich & Bailenson, 2011, for a

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historical account). Sutherland's first head-mounted display was nicknamed "the Sword of Damocles." It was so large and bulky it had to be bolted into the ceiling and users expressed fears of bodily harm if the ceiling mount happened to break while they wore it. Times have changed, and the technology required to achieve this looking glass is becoming cheaper and less cumbersome. However, as we transition into an era in which people are designing systems that immerse students, corporate collaborators, tourists, moviegoers, and videogame players into digital media experiences which look, sound, feel, and smell just like real ones, it is critical to understand how technology affects experience. The purpose of this article is to examine the degree of correlation between *immersion*—defined as a technological quality of media—and *presence*—defined as the psychological experience of "being there."

The concept of presence, or a sense of being there, is a frequently emphasized factor when discussing mediated environments. The assumption that achieving presence should be a goal of the design of virtual environments (VEs) pervades both applied and academic work. 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 mediated environment applications (e.g., the practical use of such environments as tools for entertainment, learning, training, or therapy; Nunez & Blake, 2001; Price & Anderson, 2006; Slater & Wilbur, 1997; Tamborini & Bowman, 2010; Tamborini & Skalski, 2006).

Over the last 20 years researchers have defined and explicated the concept of presence in a number of different ways (e.g., Heeter, 1992; K. M. Lee, 2004a; Lombard & Ditton, 1997; McMahan, 2003; Slater, 2009; Slater & Wilbur, 1997; Steuer, 1992; Witmer & Singer, 1998). The flagship journal of the field studying presence in virtual reality is aptly titled *Presence: Teleoperators and Virtual Environments*. The first volume of *Presence* was published in 1992, and contains work by some of the pioneers who still remain active leaders in the field, for example, Frank Biocca, Carrie Heeter, Jack Loomis, Sandy Pentland, and Thad Starner, to name a few. The articles across this issue offered an early attempt to provide theory and methods that describe the mental processes that occur when one gets psychologically drawn into a virtual world, focusing on the experience of occupying a virtual space. Biocca (1997) was one of first to hone in on particular elements of presence, with K. M. Lee (2004a) later providing a more detailed explication, introducing the concepts of social presence and self-presence, distinct from the more traditional spatial emphasis.

Within the literature presence is often related to another similar concept—immersion. The exact relationship between these two concepts is at times confusing , as authors employ the word "immersion" in a variety of ways. In some instances the terms appear synonymous, with "immersion" used to describe the feeling of presence depicted above (e.g., McGloin, Farrar, & Krcmar, 2013). Others have instead described immersion as a specific subcomponent of a larger presence construct (Witmer & Singer, 1998). One clear distinction between presence and immersion—and the one we draw upon in the present study—is provided by Slater and Wilbur (1997). They suggest that presence in a VE is inherently a function 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 (1997) note that a system is more likely to be immersive—or to shut out physical reality—if it a) offers high fidelity simulations through multiple sensory modalities, b) finely maps a user's virtual bodily actions to their physical body's counterparts, and c) 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 mediated environment and the more likely that the virtual setting will dominate over physical reality in determining user responses.

THE FORMATION OF PRESENCE

A number of prominent presence scholars have put forth a theoretical model outlining the psychological process by which presence is experienced (Wirth et al., 2007). The model understands the formation of presence as a two-step process. First, the user must draw upon spatial cues to perceive the mediated environment as a plausible space. Second, the user must also then experience his or herself as being located within that perceived space. Only then is spatial presence achieved. It is in light of this process that Wirth and colleagues (2007) define presence as "a binary experience, during which perceived self-location and, in most cases, perceived action possibilities are connected to a mediated spatial environment, and mental capacities are bound by the mediated environment instead of reality" (p. 497). With this definition in mind, the model describes presence as a two-dimensional construct, comprised of a) a sense of self-location and b) perceived possibilities to act.

Wirth et al. (2007) note specific media features that may assist with each step of the formation process—both constructing the spatial mental representation of the mediated space and then experiencing self-location within that space. Many of the spatial cues used when perceiving a virtual space are linked to the visual modality, including static monocular cues (e.g., occlusion, visual field, texture effects), dynamic monocular cues (e.g., motion parallax), and binocular cues (e.g., stereoscopy). Additionally, the mediated environment will more likely be perceived as a plausible space if these cues are both rich in quality and have a logical consistency. Regarding the second step, media factors are also thought to influence the user's ability to perceive this virtual space as their primary spatial reference frame rather than that of the real world. Indeed, as noted by Balakrishnan and Sundar (2011), this model suggests that the user's perception of both self-location and possible actions is at least partially defined by the affordances of the mediated environment. These conditions that are thought to promote spatial presence closely align with those Slater and Wilbur (1997) cite as influential on a system's immersive quality. More specifically, this framework aligns with Slater's (2009) recent description of realistic behavior in virtual reality. He suggests that displays and interactive capability are inseparable in determining a system's immersive quality—with immersive systems being those that support sensorimotor contingencies by which user actions lead to meaningful changes in the environment or user perception. According to Slater, such user action contingencies help to elicit a place illusion, or the sense of being there as described in previous presence literature, while the extent to which the environment offers events beyond the user's control creates the sense that the environment is actually happening (the plausibility illusion).

HOW IMMERSIVE IS ENOUGH?: QUANTIFYING THE BENEFITS OF IMMERSIVE QUALITY

Again, the rationale provided by Slater and Wilbur (1997) would suggest that systems of higher immersive quality may elicit greater psychological presence (Bowman & McMahan, 2007; Slater, Linakis, Usoh, & Kooper, 1996). As such, we might conclude that a designer seeking to maximize user presence 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, stereoscopic visuals and surround-sound, and avatars with photo-realistic faces, expressions, and clothing—the inclusion of these features could be expected to cause matching gains in a user's sense of presence. In terms of the two-step model, this equates to more consistent and rich spatial cues leading to a greater likelihood that the user perceives the mediated environment as spatial and himself as located within it.

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 update rates, or wider fields of view. Second, there is the pragmatic issue of usability—high immersion hardware often correlates with greater cumbersomeness and calibration requirements, for both the user (e.g., heavy equipment, placement of body markers) and the researcher or technician (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?" In other words, how much benefit does the newer or additional technology really add to users' sense of being physically present?

A formal meta-analysis can help answer this question by lending insight into the general direction and overall size of the effect of immersive technology on user presence. The quantitative steps for combining results across a corpus of studies not only permit researchers to gain a more gestalt estimate of the effect in question, but can also provide insights into inconsistencies through the discovery of potential moderators and mediators (Rosenthal, 1991; Rosenthal & DiMatteo, 2001). 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. In other words, by compiling the various operationalizations of immersion and their observed effects, 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. Further, if particular technologies are found to lead to stronger effects than others, this process may lend theoretical insight into the formation of presence.

For the purpose of our meta-analysis, we intended to gauge the overall effect of immersion on presence. Further, we have conducted multiple, separate meta-analyses for individual immersive system components (e.g., field of view, tracking level, stereoscopy) in order to help identify which immersive features are particularly effective in leading to the formation of presence.

METHOD

Selection of Candidate Studies

The first step of a meta-analysis is defining the variables of interest, both independent and dependent (Rosenthal & DiMatteo, 2001). Candidate studies for this meta-analysis needed to include the manipulation of a VE system's level of immersion and the subsequent measure of presence experienced by users. However, for theoretical and practical purposes we restricted the definitions of these variables in a few ways.

Operationalizations of presence

First, in operationally defining presence, for the sake of internal validity we decided that this initial analysis should be restricted to studies in which presence was measured through self-report. Other measures sometimes used include body vection, physiological arousal, and memory tests. However, the meaning of many of these measures is open to debate. For example, regarding vection posture, leaning forward can be construed as feeling present and engaged, but leaning back could similarly indicate feeling present and surprised. Additionally, if a user is feeling more present, there are plausible arguments for why he or she should be able to remember both more and fewer details on a memory recall test. Therefore, although there is compelling reason to suspect the most promising measures of presence are not self-report (e.g., Bailenson et al., 2004; Slater, 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 (Rosenthal & DiMatteo, 2001).

Additionally, this meta-analysis is focused on the form of presence that the majority of research has been centered on, and which K. M. Lee (2004a) later explicated as spatial presence: the superordinate feeling of being located within a virtual space. Indeed, there are simply too few studies in the existing literature that empirically examine the effect of particular immersive features on social or self-presence for conducting independent meta-analyses regarding these related concepts. To this end, when compiling studies we looked for questionnaire items that generally asked about being in a space rather than being with other people (social presence or co-presence) or about self-identifying as a virtual representation or extension within the mediated space (self-presence or body transfer).

Further, many presence questionnaires include subscales measuring other concepts alongside spatial presence that we deemed not appropriate for this meta-analysis. For instance, some studies measured engagement or involvement, but these have been considered separate concepts for the purpose of this analysis (a user can feel spatially present in a VE designed to be boring without feeling engaged in it or cognitively involved). Finally, many questionnaires include items regarding emotion, affect, or arousal. These items were not included in the analysis, as valenced responses and alterations in arousal may be moderated by presence but are not direct measures of a sense of being there. With these restrictions of dependent self-report measures in mind, we then adhered to a very specific decision tree when reading through candidate studies: a) if presence (or the synonymously used terms general, spatial, or physical presence) or immersion were reported as stand-alone measures, they were used; if more than one was reported, their effect sizes were aggregated (see details below); b) if only a composite presence score was reported (comprised of subscales for engagement, involvement, affect, or other related but distinct concepts), then we were forced to rely on that measure; c) if subscales were reported, we carefully reviewed the exact questions and decided whether or not to include them.

Operationalizations of immersion

In operationally defining manipulations of immersion, we were guided by the operationalizations of presence-inducing system factors suggested by the two-step formation model (Wirth et al., 2007) and corroborated with lists of immersive feature categories found in the literature (Bowman & McMahan, 2007). In addition to this top-down process, we were also guided bottom-up by the most common, modal operationalizations of immersion found in the empirical literature. Together, this led to a definition of immersive that largely emphasizes system configurations or specifications as opposed to aspects of the mediated content itself, such as narrative (Rampoldi-Hnilo, Kind, Devries, Tait, & Besecker, 1997), game elements (Song, Kim, Tenzek, & Lee, 2009), violence (Ivory and Kalyanaraman, 2007; Nowak, Krcmar, & Farrar, 2006) or emotional tone (Baños et al., 2004; Grassi, Giaggioli, & Riva, 2008). This resulted in the following list of immersive features to be examined through meta-analysis:

Tracking level. Tracking level refers to the number and types of degrees of freedom (DOF) with which a user is tracked by an immersive system. Manipulations of this feature include the quality of the input method (e.g., more natural movement tracking versus abstract controller input). It also refers to studies that have manipulated the relative (e.g., number of DOF tracked) or absolute (e.g., capacity to take action within the mediated environment versus simply observing the stimulus) level of tracking in order to measure its influence on feelings of presence.

Stereoscopic vision. Studies investigating this feature manipulated whether a given system provided users 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 a mediated environment. Manipulations of this feature include high versus standard definition resolution, flicker rates, lighting types, texture mapping quality, and general level of detail or overall realism.

Field of view. This refers to the relative field of the user's total 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 purpose of our analyses, this variable also includes 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).

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 presence or absence of all sound, ambient sound, diegetic sound, or spatialized sound, as well as the number of sound channels used.

Update rate. Studies in this category 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 perspective—first person (from the eyes of the user) versus third person (over the shoulder of or behind the user's representation or avatar)—through which the user views the mediated environment.

Overall high versus low. Finally, this category applies to studies in which multiple features were manipulated across conditions, thereby producing operational confounds, preventing the teasing apart of the relative contribution of a given feature. For example, a study which compares presence experienced while using a HMD with head tracking to that experienced while using a desktop PC without any such tracking falls into this category. Further, some high versus low studies compared two or more systems traditionally considered immersive (e.g., a CAVE and a HMD) rather than compare one distinctly immersive condition to one distinctly non-immersive condition. In such cases, the categorization of high versus low was based upon the details of the system as described by the authors (see Table 1 for examples). If a given study provided insufficient details for determining the relative immersiveness between the systems used the study was omitted from the analysis.

In sum, this meta-analysis includes studies that investigated the manipulation of at least one immersive system feature (as operationalized by corroborating literature) and included a self-reported measure of spatial (general, physical) presence.

Search procedures

After defining the variables of interest, the second formal step of a meta-analysis according to Rosenthal and DiMatteo (2001) is to systematically collect the relevant studies. To do this, we completed keyword searches in the PsycNET and Communication and Mass Media online databases, as well as in the Temple University ISPR Telepresence Literature *Refshare* database. Searches were conducted for any studies including "presence" and/or "immersion" and/or "virtual." Additional searches were also completed for "presence" or "immersion" and a list of key feature terms, including "update rate," "stereoscopy," "stereoscopic," "tracking," "field of view," "sound," "user

TABLE 1 Descriptive Summary of Sample Studies

Study	Date	r	CI (95%)	N	Presence measurement	Task(s)	Location	Domain	Additional notes
					Update rate				
Barfield & Hendrix	1995	.395	−.15, .94	13	Custom (6 items)	Navigation and search task	United States	Eng	25 Hz vs. 5 Hz
Barfield et al.	1998	.506	−.19, 1.20	8	Custom	Navigation and search task	United States	Eng	20 Hz vs. 10 Hz
Gandy et al.	2010	.106	−.59, .80	8	PQ (modified)	Navigation and ball-dropping task	United States	SS	60 fps vs. 15 fps
Snow & Williges	1998	.691	.12, 1.26	12	Magnitude estimate	Distance estimation, ball manipulation, navigation, search, choice/selection	United States	Eng	16 Hz vs. 8 Hz
					Tracking level				
S. J. Ahn	2011	.008	−.19, .20	101	ITC-SOPI (11 items)	Simulated tree-cutting experience	United States	SS	Self-move vs. other-move
Aymerich-Franch	2009	.000	−.26, .26	56	SUS questionnaire (modified)	Block placement game	Australia	SS	Body-tracking vs. joystick
Balakrishnan & Sundar	2011	.832	.71, .96	240	MEC-SPQ (5 select items)	Navigation and search for clues around virtual office	United States	SS	High vs. low steering control
Barfield et al.	1998	.045	−.65, .74	8	Custom	Navigation and search task	United States	Eng	6 DOF (spaceball) vs. 3 DOF (joystick)
Broek	2008	.318	.17, .46	180	SAM presence scale	Unreal Tournament 2004 (FPS game)	Netherlands	SS	Active vs. passive
Bystrom & Barfield	1999	−.271	−.71, .16	20	Custom (based on Barfield & Hendrix)	Navigation, search and location marking	United States	Eng	Head-tracking & mouse vs. neither
Fox & Bailenson	2009	.233	.00, .47	69	Custom (10-item composite)	View imitation avatar eating	United States	SS	Change vs. no-change in avatar
Hendrix & Barfield (Exp. 2)	1996b	.425	−.14, .99	12	Custom (2 items)	Navigation	United States	Eng	Head-tracking vs. none
K. J. Kim & Sundar	2013	.932	.71, 1.15	80	ITC-SOPI (spatial presence subscale)	The House of the Dead 2 (FPS game)	Korea	SS	Gun replica controller vs. traditional controller
H. Lee & Chung	2013	.464	.22, .71	64	Custom (spatial involvement subscale)	Top Spin 4 (tennis simulator game)	Korea	SS	PS Move (motion tracking) vs. PS3 controller
McGloin et al.	2011	.138	.00, .28	195	Perceived Spatial Presence (based on Skalski et al., 2011)	Top Spin 3 (tennis simulator game)	United States	SS	Wiimote (motion tracking) vs. PS3 controller
Moreno & Mayer (Exp. 1)	2002	.040	−.22, .31	53	Modified PQ	View/navigate (“plant design” environment)	United States	SS	HMD and tracked walking vs. HMD and sitting

(*Continued*)

TABLE 1 (*Continued*)

Study	Date	r	*CI* (95%)	N	Presence measurement	Task(s)	Location	Domain	Additional notes
Nordahl	2005	.566	.12, 1.02	19	SVUP (presence items only)	Navigation (museum environment)	Denmark	Eng	Hear own footsteps vs. no audio
Peck et al.	2011	−.322	−.72, .08	24	SUS	Navigation and wayfinding tasks	United States	Eng	Walking in place vs. joystick
Regenbrecht & Schubert	2002	.320	.06, .60	56	IPQ	Navigate character-based environment	Germany	SS	Move freely vs. watched prerecorded sequence
Schmierbach et al.	2012	.186	−.01, .39	96	Custom	Need for Speed: Pro Street (racing game)	United States	SS	Steering wheel vs. traditional controller
Seay et al.	2001	.266	.14, .45	156	PQ	Navigation	United States	Eng	Driving vs. watching
Snow & Williges	1998	.750	.18, 1.32	12	Magnitude estimate	Distance estimation, ball manipulation, navigation, search, choice/selection	United States	Eng	Headtracking vs. none
Welch et al.	1996	.651	.21, 1.09	20	Custom (100-point scale comparison)	Driving simulator	United States	Eng	Active vs. passive exposure
Williams	2013	.154	−.08, .39	72	Based on K. M. Lee et al. (2005) questionnaire	Punchout (boxing game)	United States	SS	Wiimote + nunchuk vs. traditional controller
Zanbaka et al.	2004	−.254	−.53, .28	23	SUS	Navigation and path visualization	United States	Eng	Virtual walking with 6 DOF vs. with 3 DOF
					Field of view				
Bracken & Botta	2002	−.059	−.17, .06	291	Custom	View movie clips	United States	SS	65-inch vs. 32-inch screen
Bracken et al.	2010	.145	.01, .28	220	Custom	View movie clips	United States	SS	32-inch vs. 2.5-inch screen
De Kort et al.	2006	.119	−.10, .34	80	ITC-SOPI (spatial presence subscale)	View nature film	Netherlands	SS	35° vs. 15°
Hendrix & Barfield (Exp. 3)	1996b	.697	.13, 1.26	12	Custom (2 items)	Navigation	United States	Eng	GFOV (90 vs. 10)
Hou et al.	2012	.322	−.04, .68	30	4 items based on T. Kim & Biocca's (1997) physical presence scale	Tomb Raider 2 (action-adventure game)	United States	SS	81′ screen (76°) vs. 12′ screen (18°)
IJsselsteijn et al.	2001	.305	−.10, .70	24	Visual analog rating scale	View moving video (rally car driver POV)	UK	Eng	50° vs. 28° (resolution and distance kept identical)
Johnson & Stewart	1999	−.091	−.53, .35	20	PQ (version 3.0)	Navigation (heliport environment)	United States	SS	HMD with wide FOV (127° × 66°) vs. HMD with narrow FOV (40° × 30°)
K. J. Kim & Sundar	2013	.976	.76, 1.20	80	ITC-SOPI (spatial presence subscale)	The House of the Dead 2 (FPS game)	Korea	SS	42″ vs. 27″ monitor

(*Continued*)

TABLE 1 (*Continued*)

Study	Date	*r*	*CI* (95%)	*N*	Presence measurement	Task(s)	Location	Domain	Additional notes
Lombard et al.	2000	.198	−.04, .44	65	Custom	View video clips	United States	SS	46-inch vs. 12-inch screen (resolution and distance kept identical)
Prothero & Hoffman	1995	.243	−.08, .56	38	Custom (5-item composite)	Capture targets (“Sharkworld” environment)	United States	Eng	unmasked screen (105°) vs. visual scene masking (60°)
Schlindwein et al.	2013	.269	−.09, .63	30	SUS	Navigation, counting	Brazil	Eng	50° vs. 20°
Seay et al.	2001	.296	.11, .42	156	PQ	Navigation	United States	Eng	180° vs. 60°
Shim & Kim	2003	.256	−.15, .66	23	PQ (modified)	View virtual fish tank	Korea	Eng	180° vs. 120°
Snow & Williges	1998	.992	.43, 1.56	12	Magnitude estimate	Distance estimation, ball manipulation, navigation, search, choice/selection	United States	Eng	High (48 × 36) vs. Low (24 × 18)
Image quality									
Bracken & Botta	2002	.085	−.03, .20	291	Custom	View movie clips	United States	SS	High vs. standard definition
Bracken & Skalski	2009	.305	.03, .58	50	Lombard & Ditton (2000) 3-item questionnaire	Perfect Dark Zero (FPS game)	United States	SS	High vs. standard definition
Bracken	2005	.211	.01, .41	95	Lombard & Ditton (2000) 3-item questionnaire	View video clips	United States	SS	High vs. standard definition
Çiflikli et al.	2010	.530	.09, .97	20	PQ	Flight simulator	Turkey	Eng	High vs. low flickering
Dinh et al.	1999	−.003	−.13, .12	256	Custom (100-point scale and 13-item composite)	Navigation	United States	Eng	Localized lighting & high res. textures vs. ambient lighting & lower res. textures
Skalski & Whitbred	2010	.121	−.11, .35	74	TPI (spatial presence subscale)	Ghost Recon Advanced Warfighter (FPS game)	United States	SS	High vs. standard definition
Snow & Williges (Exp. 2)	1998	.336	−.23, .90	12	Magnitude estimate	Distance estimation, ball manipulation, navigation, search, choice/selection	United States	Eng	Texture mapping on vs. off
Snow & Williges (Exp. 3)	1998	.156	−.41, .72	12	Magnitude estimate	Distance estimation, ball manipulation, navigation, search, choice/selection	United States	Eng	High vs. low environmental detail
Welch et al.	1996	.808	.37, 1.25	20	Custom (100-point scale comparison)	Driving simulator	United States	Eng	High vs. low pictorial realism

(*Continued*)

TABLE 1 (*Continued*)

Study	Date	*r*	*CI* (95%)	*N*	Presence measurement	Task(s)	Location	Domain	Additional notes
Zimmons & Panter	2003	−.156	−.55, .08	25	SUS	Navigation and ball-dropping task	United States	Eng	High texture resolution & lighting quality vs. low texture resolution & lighting quality
Stereoscopy									
D. Ahn et al.	2014	.224	.06, .39	144	TPI (adapted items)	View 5 minute news story	Korea	SS	Stereoscopic vs. monoscopic
Bae et al.	2012	.966	.58, 1.35	26	TPI	View video clips	United States	SS	Stereoscopic vs. monoscopic
Baños et al.	2008	−.076	−.39, .23	40	ITC-SOPI (spatial presence subscale); SUS	Navigation (emotional environment) and picture selection task	Spain	SS	Stereoscopic vs. monoscopic
Freeman et al.	2000	.652	.25, 1.05	24	Visual analog rating scale	View moving and still videos	UK	SS	Stereoscopic vs. monoscopic
Hendrix & Barfield (Exp. 1)	1996a	.377	−.19, .94	12	Custom (2 items)	Navigation	United States	Eng	Stereoscopic vs. monoscopic
IJsselsteijn et al.	2001	.478	.08, .88	24	Visual analog rating scale	View moving video (rally car driver POV)	UK	Eng	Stereoscopic vs. monoscopic
Keshavarz & Hecht (Exp. 1)	2012a	.183	−.04, .40	78	Custom	View video of roller coaster ride	Germany	SS	Stereoscopic vs. monoscopic
Keshavarz & Hecht (Exp. 2)	2012a	−.143	−.31, .17	69	Custom	View video of roller coaster ride	Germany	SS	Stereoscopic vs. monoscopic
Lane et al.	2013	.456	.17, .75	46	TPI (spatial presence subscale)	Game-based simulation for intercultural communication training	United States	SS	3D vs. 2D game interface
Ling et al.	2012	.078	−.13, .29	88	IPQ; SUS	Give two 5 min talks (public speaking environment)	Netherlands	Eng	Stereoscopic vs. monoscopic
Muhlbach et al.	1995	.103	−.24, .45	32	Custom (4 spatial presence items)	Videoconferencing	Germany	Eng	Stereoscopic vs. monoscopic
Rajae-Joordens et al.	2005	.532	.9, .97	20	Presence and Engagement Questionnaire (Häkkinen et al., 2002)	Quake III Arena (FPS game)	Netherlands	Eng	3D vs. 2D game mode
Rooney et al.	2012	.519	.16, .88	29	ITC-SOPI (spatial presence subscale)	View video clips	Ireland	SS	3D (polarized glasses) vs. 2D
Schlindwein et al.	2013	.225	−.12, .57	33	SUS	Navigation, counting	Brazil	Eng	Stereoscopic vs. monoscopic

(*Continued*)

TABLE 1 (*Continued*)

Study	Date	*r*	*CI* (95%)	*N*	Presence measurement	Task(s)	Location	Domain	Additional notes
Snow & Williges	1998	.378	−.19, .94	12	Magnitude estimate	Distance estimation, ball manipulation, navigation, search, choice/selection	United States	Eng	Stereoscopic vs. monoscopic
Takatalo et al.	2011	.041	−.21, .29	60	PIFF[2] (physical presence subscale)	Need for Speed: Underground (racing game)	Finland	SS	High stereo vs. 2D mono
Yim et al. (Exp. 1)	2012	.431	.22, .64	85	Modified PQ	View 1 min commercials	United States	SS	“Stereoscopic 3D” vs. “flat 3D”
Yim et al. (Exp. 2)	2012	.373	.18, .56	85	Modified PQ	View 1 min commercials	United States	SS	“Stereoscopic 3D” vs. “flat 3D”
					Sound				
André et al.	2012	−.212	−.63, .21	22	TPI (spatial presence subscale)	View movie clips		Eng	Wave field synthesis vs. stereo
Dinh et al.	1999	.273	.15, .40	256	Custom (100-point scale and 13-item composite)	Navigation	United States	Eng	Ambient vs. no ambient sound
Hendrix & Barfield (Exp. 1)	1996b	.322	−.17, .81	16	Custom (2 items)	Navigation	United States	Eng	Spatialized sound vs. no sound
Hendrix & Barfield (Exp. 2)	1996b	.468	−.02, .96	16	Custom (2 items)	Navigation	United States	Eng	Spatialized vs. non-spatialized sound
Jeong et al.	2008	.007	−.21, .23	80	ITC-SOPI (physical presence subscale)	Half-Life 2 mod (FPS game)	United States	SS	Screams vs. no screams
Jeong et al.	2009	.158	−.10, .41	60	ITC-SOPI (physical presence subscale)	Half-Life 2 mod (FPS game)	United States	SS	Screams vs. no screams
Keshavarz & Hecht (Exp. 2)	2012a	−.004	−.23, .24	69	Custom	View video of roller coaster ride	Germany	SS	Sound vs. no sound
Keshavarz & Hecht	2012b	−.007	−.35, .34	32	PQ	Mirror’s Edge (action-adventure game)	Germany	SS	Sound on vs. off
Larsson et al.	2007	.790	.43, 1.15	30	SVUP (presence subscale); Custom (100-point scale)	Navigation	Sweden	Eng	Sound vs. no sound
Nichols et al.	2000	−.038	−.44, .36	24	Custom	Duck hunting game	UK	Eng	Sound vs. no sound
Poeschl et al.	2013	.366	.13, .61	66	SUS	Navigation (“forest clearing” environment)	Germany	Eng	Spatialized sound vs. no sound
Skalski & Whitbred	2010	.304	.08, .53	74	TPI (spatial presence subscale)	Ghost Recon Advanced Warfighter (FPS game)	United States	SS	5.1 (surround) vs. 2 channel (Dolby stereo)

(*Continued*)

TABLE 1 (*Continued*)

Study	Date	*r*	*CI* (95%)	*N*	Presence measurement	Task(s)	Location	Domain	Additional notes
Snow & Williges	1998	.833	.27, 1.40	12	Magnitude estimate	Distance estimation, ball manipulation, navigation, search, choice/selection	United States	Eng	Sound on vs. off
User perspective									
Kallinen et al.	2007	.172	−11, .45	50	MEC-SPQ	Elder Scrolls 3: Morrowind (fantasy role playing game)	Sweden	Eng	First vs. third person video game views
Lim & Reeves	2009	.377	−.04, .80	22	Custom (3 items)	World of Warcraft (fantasy role playing game)	United States	SS	First vs. third person video game views
High vs. low immersion									
S. J. Ahn	2011	.167	−.03, .36	101	ITC-SOPI (11 items)	Simulated tree-cutting experience	United States	SS	HMD with tracking vs. desktop
Axelsson et al.	2001	.633	.34, .93	44	Custom (3 items)	Cube puzzle task	Sweden	SS	CAVE-type system vs. desktop
Baños et al.	2004	.013	−.30, .32	40	ITC-SOPI (spatial presence subscale)	Navigation (emotional environment) and picture selection task	Spain	SS	HMD with tracking vs. desktop
Botella et al.	1999	.207	−.03, .44	69	Reality Judgment Questionnaire ("Sense of presence" item")	Guided navigation	Spain	SS	"High impact workstation" vs. PC, lower quality HMD, lower quality graphics card, and 2D mouse
Felnhofer et al.	2013	−.118	−.39, .15	52	PQ	Elder Scrolls IV: Oblivion (fantasy role-playing game)	Austria	SS	HMD with tracking and stereo display vs. flat screen
Gamito et al.	2006	.186	−.05, .42	69	SUS	Search task (beach and city environments)	Portugal	SS	HMD with tracking vs. translucid screen
Gorini et al.	2011	.473	.26, .69	84	UCL; ITC-SOPI (spatial presence subscale)	Navigation and search task (find blood container in virtual hospital)	Italy	SS	High (HMD, motion tracker, 640 × 480 res) vs. Low (external monitor, 1600 × 1200 res)
Johnson & Stewart	1999	−.214	−.65, .22	20	PQ (version 3.0)	Navigation (heliport environment)	United States	SS	HMD with high resolution vs. Wide screen display with lower resolution

(*Continued*)

TABLE 1 (*Continued*)

Study	Date	*r*	*CI* (95%)	*N*	Presence measurement	Task(s)	Location	Domain	Additional notes
Juan & Pérez	2009	.578	.19, .97	25	SUS (modified)	Navigation (with pit falling)	Spain	Eng	CAVE vs. HMD with tracking
K. Kim et al. (Comparison 1)	2014	.406	.39, .93	53	PQ	Search task (modified Stroop task)	United States	Eng	HMD vs. desktop
K. Kim et al. (Comparison 2)	2014	.659	.14, .68	53	PQ	Search task (modified Stroop task)	United States	Eng	CAVE vs. desktop
Krijn et al.	2004	.486	.09, .88	25	IPQ	Navigation through acrophobic treatment environments	Netherlands	SS	CAVE (with greater update rate and wider FOV) vs. HMD
Larsson et al.	2001	.481	.13, .83	32	SVUP (presence subscale)	Navigation and search task	Sweden	Eng	Actor (drive, headtracking, stereo, HMD) vs. Observer (projection, mono)
Lo Priore	2003	.244	−.32, .81	12	ITC-SOPI (spatial presence subscale)	Navigation and a series of executive function tasks	Italy	SS	HMD with tracking vs. flat screen with joystick
Lott et al.	2003	−.239	−.70, .22	18	PQ	Lateral reaching test	Canada	Eng	HMD vs. flat screen
Moreno & Mayer (Exp. 1)	2002	.163	−.09, .41	61	Modified PQ	View/navigate environment about plant design	United States	SS	HMD and tracked walking vs. desktop
Moreno & Mayer (Exp. 2)	2002	.247	.02, .48	75	Modified PQ	View/navigate environment about plant design	United States	SS	HMD and tracked walking vs. desktop
Moreno & Mayer	2004	.279	.00, .56	48	Modified PQ	View/navigate environment about plant design	United States	SS	HMD vs. desktop
Morina et al.	2012	.566	.27, .86	43	IPQ	Environment for social phobia treatment (simulating various real world scenarios)	Netherlands	Eng	HMD with tracking vs. projection
Nichols et al.	2000	.283	−.12, .68	24	Custom	Duck hunting game	UK	Eng	HMD vs. desktop
Peer et al.	2010	−.114	−.60, .38	16	Custom (single item measuring immersiveness)	Telemanipulation task (repair burst pipe)	Germany	Eng	HMD with tracking vs. Stereo Projection
Persky & Blascovich (Exp. 1)	2008	.401	.15, .65	62	8-item scale (from Swinth & Blascovich, 2001)	Custom FPS video game	United States	SS	IVETP vs. DTP

(*Continued*)

TABLE 1 (*Continued*)

Study	Date	*r*	*CI* (95%)	*N*	Presence measurement	Task(s)	Location	Domain	Additional notes
Persky & Blascovich (Exp. 2)	2008	.360	.19, .53	127	8-item scale (from Swinth & Blascovich, 2001)	Custom FPS video game	United States	SS	IVETP vs. DTP
Rand et al. (Exp. 1)	2005	−.291	−.51, −.07	80	PQ	Complete "Birds and Balls," "Soccer" or "Snowboard" simulations	Israel	Eng	GX + HMD vs. GX + monitor
Rooney & Hennessey	2013	.479	.32, .64	150	ITC-SOPI (spatial presence subscale)	View movie in theater	Ireland	SS	3D large screen vs. 2D
Sallnäs (Exp. 1)	2005	.000	−.31, .31	40	PQ (subset)	Partner-based decision-making task	Sweden	SS	Audio vs. video + audio conference
Sallnäs (Exp. 2)	2005	.523	.08, .96	20	PQ (subset)	Partner-based decision-making task	Sweden	SS	Audio vs. video + audio conference
Takatalo et al.	2006	.249	.07, .43	120	PIFF[2] (physical presence subscale)	Need for Speed: Underground, Slick n' Slide (racing games)	Finland	SS	Near-eye display vs. external monitor
Wallis & Tichon (Exp. 1)	2013	.344	−.23, .90	12	PQ & IPQ	Speed-perception task	Australia	SS	Wide-screen vs. "cab"
Wallis & Tichon (Exp. 2)	2013	−.037	−.60, .53	12	PQ & IPQ	Speed-perception task	Australia	SS	Wide-screen vs. "cab"
Widerström et al.	2000	.791	.58, 1.00	88	Custom (2 items)	Block puzzle task	Sweden	Eng	CAVE vs. desktop
Zanbaka et al.	2004	.584	.18, .99	23	SUS	Navigation and path visualization	United States	Eng	HMD & tracked walking vs. monitor & joystick

Note. Abbreviation within the "Presence Measurement" column correspond to the following: Witmer & Singer's Presence Questionnaire [PQ], the Slater-Usoh-Steed Questionnaire [SUS], the MEC Spatial Presence Questionnaire [MEC-SPQ], the Self-Assessment presence scale [SAM], the ITC Sense of Presence Inventory [ITC-SOPI], the Swedish Viewer-User Presence Questionnaire [SVUP], the Ingroup Presence Questionnaire [IPQ], the Temple Presence Inventory [TPI], the Ingroup Presence Questionnaire (Schubert et al., 2001), the Presence-Involvement-Flow Framework2 [PIFF2], and the University College London presences scale [UCL]. Abbreviations within the "Domain" column correspond to Social Sciences [SS] and Engineering [Eng]. Our literature review identified a few relevant studies in which haptic or tactile immersive features were manipulated and self-reported levels of presence were gathered, but sufficient statistics for inclusion in the current meta-analysis could not be obtained.

perspective," "resolution," "haptics," "HMD," and "CAVE." Similar searches for "presence" and key terms were completed using Google Scholar. Additionally, we directly reviewed the full journal archives for *Presence: Teleoperators and Virtual Environments* and *CyberPsychology, Behavior & Social Networking* for relevant studies. We also reviewed the full conference proceedings of the International Society for Presence Researchers (ISPR) and the IEEE Virtual Reality annual conference. From the initial list of studies produced through these searches, we then back-referenced through their citations, finding additional research reports from the proceedings of annual conferences for the Association for Computing Machinery (ACM) and the ACM Special Interest Group on Graphics and Interactive Techniques (SIGGRAPH), as well as articles from various journals related to human–computer interaction, human factors design, and communication science, as well as unpublished manuscripts. A special call for relevant papers was also posted on the ISPR homepage soliciting researchers for information regarding any relevant studies. Finally, publication bias is inherently a concern when conducting a meta-analysis, as nonsignificant effect sizes are commonly not reported or published. In an attempt to pursue unpublished work, authors were emailed with direct requests for any unpublished relevant studies.

This search process yielded over two hundred studies regarding user presence related to immersive technology. We then checked this list against criteria for inclusion. Specifically, in order to be included in the analysis, a study had to meet the following criteria:

1. include the manipulation of one or more specific immersive technology features;
2. include at least one self-report measure of user presence;
3. include sufficient detail to determine the relative immersiveness of the conditions compared; and
4. report an effect size or include sufficient details to calculate an effect size based on the condition comparisons relevant to the present analysis.

Of the initial pool of studies, 38 studies were excluded because they did not include a discrete manipulation of one or more immersive features. Studies excluded for this purpose typically manipulated factors not related to the system hardware (Ravaja et al., 2006). Additionally, 42 studies were excluded because they did not provide a self-reported measure of presence. These studies often included measures of related but different concepts—such as arousal or realism (Huang, Tsai, Sung, Lin, & Chuang, 2008)—or social or co-presence (Hauber, Regenbrecht, Hills, Cockburn & Billinghurst, 2005; Huang, 2003), but did not measure the more general form of spatial presence of focus in this analysis. Many of the studies excluded for failing this criteria focused on the effect of immersion on performance rather than user presence (e.g., Pausch, Proffitt, & Williams, 1997). An additional four studies were excluded because they did not provide enough details on system specifications to ascertain the relative immersiveness of each study condition. Finally, five research abstracts and conference papers from the original pool were excluded as they contained the same data sets from journal articles published at a later date and already included in our sample. For the remaining candidate studies, if the required details for calculating an effect size were not included, direct emails were sent to the authors. After multiple attempts to contact authors, 29 candidate studies were then omitted from our analysis due to insufficient study details. In total, we accumulated 83 studies that met the criteria and also provided enough details to include in our analysis, providing 115 separate effect sizes for manipulations of immersive quality.

The relative inclusion of the required criteria, along with several other study details, were coded by both authors. The authors initially trained on a specific coding scheme, with detailed rules on what constituted each value for a given study variable, and then together discussed each study to arrive at agreed upon values for each variable. Coded variables included the relative presence of the independent and dependent variables noted above, demographic and descriptive details of the participants, aspects of the mediated task (e.g., whether a spatial reasoning exercise, whether a game, whether narrative based), the presence of others during the mediated task (e.g., whether multiple users simultaneously engaged the system; whether experiences included digital humans in the form of avatars, agents, or other potential actors), the geographic location where the study was conducted, the disciplinary background of the study (whether conducted by social scientists or engineers, based on author affiliations and publication venue), and the particular self-report instrument used to gauge user presence.

Statistical Analysis and Procedures

The meta-analysis was conducted using the procedures described by Rosenthal and DiMatteo (2001) and, particularly in computing tests of heterogeneity, those detailed by Hunter and Schmidt (1990). These procedures were conducted for the full sample of studies as a whole as well as individually for each immersive feature category.

Effect size calculations and combination

In order to combine the results of the total pool of studies, an effect size was first computed for each study. Some studies included multiple experiments or independently tested multiple immersive features; in such cases each effect size was treated as a separate entry into the current meta-analysis. We standardized all effect sizes to the common metric of the correlation coefficient (*r*), as this is one of the more versatile effect size metrics available—not only is the correlation coefficient widely used, its practical importance is more easily interpreted than that of the alternative Cohen's *d* or Hedge's *g* (Rosenthal & DiMatteo, 2001).

Correlation coefficients were mainly derived from the group means and standard deviations on a given dependent variable measure. In instances where these statistics were reported across multiple groups (e.g., within a 2-×-2 design, offering two separate conditions with each level of the variable of interest), these statistics were aggregated with pooled variances. When means and standard deviations were not reported, the correlation coefficient was derived from *t* values or *F* values in which the numerator included only one degree of freedom (Rosenthal & DiMatteo, 2001). If a given study included multiple effect sizes of interest (e.g., multiple measures of spatial, general, or physical presence) these values were aggregated into a single effect size. To do this, the correlation coefficients for the measures were standardized through a Fisher *Z* transformation and averaged, with that average value then transformed back into a single correlation coefficient for the study.

Once a single correlation coefficient (*r*) was computed for each study manipulation, each was run through a Fisher *Z* transformation. Each transformed score (*z*) was then weighted by its respective study's sample size. Specifically, they were weighted by the inverse variance, *N-3*, where *N* is the number of paired observations of the different levels of the independent variable in that study (Lipsey & Wilson, 2001). Note, when different conditions included unequal numbers of observations, the higher value was used. Each of these weighted, transformed scores (*z* weighted) was then averaged into a single overall *z* score (overall *z*), which was then converted back into a single overall correlation coefficient (overall *r*). This value represented the overall effect size. This process was repeated multiple times—once to combine all studies included in the sample and then an additional time for each of the individual immersive features listed above (i.e., once for all tracking level studies, once for all stereoscopy studies, and so on). This allowed us to observe the overall effect of immersion as a whole on spatial presence, as well as to independently determine the relative effect of each immersive feature.

Interpretation of overall effect size

By Cohen's (1988) conventions a correlation coefficient of .10 can be interpreted as a relatively small effect size, with an *r* of .30 being considered a medium effect size, and an *r* of .50 or more being a relatively large effect size. With this framework, the relative size of the influence of one immersive feature on user presence can be compared to that of another. Of course, coupled with this loose rule of thumb should be consideration of the practical significance of the effect: Features yielding small effect sizes may be noteworthy, particularly in cases where the implementation of features providing larger effect sizes are constrained by cost or other factors.

In addition to this convention, the extent to which effect sizes significantly differ from one another may be formally tested as outlined by Cohen and Cohen (1983). By this procedure, two independent correlation coefficients and their respective sample sizes can be converted to a z score using a Fisher transformation. The value and direction of the z score provide a measure of whether the first effect size is significantly larger or smaller than the other. To this end, the overall effect sizes for the various immersive features can be compared to each other, allowing direct comparisons of their relative impact on user presence.

Tests of heterogeneity

Additionally, each overall effect size (one for the full pool of studies, plus another for each individual immersive feature category) was subjected to a test of heterogeneity (Hunter & Schmidt, 1990). This chi-squared test provides a measure of the heterogeneity of variance in correlation coefficients across the studies included in the sample. A significant result indicates that the variance is not completely due to sampling error and that there may be potential moderators within the sample. In such an event, potential moderating variables were then independently investigated. Hunter and Schmidt (1990) alternatively note what is known as the 75% rule, which asserts that if 75% or more of the variance across correlation coefficients can be attributed to corrected artifacts, including sampling error, then the remaining 25% is likely due to uncorrected artifacts rather than any moderating variables. Both chi-squared tests of heterogeneity and calculations of the percent of variance attributable to sampling error are provided in the analysis below.

RESULTS

Summary of Sample

In addition to their correlation coefficients, Table 1 includes additional descriptive information for all studies included in the sample. This allowed the researchers to not only categorize studies by the particular immersive feature each examined (which were then subjected to independent meta-analyses), but to also track values for variables that may potentially moderate the effect sizes observed (e.g., year conducted, social science vs. engineering discipline). Additional notes for a given study, such as which exact levels of an immersive feature were compared or which dependent measures of a given study were included in the analysis, are also indicated.

As seen in Table 1, studies that manipulated multiple features in tandem (overall high versus low levels of immersion) were the most common.

Next, were those comparing the impact of the tracking level or the use of stereoscopic vision, followed by those examining different fields of view, sound quality, and image quality. Least common were those that explicitly investigated the effects of update rate or user perspective.

The tasks comprising the mediated experiences of the sample studies included a range of activities, such as navigating traditional immersive virtual reality environments, playing video games, or participating in videoconferencing. Several studies simply required participants to enter an immersive virtual environment, explore the virtual space freely, then exit. Others included explicit spatial reasoning tasks (10 articles, offering 20 effect sizes), in which participants were required to make distance estimations, navigate a route as quickly as possible, or sketch a map of the environment afterwards. Twenty seven of the effect sizes collected came from studies that required participants to play a video or computer game with a particular immersive feature manipulated.

Although not depicted in Table 1 due to limited space, it should also be noted that the participants included in the studies analyzed were relatively homogenous in nature. Of the studies included in the analysis, the vast majority relied on generic convenience samples common to university-based research. The majority of studies included roughly even gender ratios (with exceptions typically being those with particularly small sample sizes). Sixty nine of the effect sizes analyzed came from samples with a mean age between 18 and 30 years old, while only nine effect sizes came from studies reporting older samples. This likely reflects that fact that 78 effect sizes came from convenient university-based sampling methods while only 10 came from studies using specially selected populations (such as expert drivers, phobic patients, and military pilots).

Conventional Interpretation of Effect Sizes

The results of the multiple meta-analyses—one combining all studies in the sample and then additional analyses for each immersion feature category—are presented in Table 2. Overall, immersive features as a whole had a medium-sized effect on spatial presence ($r = .316$), fitting the causal relationship typically assumed to exist. However, a more nuanced understanding of this result was offered by independently examining the relative effect size of each immersive feature.

Two of the independent features—update rate and user perspective—included particularly small sample sizes (K in Table 2). In turn, it may be especially risky to draw general conclusions about these features. However, we might more safely remark on the observed effect sizes for some of the features for which larger samples were obtained. Indeed, as seen in Table 2, certain features appear to influence presence more than others. Image quality—herein including manipulations of visual detail, quality, and

TABLE 2 Meta-Analysis Results for Overall Immersion and Individual Immersive Features

Independent variable	K	r (weighted)	95% Confidence interval	N	χ^2	Variance attributable to sampling error (%)
Immersion (all studies)	115	.316	.295 to .338	6998	2069.179*	15
Update rate	4	.529	.311 to .747	41	4.391	100
Tracking level	22	.408	.360 to .456	1566	319.772*	8
Natural vs. abstract mapping	7	.360	.279 to .441	587	133.295*	6
Many vs. some	6	.645	.546 to .745	390	44.578*	1
Some vs. none	10	.281	.204 to .358	645	189.786*	32
Field of view	14	.304	.246 to .363	1081	487.886*	5
Image quality	10	.150	.086 to .214	855	259.432*	39
Stereoscopy	18	.320	.257 to .383	928	270.748*	16
Sound	13	.260	.203 to .317	757	202.378*	30
User perspective	2	.234	.003 to .464	72	38.775*	100
High vs. low	32	.339	.294 to .385	1698	476.491*	30

*$p < .001$.

overall levels of realism—provided a small effect on presence ($r = .150$). Studies manipulating the relative presence or absence of sound also provided a small- to medium-sized effect on user presence ($r = .260$).

By comparison, other features produced effect sizes near or above the overall average. Studies that manipulated the field of view provided to the user had a medium effect size ($r = .304$). Stereoscopy—a commonly implemented feature in many immersive environment systems—offered a medium effect of .320. Comparably, overall high versus low manipulations of the immersive level of the system used (e.g., HMD with headtracking compared to a desktop display, CAVE simulation with motion tracking versus PC with keyboard and mouse inputs) had a medium impact on presence experienced ($r = .339$). In addition, tracking level—including any studies in which the number of degrees of freedom of user inputs was manipulated—provided a medium to large effect size ($r = .408$). The nature of the effect of tracking level on presence was then further examined by calculating the correlation coefficients for particular subgroups of tracking studies. Specifically, in order to examine the relative impact of direct mapping, an effect size was calculated for studies whose manipulations compared natural versus more abstract tracking of user inputs ($r = .360$). Additionally, a number of studies compared conditions in which users had no control over orientation or navigation through the mediated environment to conditions in which some control was afforded (labeled "Some vs. none" in Table 2), while other studies compared conditions in which relatively many versus relatively few degrees of freedom were tracked (labeled "Many vs. some" in Table 2). While some versus none studies yielded a small to nearly medium effect size

(r = .281), the many versus some studies provided a particularly large effect on presence (r = .645). Finally, update rate also had a large impact on user presence (r = .529), though again, the representativeness of this measure may be dubious in light of a small sample size (only four studies).

Tests of Heterogeneity of Effect Sizes and Moderator Analysis

Heterogeneity tests were conducted for each of the meta-analyses. A test was performed both for the overall sample as well as each of the subsamples clustered by immersive feature. A significant chi-squared statistic suggests that the correlation between immersion and presence varied across studies to such an extent that it cannot be attributed to sampling error alone. When this is the case, potential moderating variables across the sample need to then be examined.

As noted in Table 2, the overall sample of all immersion studies was significantly heterogeneous (p < .001). Additionally, this variance could not be accounted for through different operationalizations of immersion, as the vast majority of all individual immersive feature subsamples also contained a significant level of heterogeneity. The only exception was update rate (a subsample comprised of four studies).

These tests were followed by a search for potential moderators that could help account for variance between correlations. Various potential moderators between the studies were examined. Several demographics regarding study sample and background were examined, including the study and participant geographic location, the year in which the study was conducted, and the mean age of the sample. Methodological variables were also factored as potential moderators, including the sample recruitment type (common university-based convenience sample versus special population versus other), disciplinary background of the study (i.e., whether it was conducted by social scientists or sourced from the engineering literature on immersive technology), and the self-reported presence instrument used (comparing custom questionnaires versus seven of the most commonly used established instruments[1]). A number of variables regarding the tasks comprising the studies were also tested, including whether the task included spatial reasoning exercises, whether it involved playing a computer or video game, and whether the virtual task environment included other digital actors (avatars, agents, video actors) or only virtual objects. Finally, the social context of the study tasks was also considered, specifically whether or not participants engaged the mediated environment alone or simultaneously with other users. For each moderator, a Q statistic was calculated and then compared to a normal distribution through a chi-squared test in order to examine whether the heterogeneity of effect sizes was significant. Though accounting for these moderators slightly reduced the heterogeneity in correlations none provided statistically significant reductions in the heterogeneity of variance of effect sizes observed across the studies. However, these results are not surprising considering the relatively small number of studies comprising any particular level of the moderating variables tested.

Formal Comparison of Effect Sizes

Again, Fisher *Z* transformations were employed to also provide formal tests of whether the effects of two given immersive features were significantly different from one another. Table 3 lists the *z* scores and their respective significance levels for each comparison. Most notably, the effect of tracking level on user presence was found to be significantly larger than that of nearly all other immersive features (with the exceptions being the effects of update rate and user perspective, which again, may be questionable in light of their small sample sizes). Stereoscopy and field of view also provided relatively strong effects, both of which were significantly larger than that of image quality. Indeed, the impact of image quality on presence was particularly low in comparison to that of other features, with an effect size that was significantly smaller than that of update rate, tracking level, field of view, stereoscopy, sound, and overall high versus low manipulations. Similarly, the impact of sound on user presence was also relatively small compared to that of other features, with a significantly weaker effect than update rate, tracking level, and overall high versus low manipulations.

DISCUSSION

The relationship between the immersive quality of a mediated environment and the level of presence experienced by the user has been a topic of considerable theoretical discussion and empirical investigation. This pursuit is often predicated on the assumption that greater system immersion begets greater user presence, which, in turn, enhances the applied effectiveness of the mediated environment, across domains including healthcare and rehabilitation (Kalyanaraman, Penn, Ivory, & Judge, 2010; Riva, 2002), learning and formal education (Monahan, McArdle, & Bertolotto, 2008; Reeves, Cummings, Scarborough, & Read, 2010), and persuasion and commercial advertising (S. J. Ahn & Bailenson, 2011; Grigorovici, 2003), to name a few.

In light of an empirical literature containing varied operationalizations of immersion and varied operationalizations of presence this study employed a meta-analytic approach to examine the overall effect of immersion of presence. Specifically, it explored how some of the most commonly employed and theoretically interesting immersive features contributed to user reports of spatial presence. Overall, immersion was found to have a conventionally medium-sized effect on presence, while individual immersive features were found to vary in their effect sizes.

TABLE 3 Comparison of Differences in Effect Sizes for Individual Immersive Features

	Update rate	Tracking level	Field of view	Image quality	Stereoscopy	Sound	User perspective	High vs. low
Update rate $r = .529$, $N = 41$	—							
Tracking level $r = .408$, $N = 1566$	−0.95	—						
Field of view $r = .304$, $N = 1081$	−1.66*	−3.00**	—					
Image quality $r = .157$, $N = 830$	−2.64**	−6.63***	−3.57***	—				
Stereoscopy $r = .344$, $N = 859$	−1.55	−2.44**	0.39	3.81***	—			
Sound $r = .278$, $N = 688$	−1.94*	−3.76***	−1.01	2.31**	−1.34	—		
User perspective $r = .233$, $N = 72$	−1.74*	−1.59	−0.62	0.70	−0.75	−0.23	—	
High vs. low $r = .339$, $N = 1698$	−1.43	−2.28**	1.00	4.82***	0.52	1.99**	0.94	—

Note. Formal comparison of the extent to which the effect sizes of given immersive features are significantly different are listed above. Each value represents a Z score computed using the correlation coefficient and sample size of each feature. The effect of tracking level is significantly greater than most other features, with only update rate providing a larger effect. The effect of update rate is generally stronger than that of most features, though it is derived from a very small sample of four studies. Stereoscopy and field of view also each provide a larger effect than those of several other features. Finally, the effect of image quality is seen to be significantly lower than that of most other immersive features, including update rate, tracking level, field of view, stereoscopy, sound, and high vs. low manipulations of overall immersiveness.

$^{*}p < .1$.
$^{**}p < .05$.
$^{***}p < .001$.

The relative effects of a few individual immersive features are of particular note, both for the variance observed in their respective influence on presence as well as their practical implications. A few features in particular were found to have a relatively larger effect on spatial presence—tracking level, stereoscopy, and field of view. Discounting update rate (which was also found to have a large effect size, although based on a small sample of studies), tracking level, stereoscopy, and field of view have a stronger impact on user presence compared to other features, particularly image quality and resolution and sound. In other words, all else equal, given a fixed budget for designing an immersive system, a designer of mediated environments might be best advised to focus on tracking level, stereoscopic vision, and field of view rather than higher quality visual and auditory stimuli.

However, beyond practical considerations for system designers, the finding that particular immersive features provide greater gains than others in terms of user presence also offers some interesting theoretical implications. Indeed, these results may offer some compelling evidence for the formation of presence as outlined by the spatial situational model framework proposed by Wirth et al. (2007). Again, this framework suggests that presence is achieved through a two-step formative process, in which the user first constructs a spatialized mental model of the mediated environment (e.g., ascertains that the environment is a space) and then comes to accept this mediated environment over grounded reality as his or her primary frame of self-reference (e.g., ascertains that he or she is situated within that space). Completing this second step is thought to result in the experience of spatial presence, a two-dimensional construct construed in terms of perceived self-location and perceived possibilities to act within the environment at hand. That is to say, presence and its formation, as conceived by this framework, are premised on being able to tell where you are in a space. Supporting this, in empirically testing this framework Balakrishnan and Sundar, (2011) found the ability to navigate oneself through the mediated environment was key to experiencing presence.

General trends in virtual reality research and design align with this perspective, as the majority of the field is focused on aspects of sight and sound—senses responsible for gauging relative position in a large environmental space (Blascovich & Bailenson, 2011). To this extent, some of the most commonly considered features, as iterated by the sample of studies acquired here, pertain to overall improvement of visuals (in terms of resolution, detail, realism, etc.) and sound quality. What's particularly interesting, however, is that despite the prominence of these component features of immersive systems, they apparently contribute relatively weakly to user presence when compared to other features like field of view, stereoscopic vision, and tracking level.

One approach to understanding this distinction is to consider the extent to which each of these variables make a unique contribution to the user's sense of presence. For instance, image quality may not be particularly crucial to one's ability to construct a spatial model or self-locate. Surprisingly low thresholds of detail and realism have been found to often be more than enough to enable object identification and a sense of depth. Reeves and Nass (1996) found fidelity of visuals have no impact on user attention, recognition, or subjective experience, suggesting that people may not even notice when technology improves visual quality. Indeed, as Hochberg (1962) noted, "Perfect physical fidelity is impossible and would not be of psychological interest if achieved, but perfect *functional* fidelity . . . is completely achievable and is of considerable psychological interest" (p. 30). Functionally, most viewers are able to negotiate the spatial cues of low fidelity visuals, easily linking an image to what it is supposed to represent. This capacity may be attributed to innate properties of human perception, thereby removing the onus of fidelity from the media message itself (K. M. Lee, 2004b).

Bearing in mind the two-step model of presence formation, the concept of functional fidelity may be particularly appropriate in discerning not only why image and sound quality have a relatively smaller effect on presence than other features, but also why tracking level, stereoscopy, and field of view have a greater impact. The ability to interpret spatial cues so as to construct a spatial situational model is only the first step of the process; not only is physical fidelity not needed, but even if afforded through improved resolution, texturing, and the like, it will primarily only assist users in completing the first step of the formative process—construing the mediated environment as a spatial situation. In turn, other, different immersive features may be much more important to the second step—perceiving oneself as being located with that space and having the possibilities to take action in or navigate through it. Tracking level, for instance, might be much more important in regards to this step of presence formation. Systems that more finely track and incorporate multiple, natural user inputs—that is, track more degrees of freedom—likely provide users with a better sense of self-location, navigation, and action possibilities than do those with improved sound quality or visual realism. Further, the ability to discern relative depth of virtual objects through stereoscopy may assist users in processing the virtual space as one in which they are relatively positioned. Additionally, the observed impact of field of view on user presence also makes sense in light of this approach. When the mediated field of view encompasses a fuller proportion of the user's natural field of view, it may be easier to experience oneself as located within that virtual space as opposed to external reality.

In generalizing these findings to the design and implementation of immersive systems, it should be kept in mind that they apply to presence as it is most generally conceptualized, what K. M. Lee (2004a) construes as spatial presence. These results may not carry over to designing mediated experiences for eliciting feelings of self-presence or social presence.

For example, the situational model users must construct to experience social presence may depend far less on spatial cues and far more on issues of communication channels. If so, immersive system features are perhaps not the independent variables of concern when looking at social presence; rather, multi-modality, synchronous versus asynchronous communication, familiarity, and manipulations of artificial intelligence of agents and social actors may be more relevant variables to consider.

One potential limitation to this meta-analysis is that it compares studies involving technologies that change and improve over time. As such, the level used to operationalize high immersion in an older study might constitute low immersion in more recent research. To this end, the present meta-analysis relies on relative rather than absolute levels of immersion when comparing effects across studies. Doing so still permits a meaningful comparison of the relative contribution of different features in eliciting a sense of presence, however, it might make it more difficult to identify an exact threshold level at which a given immersive feature is enough or its effect plateaus. There is some comfort, however, in the fact that a reliance on relative comparisons is inherent to meta-analyses, as well as the finding that the year of publication—serving as a rough proxy for technological progress—was not seen to moderate the overall effects observed.

Further, particular restrictions should be considered when applying the findings yielded in this meta-analysis. Again, in examining the relationship between immersive system quality and user presence we relied on self-report measures. This conservative operationalization was for the sake of conceptual parity, as required by a meta-analysis. However, additional summative analyses, whether quantitative or qualitative in nature, are needed to similarly examine any overall trends in behavioral measures of presence (such as vection or physiological activity). Similarly, operationalizations of immersion were restricted to the most common, modal features manipulated in the literature. As a result some potentially interesting manipulations of immersion are not considered here. Although sight- and sound-related features are the most pervasive, newly emerging forms of immersive technology—including haptic or even olfactory features—may become more common in coming years. If so, a meta-analytic review of their relative contributions would be beneficial in the future.

Other future efforts could also investigate potential moderators of the relationship between immersion and presence. The variance in effect sizes across studies was here found to be significantly heterogeneous. The different operationalizations of immersion failed to fully account for this heterogeneity, as did several proposed moderating variables tracked here. Whereas the moderator analysis of a meta-analysis simply attempts to account for variance ad hoc, future studies could intentionally isolate and empirically manipulate potential moderators of interest in a more controlled, experimental fashion.

In "Virtually There" (2001), virtual reality pioneer Jaron Lanier outlined his vision of a world in which mediated reality would one day be capable of substituting many of the physically located elements of business, travel, and everyday interpersonal experiences. The long line of empirical work on presence, including the studies comprising the current analysis, have helped serve to fulfill this vision: After decades of research, development, implementation, and testing, immersive technologies are advancing to the point that such a world is near. What we find here, in a meta-analysis of those efforts, is that certain immersive system features may be more important than others in achieving the sense of being there that ultimately drives the promise of such technology. Future designs might therefore focus on such features—particularly tracking level, stereoscopy, and field of view—to better ensure that users process virtual environments as actual spaces in which they feel physically present.

NOTE

1. The included Witmer and Singer's (1996) Presence Questionnaire, the Slater–Usoh–Steed Questionnaire (Slater, Usoh, & Steed, 1994, 1995), the Temple Presence Inventory (Lombard, Ditton, & Weinstein, 2009), the Ingroup Presence Questionnaire (Schubert, Friedmann, & Regenbrecht, 2001), the ITC Sense of Presence Inventory (Lessiter, Freeman, Keogh, & Davidoff, 2001), the MEC Spatial Presence Questionnaire (Vorderer et al., 2004), and the Swedish Viewer-User Presence Questionnaire (Larsson, Västfjäll, & Kleiner, 2001).

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