A Survey of Presence in Virtual Environments and Related Concepts

RICHARD SKARBEZ, University of North Carolina at Chapel Hill
FREDERICK P. BROOKS, JR., University of North Carolina at Chapel Hill
MARY C. WHITTON, University of North Carolina at Chapel Hill

The presence construct, most commonly defined as the sense of "being there", has driven research and development of virtual environments (VEs) for decades. Despite that, there is not widespread agreement on how to define or operationalize this construct. The literature contains many different definitions of presence, and many proposed measures for it. This article reviews many of the definitions, measures, and models of presence from the literature. We also discuss several related constructs, including immersion, agency, transportation, and reality judgment. We also present a meta-analysis of existing models of presence informed by Slater's Place Illusion and Plausibility Illusion constructs.

CCS Concepts: • **Human-centered computing** → **Virtual reality;**

Additional Key Words and Phrases: Presence, Place Illusion, Plausibility Illusion, immersion, coherence, virtual reality, virtual environments

ACM Reference Format:
Richard Skarbez, Frederick P. Brooks, Jr., and Mary C. Whitton. 2016. A survey of presence and related concepts. *ACM Comput. Surv.* 0, 0, Article 0 (2016), 27 pages.
DOI: 0000001.0000001

1. EVALUATING VIRTUAL EXPERIENCES

Virtual environments (VEs) are tremendously sophisticated human-computer interfaces that are used for a wide variety of applications. Examples include psychological treatment, psychological research, military and medical training, entertainment, and sociological research. Each of these applications has different task requirements and objectives, and suggests different hardware or software implementations. Additionally, there is no consistent definition for what constitutes an effective VE. For these reasons, there does not yet exist a single, generalizable metric that can be used to determine whether a given VE is a success or not.

It is possible to identify specific measures that determine the effectiveness of a particular VE. For example, if a VE is developed to train participants to complete an assembly task, one could create tests of that training, e.g., number of units assembled per unit time, number of errors per unit time, or percentage of units correctly assembled. One could then develop a controlled experiment where some participants are trained using the VE and some are trained using whatever the traditional technique is. Then, when both sets of users are tested post-training, these measures would give some concrete evidence for whether the VE was effective at training. Such formal training transfer studies are rarely done, however, due to the time, effort, and cost required. Even if they were done, though, they would not enable the comparison of results among different VEs designed for different purposes.

The development of generalizable measures of VE effectiveness, then, remains an open research problem. One such concept, that of presence, has been driving VE research for decades.

Author's addresses: R. Skarbez, F. P. Brooks, Jr., and M. C. Whitton, Department of Computer Science, University of North Carolina at Chapel Hill.

DOI: 0000001.0000001

2. PRESENCE: WHAT AND WHY

The presence concept was introduced to the computing literature by Akin and colleagues, who defined *telepresence* as the condition that occurs when, "At the worksite, the manipulators have the dexterity to allow the operator to perform normal human functions. At the control station, the operator receives sufficient quantity and quality of sensory feedback to provide a feeling of actual presence at the worksite" [Akin et al. 1983]. Presence has since been defined and operationalized in many ways by different researchers, but it is most commonly defined as something akin to the feeling of "being there" in a virtual place. One example comes from Witmer and Singer, who defined presence as "the subjective experience of being in one place or environment, even when one is physically situated in another" [Witmer and Singer 1998].

Presence has the distinct advantage of being a metric applicable to any VE. One can reasonably ask how present a user was in any given VE *A*, and then ask how present the user was in some VE *B*, and if the user reports more presence in VE *A*, then that is some evidence that enables the comparison of VEs *A* and *B*, though they may represent entirely different scenarios and be designed for entirely different purposes.

While conceptually appealing, the evaluation procedure described in the previous paragraph has several very important flaws. First is that determining "how present" a user is is in itself a very difficult problem. Presence is what the philosophy literature calls a *quale* (plural *qualia*), which is defined as a subjective and internal feeling elicited by sense perceptions. This subjective and internal nature makes measurement of presence (or any quale) extremely difficult. The predominant method has been to use one or more post-experiment questionnaires to measure presence, but this is itself problematic. There have been efforts to develop objective correlates of presence, including physiological [Meehan et al. 2002] and behavioral [Freeman et al. 2000] measures, but these are also flawed, requiring the addition or modification of elements of the VE to enable measurement of presence.

For example, the most common physiological surrogate for presence is arousal, which can be detected using measures of heart rate or skin conductance. The change in heart rate associated with the onset of a stressful stimulus was shown by Meehan to correlate with presence [Meehan et al. 2002]. However, adding a stressful stimulus to a non-stressful training task may violate the ecological validity of the training. Or, if a task also involves physical exertion, it may not be possible to distinguish the effect of the stressful stimulus from the heart rate changes associated with the exertion. Therefore, while physiological and behavioral metrics are promising, they are not one-size-fits-all solutions.

Hendrix and Barfield proposed that a subjective measure of presence should be relevant, sensitive, convenient, nonintrusive, and reliable [Hendrix and Barfield 1996a]. In Meehan's dissertation he posited that an ideal measurement of presence would be reliable, i.e., producing repeatable results, both within and between subjects; valid, i.e., demonstrated to correlate with the subjective feeling of presence; multi-level-sensitive; and objective [Meehan 2001]. These are standard principles of sound testing practices [AERA/APA/NCME 2014]. We would go further and suggest that such an ideal metric should also be measurable contemporaneously, continually, and without modification to the scenario, and should be generalizable across VEs. No measure of presence yet exists that meets all of these criteria.

A second important flaw, beyond the difficulty inherent in measuring presence, is that it has not been conclusively demonstrated that more presence is necessarily a good thing. Welch argues powerfully that there is no inherent reason to think that more presence leads to improved task performance in a VE [Welch 1999]. Experimental results linking presence and task performance are mixed [Slater et al. 1996] [Witmer and Singer 1998] [Snow 1998] [Modjeska and Waterworth 2000], and even so, it is difficult to distinguish whether any benefits would be due to increased presence or increased immersion. (Unless specifically stated otherwise, *immersion* is used in this article to mean Slater's conception of immersion as an objective characteristic of a VE system [Slater 1999]. The different definitions of immersion in the VE literature are addressed in Section 5.1.1.)

So, presence is defined and operationalized in many different and occasionally conflicting ways, is inherently difficult to measure, there are many different measures to choose from, and it may not actually correlate with what one actually cares about in a VE in the first place. To address some of these concerns, Slater proposed a theory that presence is composed of two orthogonal components, Place Illusion and Plausibility Illusion, and that together these factors will enable a user to react-as-if-real (RAIR) while in a VE [Slater 2009]. For many applications, eliciting RAIR from users is in fact what it means for a VE to be effective.

3. PLACE ILLUSION AND PLAUSIBILITY ILLUSION

In 2009, Slater introduced the concepts of Place Illusion (PI) and Plausibility Illusion (Psi) as the two constructs that contribute to realistic response in virtual environments. He defined PI as, "the…illusion of being in a place in spite of the sure knowledge that you are not there," and Psi as, "the illusion that what is apparently happening is really happening (even though you know for sure that it is not)" [Slater 2009]. PI, then, corresponds to the traditional conception of presence as "being there", while Psi represents an entirely different conception of presence, that of believing what you are seeing. For example, assume you are in a VE intended to represent a library. Here, presence would be your feeling of, "I am in a real library." If you turned your head and saw more bookshelves, that would reinforce your feeling of PI. If all the library patrons were being quiet, that would reinforce your feeling of Psi. Contrarily, if you turned your head and the imagery didn't change, that would break PI, and if patrons were yelling loudly in the library, that would break Psi.

4. INTRODUCTION

In Section 2, we introduced the presence construct, along with comments regarding the ways in which it is defined and measured. In the remainder of this article, we explicate many of these definitions and methods of measurement, identify some of the core themes and key differences in how presence is discussed, and introduce related concepts including transportation, agency, and reality judgment. We present the work on presence as three sections: definitions of presence, measurement of presence, and models of presence—that is, works that propose a list of factors that contribute to presence. We present our analyses at the end of each section.

5. DEFINING PRESENCE

There have been many definitions of presence proposed in the literature. We propose that these can be grouped into three categories: being there, non-mediation, and other. Those definitions we classify as *being there* consider presence to be the feeling of being in an environment, while those we classify as *non-mediation* consider presence to be a lack of attention to the mediating technology. Those definitions grouped under *other* define presence as the experience of virtual objects as a focus on direct perceptual processing [Waterworth and Waterworth 2001], presence as the perception of objects as real [Lee 2004], or presence as the sense of feeling real [Parola et al. 2016].

We further propose that the being there definitions can be subdivided into two subcategories, active (in which the ability to act is specifically considered as part of the definition) and passive (in which user actions are not specifically addressed). we also propose that non-mediation definitions consist of two subcategories, internal (in which the focus is on one's thoughts, as in "suspension of disbelief" and external (in which the focus is on the technology, as in the "illusion of non-mediation"). The classification of definitions into these categories and subcategories can be seen in Table I.

Table I. Categories of presence definitions

Being there		Non-mediation		Other
Active	Passive	External	Internal	Perceptual processing
[Steuer 1992]	[Witmer and Singer 1998]	[Lombard and Ditton 1997]	[Slater and Usoh 1993]	[Waterworth and Waterworth 2001]
[Schloerb 1995]	[Sas and O'Hare 2003]	[International Society for Presence Research 2000]		
[Flach and Holden 1998]	[Spagnolli and Gamberini 2004]			Real objects
[Zahorik and Jenison 1998]	[Wirth et al. 2004]			[Lee 2004]
[Mantovani and Riva 2001]				
[Biocca 2001]				Feeling real
[Slater 2004]				[Parola et al. 2016]
[Carassa et al. 2005]				
[Witmer et al. 2005]				
[Riva et al. 2006]				
[Herrera et al. 2006]				
[Wirth et al. 2007]				

In the remainder of this section, we present these definitions grouped by category, and arranged in chronological order within each category, to better highlight the evolution of the concept over time. Our comments follow at the end of this section.

5.1. Definitions

The notion of presence as it is used in the context of virtual reality can be traced to psychologist James Gibson, who defined *presence* as "the experience of one's physical environment. . . not [one's] surroundings as they exist in the physical world, but [the] perception of those surroundings as mediated by both automatic and controlled mental processes" [Gibson 1979]. In this Gibsonian context presence is explicitly in the context of the real world, but already the idea is in place that presence can't be determined simply by considering the ground truth of the real environment, it is a *subjective* feeling generated by our perception of the real world as *mediated* by our sense organs and the mental processes governing and integrating them.

5.1.1. Being there. Steuer introduced Gibson's notion of presence to the field of computer-mediated environments, defining the term *telepresence* as "the experience of presence (in the sense of Gibson) in an environment by means of a communication medium" [Steuer 1992]. Steuer's definition marks the start of some significant confusion, as many researchers have been concerned primarily—or only—with the sense of presence in computer-mediated or virtual environments, but common practice has been to refer to the sensation simply as presence, rather than "telepresence" or "virtual presence."

Schloerb introduced a different, "objective" definition of presence [Schloerb 1995]. *Subjective presence* occurs when one perceives oneself as physically present in an environment. However, one is only *objectively present* if one can successfully complete a specified task in the environment. Here, then, we have an explicit, and in fact definitional, link between presence and task performance: If one can successfully complete more tasks more often, one is more present.

Flach and Holden returned to Gibson's research as the basis of presence, but not just in terms of his definition of presence [Flach and Holden 1998]. To Gibson, "the reality of experience is grounded in action"—humans see the world in terms of affordances; that is, in how can they interact with the world around them. The important characteristics of the world, then (and in particular, the characteristics of the world that are important for experiencing presence) are behavioral, rather than aesthetic.

Continuing that line of thinking, Zahorik and Jenison described presence as "tantamount to successfully supported action in the environment" [Zahorik and Jenison 1998]. To them, presence is determined by the extent that the perception/action coupling in the virtual world matches our learned perception/action coupling in the real world.

Mantovani and Riva presented a view of the Gibsonian actor in [Mantovani and Riva 2001]. For such an ecologically situated actor there is not a clear separation of the subjective internal model of the world and the objective ground truth of the outer world. Rather, the actor is constantly in a process of adaptation to the estimated (that is, mediated) world in which they exist. In this picture, one's willingness to "react as if real" to the observed stimuli and the world's ability to "react as if real" to their sensorimotor actions are in fact inseparable.

In the paper which presented their landmark Presence Questionnaire, Witmer and Singer defined *presence* as, "the subjective experience of being in one place or environment, even when one is physically situated in another" [Witmer and Singer 1998].

In 2001, Biocca defined *presence* as "the phenomenal state by which an individual feels located and active in an environment, and, especially in the case of telepresence, the class of experience where the environment is mediated by a technology" [Biocca 2001]. So here, the user must not only be "located" (the traditional sense of "being there"), but must also be "active." This is in keeping with the Gibsonian tradition, as in Zahorik and Jenison [Zahorik and Jenison 1998] and Flach and Holden [Flach and Holden 1998]. Note also that all these authors treat telepresence as a special case of presence, and that presence can be (and normally is) felt in the real world.

In 2003, Slater revisited presence terminology, describing presence as a "response" to "an appropriate conjunction of the human perceptual and motor system and immersion" [Slater 2004]. This is quite similar (albeit using very different terminology) to Zahorik and Jenison's conception of presence as being-in-the-world [Zahorik and Jenison 1998]. To Slater, if we assume there is an actor (with a functioning perceptuomotor system) ecologically situated in the world (the precise nature of the world and this situation being defined as *immersion*), then presence arises to the extent that a valid perception/action coupling is supported by the virtual environment (VE) system. Also, note the novel conception of presence as a "response." Presence, in this conception, can occur involuntarily: if the correct set of stimuli are provided (in terms of the immersion of the system and the perceptuomotor characteristics of the individual user), then presence will result. This seems to represent an evolution in thinking from Slater's earlier definition of presence involving suspension of disbelief.

Immersion

An aside about immersion: The concept of immersion is the source of some confusion in its own right. Slater has consistently regarded immersion as an objective characteristic of a VE system [Slater 1999]. This is in contrast to Witmer and Singer, who define *immersion* as, "a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences" [Witmer and Singer 1998]. Lombard and colleagues refer to these different conceptions of immersion as *perceptual immersion* [Biocca and Delaney 1995] and *psychological immersion*, respectively [Lombard et al. 2000]. These are clearly related concepts—Slater's immersion is what makes it possible to experience Witmer and Singer's immersion—but using them interchangeably has led to a lack of clarity in the VR literature. In particular, immersion is often used as a term roughly synonymous with presence. (For just one example of such, see [McGloin et al. 2013].) In this document, we follow Slater in using immersion to mean an objective characteristic of a VE system. Specifically, we define *immersion* as the set of valid actions supported by a VE system [Slater 2009].

Coherence

In the paper that introduced Place Illusion and Plausibility Illusion, Slater stated that "Immersion provides the boundaries within which PI can occur" [Slater 2009]. That is, immersion gives rise to PI. In his dissertation, Skarbez argues that there must be a parallel construct to immersion, that is, an objective characteristic of a virtual scenario that gives rise to Plausibility Illusion. To that end, he defines *coherence* as the set of reasonable circumstances that can be demonstrated by the scenario without introducing unreasonable circumstances, where a *reasonable circumstance* is a state of affairs in a virtual scenario that is self-evident given prior knowledge [Skarbez 2016].

Sas and O'Hare offered a slightly different conception of presence: one is *present* in another world (mediated or imaginary) if (1) one's cognitive processes are oriented toward that world to the extent that one experiences "being there", and (2) one's focus of consciousness is on the proximal (body-oriented, perhaps) stimuli in the mediated or imaginary world [Sas and O'Hare 2003]. Here, as in Biocca [Biocca 2001], we see a definition of presence as "being there plus", in this case, the "plus" being the fact that one is responding to stimuli from the virtual world, rather than the real one. It appears that this definition assumes that one can, at any given moment, be present in one or the other environment; that consciousness can have two foci seems unlikely.

Spagnolli and Gamberini, on the other hand, maintained the focus of presence on location [Spagnolli and Gamberini 2004]: "Whenever a person is qualified as 'present'... her location is the salient, characterizing feature." So an interaction with a virtual human in the real world might elicit a whole host of feelings, but it would not elicit a sense of presence.

Wirth and colleagues defined *spatial presence* as "the subjective experience of being in the mediated environment" [Wirth et al. 2004]. Here again we have presence limited to mediated environments. For the authors it has two components: the sensation of being physically situated in the

environment (self-location) and the perception of possibilities to act in that environment (possible actions). This is another example of "being there plus", as well as another definition of presence that is largely in keeping with the traditional Gibsonian definition.

Carassa and her colleagues proposed a definition of *presence* inspired by situated cognition theory, in which "presence depends on the proper integration of aspects relevant to an agent's movement and perception, to her actions, and to her conception of the overall situation in which she finds herself, as well as on how these aspects mesh with the possibilities for action afforded in the interaction with the virtual environment" [Carassa et al. 2005]. In our interpretation, this correctly integrates a user's learned expectations for correct behavior into the Gibsonian model of presence in virtual environments.

Witmer and Singer clarified their definition of *presence* in [Witmer et al. 2005]. Here, *presence* is defined as a psychological state of "being there" mediated by an environment that engages our senses, captures our attention, and fosters our active involvement." They also define *involvement* as "a psychological state experienced as a consequence of focusing one's mental energy and attention on a coherent set of stimuli or meaningfully related activities or events."

Riva and colleagues defined *presence* as "the non-mediated (prereflexive) perception of successfully transforming intentions in action (enaction) within an external world" [Riva et al. 2006]. This builds on Zahorik and Jenison's conception of presence as successfully supported action in the environment [Zahorik and Jenison 1998]. Here, we have no distinction between real, virtual, or imaginary worlds: you can feel present in any or all of them if you are able to transform your intentions into action. Also, it is a prereflexive, or intuitive, perception: it is again something that "just happens" if the system is sufficiently in tune with your needs (or vice versa), similar to Slater's conception of presence as a response.

Herrera et al. defined *presence* as the "conscious awareness of self, as both agent and experiencer, which characterizes the experiencing self of natural environments" [Herrera et al. 2006]. Here again, this could apply to real, virtual, and mediated environments (although, the authors state, not imaginary ones—the environments they refer to are "experienc[ed]", not imagined). This conception of self as both "agent and experiencer" again echoes Gibson, in whose view one is always both acting on and being acted upon by the environment.

Wirth and colleagues refined their definition of *spatial 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" [Wirth et al. 2007].

5.1.2. Non-mediation. Slater and Usoh introduced the notion that *presence* in a mediated environment is "(suspension of dis-)belief that [one] is in a world other than where [one's] body is located" [Slater and Usoh 1993]. Slater and Usoh's definition introduced several new ideas: one, that we first believe that we are not in the mediated environment, and two, that by some process, we can overcome that belief. This idea of presence involving "suspension of disbelief" is a recurring concept in the presence literature.

Lombard and Ditton proposed that *presence* is "the perceptual illusion of nonmediation" [Lombard and Ditton 1997]. Note that this definition is explicitly for tele- or virtual presence, not presence in a real environment; it assumes the existence of a communication medium that can seem to disappear. One could make the argument, as in Gibson, that our experience of the world is always mediated—that our perception of the world is not the same as the world itself—and so presence in the real world is only a special case of such mediated presence experiences. Lombard and Ditton did not make this argument.

Lombard and Ditton also explicitly defined presence as binary: "It does not occur in degrees but either does or does not occur at any instance during media use." This is closely associated to the conceptualization of presence as an illusion: either the illusion is in place, or it is broken. Slater's later conceptions of Place Illusion and Plausibility Illusion are very much in keeping with this school of thought [Slater 2009].

Presence was officially defined by the International Society for Presence Research as follows:

> "*Presence* (a shortened version of the term *"telepresence"*) is a psychological state or subjective perception in which even though part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience. Except in the most extreme cases, the individual can indicate correctly that s/he is using the technology, but at *some level* and to *some degree*, her/his perceptions overlook that knowledge and objects, events, entities, and environments are perceived as if the technology was not involved in the experience. *Experience* is defined as a person's observation of and/or interaction with objects, entities, and/or events in her/his environment; *perception*, the result of perceiving, is defined as a meaningful interpretation of experience" [International Society for Presence Research 2000].

This definition is clearly indebted to Lombard and Ditton, as the focus is on the illusion of non-mediation rather than the experience of a place. However, it would seem that the ISPR authors reject Lombard and Ditton's belief that presence is binary, with the language of "part or all" of an individual overlooking the mediating technology to "some level and to some degree." Note also that the authors are explicit about the fact that they are using *presence* to mean *telepresence*, indicating clearly that this definition is only applicable to technology-mediated interactions.

5.1.3. Other - Focus on perceptual processing. Waterworth and Waterworth defined *presence* as "psychological focus on direct perceptual processing", and *absence* as "...conceptual processing", such as reflection or hypothesis testing. They specifically stated that presence as so defined can be felt in the real world, as the perceptual processing is "of things that are present in the current environment, whether real or virtual" [Waterworth and Waterworth 2001]. In this paper they also proposed that there are three dimensions of experience: focus (whether one is processing information perceptually or conceptually), locus (whether attention is devoted to the real or the virtual world), and sensus (whether one is conscious or unconscious). All of these indicate an attentional component of presence in their conception of it.

5.1.4. Other - Objects are experienced as real. Kwan Min Lee defined *presence* as "a psychological state in which virtual (para-authentic or artificial) objects are experienced as actual objects in either sensory or nonsensory ways" [Lee 2004]. This is a new definition, that clearly puts the focus on things in the virtual world. If one experiences these things as actual objects, they are present; if one doesn't, they aren't. The "sensory or nonsensory" language is included specifically to account for situations where feelings of presence are elicited by non-immersive media such as text (known as the "book problem"). So "being there" is no longer the primary quality of the experience, making this definition more amenable to usages in applications where one, for example, interacts with a virtual human rather than experiencing a new place.

5.1.5. Other - The sense of feeling real. Parola et al. defined *presence* as "the sense of feeling real". They refer to the presence formation process as an "alignment of external stimuli with an internal set of schemata", which highlights the importance of user expectations and prior experiences in that process [Parola et al. 2016]. This definition has more in common with Slater's Psi [Slater 2009] or Baños's reality judgment [Baños et al. 2000] than it does with any other definitions of presence. Notably, it conflicts with definitions that place a central focus on the feeling of being in a place, including, but not limited to, Spagnolli and Gamberini's [Spagnolli and Gamberini 2004].

5.2. Analysis

So what, in the end, do we mean when we say *presence*? It seems to us that the shortest and most commonly used definition, "the feeling of 'being there'," actually comes quite close to the heart of the matter. Defining presence as a feeling has some theoretical grounding, as well; Schubert

conceptualizes presence as a "cognitive feeling," with all that entails. (It is caused by unconscious processes, it is immediate, it can vary in intensity, etc.) [Schubert 2009].

We do not agree with some aspects of presence that appear in the definitions in the previous section. Firstly, we disagree with definitions that require the illusion of nonmediation. Spagnolli and Gamberini showed that users were capable of acting simultaneously in the virtual/mediated environment and the real environment [Spagnolli and Gamberini 2002]. It seems clear in this case that the user is aware, at least on some level, that it is a mediated experience, since they are able to speak and act in ways that demonstrate their awareness of the mediation. Similarly, we feel that the very existence of the book problem [Biocca 2002] is reason to doubt this conception of presence. We are not aware of any study that attempted to demonstrate that readers are present only in the environment presented in the book, but we suspect, on face, that while a user reading a book may report feeling presence, they are always aware of the fact that they are reading a book.

We also feel that the conception of presence as a binary (on/off) construct is not necessarily true. The Spagnolli and Gamberini study cited above provides some evidence to the contrary, and Schubert also argues against this requirement. It may be true that users will report feeling present primarily in one space at any given time, but even so, there is no reason to believe that the strength of this feeling must be constant. It may be that "feeling of presence" can be conceived of as a continuous function that, as it rises and falls, may rise above or fall below a binary threshold.

Definition of presence in this article

In this article, we follow Schubert in defining *presence* as the cognitive feeling of being in a place. This feeling can change based on the sensory representation of the place (particularly in the case of a mediated environment, where this is dictated by the immersion of the mediating technology), the affordances available to the user, the scenario in which the user finds himself, and the user's personal history, state, and traits. Or, in short, the user who is present is located and active in the space, whether real or mediated.

We claim that presence arises from the immersion of the system (the sensorimotor and effective valid actions it supports), the coherence of the scenario, and the individual characteristics of the user. That is, it arises naturally in a user who experiences Place Illusion and Plausibility Illusion.

6. MEASURING PRESENCE

Welch and colleagues identified self-report, behavioral, and physiological measures as potential means of measuring presence [Welch et al. 1996]. We follow that categorization here in discussing the variety of presence measures that appear in the literature.

6.1. Self-report

Self-report refers to all techniques in which users report their subjective feelings of presence to the experimenter. An important subset of self-report measures are post-experience questionnaires, which are discussed separately below.

6.1.1. Questionnaires. This section briefly describes several existing questionnaires designed to measure presence (typically referred to as *presence questionnaires*), and concludes with discussion of their history of use. These questionnaires are summarized in Table II. (This table inspired by similar ones appearing in [Lombard et al. 2009] and [Lombard et al. 2011].)

The first commonly used presence questionnaire to appear in the literature was the Slater-Usoh-Steed (SUS) questionnaire, which first appeared in some form in [Slater et al. 1993] (later republished as [Slater et al. 1995]). In the 1993 version of the SUS questionnaire there were only three questions. The more common form of the questionnaire has six questions, and can be seen in, for example, [Usoh et al. 2000].

Kim and Biocca introduced a questionnaire based around the constructs of arrival and departure [Kim and Biocca 1997]. *Arrival* is the feeling of being there in a mediated environment, *departure* is the feeling of not being in the real environment.

Table II. List of presence/telepresence questionnaires

Questionnaire	# Items	Subscales	Intended use
Slater-Usoh-Steed (SUS) questionnaire [Usoh et al. 2000]	6	No separate subscales	Virtual environments
Arrival/Departure [Kim and Biocca 1997]	8	Arrival; Departure	Cross-media
Witmer-Singer Presence Questionnaire (PQ) [Witmer and Singer 1998]	19	Involved/Control; Natural; Interface Quality	Virtual environments
Reality Judgment and Presence Questionnaire (RJPQ) [Baños et al. 2000]	77	Reality judgment; Presence; Emotional involvement; Interaction; control; Attention/Flow; Realism, Congruence/Continuity; Expectations	Virtual environments
Swedish Viewer-User Presence (SVUP) questionnaire [Larsson et al. 2001]	150	"quality evaluations, attitudes, presence, and realism, and information from different modalities as well as simulation sickness items"	Virtual environments
ITC-Sense of Presence Inventory (ITC-SOPI) [Lessiter et al. 2001]	44	Sense of physical space; Engagement; Naturalness; Negative effects	Cross-media
Igroup Presence Questionnaire (IPQ) [Schubert et al. 2001]	14	Presence; Spatial presence; Involvement; Realness	Virtual environments
Sas and O'Hare questionnaire [Sas and O'Hare 2003]	34	Being there; Not being here; Reflective consciousness	Virtual environments
MEC-Spatial Presence Questionnaire (MEC-SPQ) [Vorderer et al. 2004]	L: 72; M: 54; S: 36	Attention allocation; Spatial situation model; Self-location; Possible actions; Cognitive involvement; Suspension of disbelief; Domain-specific interest; Visual/spatial imagery; absorption	Cross-media
Experimental Virtual Environment - Experience Questionnaire (EVEQ) [Takatalo 2002]	124	Physical presence; Situational involvement; Competence	Virtual environments
Temple Presence Inventory (TPI) [Lombard et al. 2009]	42	Transportation; Immersion; Realism; Social actor within a medium; Social richness	Cross-media
Virtual Experience Test (VET) [Chertoff et al. 2010]	17	Affective; Cognitive; Sensory; Active; Relational	Cross-media

Witmer and Singer introduced their Presence Questionnaire (PQ) in [Witmer and Singer 1998]. The PQ is based on the authors' conception of presence as having four major categories of factors: control, sensory, distraction, and realism. Each of the nineteen questions (reduced from thirty-two) is designed to address some aspect of one of these four factors.

In the same paper, Witmer and Singer introduced their Immersive Tendencies Questionnaire (ITQ). This questionnaire is intended to measure an individual's tendency to become involved in everyday activities, as a proxy for their likelihood to experience presence in a VE. The ITQ contains eighteen questions, reduced from twenty-nine.

Lombard et al. discussed their efforts to develop an instrument for presence based on their theoretical model of its components in [Lombard et al. 2000]. In the paper, they identify six "dimensions" of presence they found in the literature: presence as social richness, presence as realism (both social and perceptual), presence as transportation, presence as immersion, presence as a social actor within

a medium, and presence where the medium is a social actor. The authors claim that the common element among these types of presence is a perceptual illusion of nonmediation. To measure these different conceptions of presence, the authors present a 103-item questionnaire.

Baños and her colleagues argued that presence and reality judgment (the belief that our experiences are real, or, they say, willing suspension of disbelief) are separate constructs and should be treated as such [Baños et al. 2000]. They presented an initial seventy-seven-item questionnaire, the Reality Judgment and Presence Questionnaire (RJPQ), intended to measure both constructs. They chose questions to address nine factors of experience: reality judgment, presence, emotional involvement, interaction, control, attention/flow, realism, congruence/continuity, and expectations.

Larsson, Västfjäll, and Kleiner used a subset of the Swedish Viewer-User Presence Questionnaire (SVUP) to measure presence in [Larsson et al. 2001]. In this experiment, they used eighteen items covering interaction, presence, awareness of external factors, sound quality, enjoyment, and simulation sickness. The full questionnaire is unpublished, but is said to comprise, "150 items covering quality evaluations, attitudes, presence, and realism, and information from different modalities as well as simulation sickness items."

Lessiter and colleagues introduced the ITC Sense of Presence Inventory (ITC-SOPI) in [Lessiter et al. 2001]. The intent of this 44-item questionnaire is to focus entirely on the user's experience with the media, and so there are no questions that address specific properties of either the system (e.g., input devices), or the content (e.g., story elements). It is intended to be usable with a variety of media types, including non-immersive and non-interactive media, such as television programs or movies.

Schubert, Friedmann, and Regenbrecht introduced the igroup Presence Questionnaire (IPQ) in [Schubert et al. 2001]. The authors follow Zahorik and Jenison in connecting presence to supported action in the VE [Zahorik and Jenison 1998]. This fourteen-item questionnaire is intended for use in all forms of virtual environments, including immersive VR systems, desktop VR, 3D games, and text-based VEs such as MUDs (multi-user dungeons).

Sas and O'Hare developed a novel thirty-four-item questionnaire for their experiment in [Sas and O'Hare 2003]. They validated this questionnaire by demonstrating that it was highly significantly correlated with the SUS questionnaire.

Vorderer et al. presented the MEC Spatial Presence Questionnaire (MEC-SPQ) in [Vorderer et al. 2004]. This questionnaire assumes that spatial presence is built of nine constructs: four process factors (attention allocation, spatial situation model, spatial presence—self location, spatial presence—possible actions), two psychological state factors (higher cognitive involvement, suspension of disbelief), and three psychological trait factors (domain-specific interest, visual/spatial imagery, and absorption). They offer short, medium, and long versions of the MEC-SPQ, comprised of four, six, or eight questions, respectively, for each construct (thirty-six, fifty-four, or seventy-two questions in total).

Takatalo and colleagues developed the Experimental Virtual Environment - Experience Questionnaire (EVEQ) [Takatalo 2002]. The EVEQ consists of 124 questions drawn from other questionnaires and translated into Finnish. These were reduced into nineteen subscales, five of which comprised the physical presence scale. These subscores were spatial, action, attention, real[ness], and arousal [Takatalo et al. 2008].

Lombard, Ditton, and Weinstein continued their efforts to develop a "conceptually comprehensive" (based on their literature-based model of presence put forward in [Lombard et al. 2000]) measure of presence with the Temple Presence Inventory (TPI) [Lombard et al. 2009]. The TPI consists of forty-two questions (reduced from 137) relating to five of their six dimensions of presence (excluding *medium as social actor*).

Chertoff and colleagues presented a survey developed to measure "holistic virtual environment experiences" in [Chertoff et al. 2010]. By holistic, the authors seem to mean that the environment incorporates aspects of experiential design; specifically that it includes affective (emotion) and cognitive (engagement) aspects. The survey includes 17 questions addressing five dimensions of ex-

periential design: affective, cognitive, sensory (immersion), active ("personal connection... to an experience"), and relational (social).

Published use of questionnaires

Rosakranse and Oh identified five canonical presence questionnaires—the Slater-Usoh-Steed (SUS) questionnaire, the Witmer-Singer Presence Questionnaire (PQ), the igroup Presence Questionnaire (IPQ), the ITC-Sense of Presence Inventory (ITC-SOPI), and the Lombard and Ditton questionnaire—and tracked their histories of use in three academic publishing outlets—*Presence: Teleoperators and Virtual Environments*, the ISPR conference proceedings, and *Cyberpsychology, Behavior, and Social Networking* [Rosakranse and Oh 2014]. It is notable that these three outlets represent different research communities. *Presence* tends to focus on research in immersive virtual environments, while the ISPR conference primarily focuses on media scholarship, and *Cyberpsychology* is an outlet for psychology researchers.

Rosakranse and Oh found that in *Presence*, the PQ and SUS questionnaires have remained dominant, while in ISPR, the ITC-SOPI questionnaire is now most commonly used, and in *Cyberpsychology*, SUS, PQ, IPQ and ITC-SOPI are all used approximately equally often. Note that all of these questionnaires came into use before 2002 and are still in use in 2014 (when the paper was published). Of particular note, the authors do not consider the usage of the TPI or the MEC-SPQ.

Cummings and Bailenson performed a meta-analysis of published studies that explored the effect of different levels of immersion on presence as measured by questionnaires [Cummings and Bailenson 2016]. Eighty-three studies were included in this meta-analysis, using many of the questionnaires discussed in this section.

6.1.2. Other self-report measures. Welch et al. reported the results of two studies where participants experienced a simulated driving scene [Welch et al. 1996]. In these studies, presence was measured by means of paired comparisons—after every pair of exposures, the participant marked on a scale of 1 to 100 how different their senses of presence were between the most recent exposure and the previous one.

Snow and Williges used the technique of free-modulus magnitude estimation to measure presence in VEs [Snow and Williges 1998]. In free-modulus magnitude estimation, a participant is presented with a series of stimuli and asked to assign a numeric value representing their level of the desired quantity—in this case, presence—to each stimulus. There is no predetermined scale. The participant is instructed to assign any positive number to the first stimulus, and then score all successive stimuli relative to that first number.

Freeman et al. presented a novel form of direct subjective presence evaluation and the results of three experimental studies using it [Freeman et al. 1999]. They gave users a handheld slider that was continuously sampled during each trial. They instructed users to move the slider depending on how present they felt. However, rather than analyze these slider values as a continuous measure of presence, the mean of the slider value was computed for each trial for each participant, and these means were the values used in their analyses.

Techniques based on measuring breaks in presence, as introduced by Slater and Steed, are important variations on the self-report theme. In these methods, rather than reporting their level of felt presence, users report the moments when they do not feel present, and this series of events can be analyzed to generate a measure of presence. In the original paper [Slater and Steed 2000], the breaks in presence were used to generate a Markov chain that continuously modeled the probability that a user felt present at any given time. Subsequent research evaluated raw counts of breaks in presence, rather than the more complex Markov chain analysis, and demonstrated that the overall count of breaks in presence is significantly negatively correlated with presence as measured by questionnaire [Brogni et al. 2003].

Breaks in presence have also been investigated in combination with physiological measures [Slater et al. 2003] [Slater et al. 2006], as well as with other types of self-report measures. Garau et al. induced breaks in presence in a virtual environment, then followed up with semi-structured

interviews, the transcripts of which were subjected to content analysis (in which researchers define categories of interest before the experiment and then measure them quantitatively by looking for key words or phrases in the transcript) and thematic analysis (which looks for ideas that are not connected to the initial research questions). Participants also were asked to draw graphs corresponding to their sense of "being there", with time on the X-axis and the environment (lab or bar) on the Y-axis [Garau et al. 2008].

Kuschel and colleagues proposed a new measure of presence based on perception of conflicting information across multiple sensory modalities (in their specific case, visual and haptic). In this measure, the user is presented with two or more streams of conflicting sensory data in different modalities, and is considered present in whichever one they report as dominant [Kuschel et al. 2007].

Riener and Proffitt proposed a means of quantifying spatial presence by comparing the results of visual illusions (specifically the vertical-horizontal illusion (Figure 1) and the Ponzo illusion (Figure 2) in photographs, the real world, and in virtual environments. Here the measure is the users' estimated lengths of the lines in each illusion. They found that the size misestimations in virtual environments were closer to those in the real world for the vertical-horizontal illusion, while they were closer to photographs with strong perspective cues for the Ponzo illusion [Riener and Proffitt 2002].

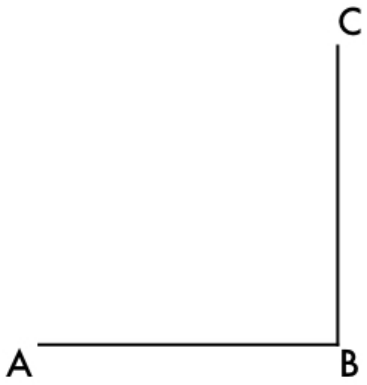

Fig. 1. **Vertical horizontal illusion**: Even though line segments AB and BC are the same length, participants estimate BC to be longer than AB. (3-6% longer in photographs, 20-40% longer in the real world.)

6.2. Physiological metrics

Dillon et al. put forward a plan to compare skin conductance response (SCR) (also referred to as galvanic skin response, GSR, or electrodermal activity, EDA) and electrocardiogram (EKG) data with presence as measured by the ITC-SOPI [Lessiter et al. 2001] in a study where participants view a video stream presented either stereoscopically or monoscopically [Dillon et al. 2000]. The results of that study are summarized in [Dillon et al. 2002], and the results of another study investigating the effects of emotional media content and display size on presence and arousal are also presented there. The authors did not find a correlation between physiological metrics and presence. Note that the stimuli in these studies were neither immersive nor inherently arousing.

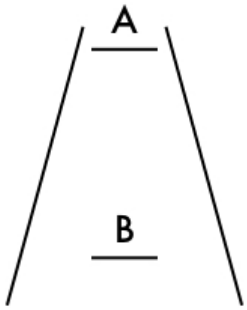

Fig. 2. **Ponzo illusion**: Even though line segments A and B are the same length, participants estimate A to be longer than B. (20-30% in photographs, 45% in the real world.)

Meehan explored the same measures as well as skin temperature in an immersive virtual environment that did contain an inherently stressful stimulus, a visual cliff scenario [Meehan et al. 2002]. There, Meehan and colleagues did find that a larger increase in heart rate when exposed to the visual cliff significantly correlated with an increase in presence as measured by the SUS questionnaire, indicating that physiological measures such as change in heart rate may be able to serve as an objective proxy measure for presence in such scenarios. (That is, in virtual environments that contain a known arousal-inducing stimulus, such as the visual cliff.)

As mentioned in the previous section, when talking about breaks in presence, Slater and colleagues have used physiological metrics (heart rate, heart rate variability, and EEG) to measure users' responses to breaks in presence in virtual environments, both experimenter-caused [Guger et al. 2004] [Slater et al. 2006] and incidental [Slater et al. 2003].

More recently, Baumgartner et al. [Baumgartner et al. 2008] and Bouchard et al. [Bouchard et al. 2009] [Bouchard et al. 2010] [Bouchard et al. 2012] have used fMRI technology to investigate the neural correlates of presence. Both authors have identified regions of the brain that seem to correlate with the feeling of presence in participants; Baumgartner et al. point to the dorsolateral prefrontal cortex, while Bouchard et al. identify the parahippocampus as the brain region most associated with the feeling of presence. Baumgartner et al. speculate that this difference may be due to the different study methodologies (Baumgartner et al. presented two different VEs for the two groups in their study, while Bouchard et al. presented the same VE to both groups, but it was explained differently.)

6.3. Behavioral metrics

Sheridan proposed that in addition to self-report methods, presence could be measured by behavioral methods such as response to threatening stimuli (for example, flinching out of the way of a virtual ball) or to socially-conditioned behaviors (for example, saying, "Gesundheit," in response to a sneeze in the VE) [Sheridan 1992].

Regenbrecht, Schubert, and Friedmann demonstrated that fear increased with higher presence in a virtual environment designed to elicit fear of heights [Regenbrecht et al. 1998]. Presence was measured using Likert-style responses to fourteen questions that included questions from [Slater et al. 1994] and [Hendrix and Barfield 1995]; anxiety was measured using the State-Trait Anxiety Index, a twenty-item questionnaire [Laux et al. 1981]. We classify this with the behavioral metrics

rather than the self-report metrics because the self-reported quantity is not presence, as it is in all the other measures classified as self-report.

Freeman et al. proposed the use of behavioral metrics for presence; specifically the magnitude of postural response for seated participants viewing a video [Freeman et al. 2000]. The authors conducted a 24 participant study to evaluate this metric. Participants viewed two video clips: one was excerpted from a video recorded from the hood of a rally car, and the other was a still frame from a video taken at the side of the rally track. The soundtrack was the same in both videos, giving the impression of a car off in the distance in the still video case. All participants saw both stimuli in both monoscopic and stereoscopic presentations. Participants rated their presence (as well as involvement, self-motion, and sickness) on a scale from 0 to 100 on a visual analogue scale after each trial, and their postural responses were tracked. Participants' self-rated presence scores showed significantly higher presence for stereoscopic presentation and for the moving video stimulus, with no interaction between the factors. There was no significant relationship between presence and postural response, however.

6.4. Analysis

The proliferation of questionnaires adds complexity to presence research. Previous experience with using multiple presence questionnaires in response to the same virtual experience has shown their results to be extremely highly correlated (e.g. [Skarbez et al. 2016]). Based on these observations, we believe that it is only necessary to use one questionnaire, although which to use may change based on the specifics of the experiment. For example, if one is particularly interested in reality judgment, or one or more of the subscores of the MEC questionnaire, one should certainly use the RJPQ or MEC-SPQ, respectively. For a general presence measure, we would recommend the SUS questionnaire, as it is both the shortest (saving both experimenter and participant time) and the questionnaire that most directly measures the feeling of presence.

We believe that behavioral metrics are a promising area of study that has so far been understudied. Physiological metrics may ultimately be limited in their utility as they have been shown to be useful only in experiments that are known to affect physiological signals in particular ways (e.g., increasing arousal in a stressful environment), or place severe restrictions on the design of the VE (as in fMRI studies) but it is likely that appropriate behavioral signals could be found in nearly any virtual scenario.

7. MODELS OF PRESENCE

In this section, we have grouped together those papers that posit a list of components asserted to contribute to presence. Some of these groupings are purely theoretical, and some were either the basis of questionnaires or factors derived from questionnaires in use. Therefore, some papers mentioned in the questionnaire section also appear here. As well as presenting these theorized components of the presence construct here together, we also demonstrate how these components can be usefully grouped. The models are presented in chronological order, as in Table III. There is no implied relationship among the data columns in Table III: the components for each publication are listed across each row in no particular order. Figure 3 contains an illustration of these same components, grouped by higher-order concept. Note also that Slater's Place Illusion and Plausibility Illusion are not included in Table III, but they do appear as higher-order concepts in Figure 3.

Table III. List of presence/telepresence models and their components

[Akin et al. 1983]	Ability to act in remote environment	Ability to sense in local environment			
[Heeter 1992]	Subjective personal presence	Social presence	Environmental presence		
[Sheridan 1992]	Extent of sensory information	Control of sensors	Ability to modify physical environment	Task dependent characteristics	
[Held and Durlach 1992]	Sensory factors	Motor factors	Correlation between feedback and actions	Identification with the robot	Familiarity with the system
[Kim and Biocca 1997]	Arrival	Departure			
[Draper et al. 1998]	Attention to mediated environment	Attention to ignoring distractors			
[Witmer and Singer 1998]	Control	Sensory	Distraction	Realism	
[Baños et al. 2000]	Reality judgment	Presence	Emotional involvement	Interaction	Control
	Attention/Flow	Realism	Congruence/Continuity	Expectations	
[IJsselsteijn et al. 2000]	Extent and fidelity of sensory information	Match between sensors and display	Content factors	User characteristics	
[Lombard et al. 2000]	Social Richness	Realism (Social)	Realism (Perceptual)	Transportation	Immersion
	Social Actor in a Medium	Medium as Social Actor			
[Sas and O'Hare 2003]	General cognitive factors	Task specific cognitive factors	Technological factors	Media content	
[Takatalo et al. 2008]	Spatial	Action	Attention	Real[ness]	Arousal
[Vorderer et al. 2004]	Attention allocation	Spatial situation model	Spatial presence: self-location	Spatial presence: possible actions	Higher cognitive involvement
	Suspension of disbelief	Domain-specific interest	Visual/Spatial imagery	Absorption	
[Chertoff et al. 2010]	Affective	Cognitive	Sensory	Active	Relational

7.1. Models

Akin and colleagues defined telepresence as the condition that occurs when, "At the worksite, the manipulators have the dexterity to allow the operator to perform normal human functions. At the control station, the operator receives sufficient quantity and quality of sensory feedback to provide a feeling of actual presence at the worksite" [Akin et al. 1983]. In other words, we would argue that the authors identified two factors of telepresence: ability to act in the remote environment and sensory fidelity delivered to the user. Note that this definition is specifically referring to telepresence and not presence or virtual presence, hence the references to worksite and control station.

Heeter proposed three dimensions of presence: subjective personal presence (feeling that you are in the virtual environment), social presence (feeling that other beings exist in the world and react to you), and environmental presence (feeling that the environment acknowledges and reacts to you) [Heeter 1992].

Sheridan proposed three factors of presence: extent of sensory information, control of the relation of sensors to the environment, and ability to modify the physical environment [Sheridan 1992]. He also argues that presence is likely task-dependent, and that "fixed" characteristics of the system (immersion factors and task properties) should affect dependent measures of user experience, such as presence, training efficiency, task performance, and so on.

Held and Durlach speculated on the value of telepresence, as well as its potential causal factors in [Held and Durlach 1992]. They argued that telepresence is most desirable in applications where the tasks are wide-ranging, complex, and uncertain, "because the best general purpose system known to us. . . is us." They go on to speculate on the factors that contribute to telepresence, identifying sensory factors—resolution, field of view, consistency of information across modalities, and displays that are "free from production of artificial stimuli that signal the existence of the display", motor factors—support for movements of sensory organs and of viewed effectors, high correlation between kinesthetic feedback and sensed actions from the remote environment, identification with the robot (visual similarity), familiarity with the system, and "the cognitive representation of the operator's interaction with the world" as factors that are likely to contribute to greater telepresence.

Arrival and departure were identified as the two factors in the presence questionnaire created by Kim and Biocca [Kim and Biocca 1997]. *Arrival* is the feeling of being there in a mediated environment, *departure* is the feeling of *not* being in the real environment, and presence arises from the combination of the two.

Draper and his colleagues reviewed existing conceptions of telepresence, and put forward an attentional resource model for telepresence in [Draper et al. 1998]. This model argues that telepresence increases as a function of the sum of attentional resources devoted to processing task-related stimuli from the mediated environment and the attentional resources devoted to overcoming distractors.

In the development of their presence questionnaire, Witmer and Singer proposed four major categories of factors that affect presence: Control, Sensory, Distraction, and Realism [Witmer and Singer 1998]. They also claimed that factors may influence presence by acting on psychological immersion, involvement, or both. For example, they theorize that control factors impact psychological immersion but not involvement, while realism factors impact involvement but not psychological immersion. Distraction and sensory factors are theorized to affect both. Control factors include predictability, interactivity of the environment, and input controls; sensory factors include richness of the environment, number and fidelity of sensory modalities, and consistency of multimodal stimuli; distraction factors include isolation from the physical environment and interface awareness; and realism factors concern the degree to which the experience is meaningful and coherent with expectations from the real world. Each question on the PQ is intended to address some aspect of one of these factors. The results of a cluster analysis of four studies using the Witmer and Singer PQ identified three subscales in the PQ data—Involvement/Control, Naturalness, and Interface Quality.

Bystrom et al. proposed the immersion, presence, performance (IPP) model for interaction in virtual environments. The authors adopt Slater's definition of immersion, and presence is used in

the common sense of "being there". The IPP model, in brief, claims that sensory fidelity (resulting from a sufficiently immersive system) causes a user to allocate attentional resources to the VE, and that this allocation of attentional resources enables the user to experience presence in the VE and perform the given task. Furthermore, it claims that there is a feedback loop: more attention causes more presence and more task engagement, and increased task engagement causes the user to allocate more attentional resources [Bystrom et al. 1999].

Bystrom et al. state that this model is based on the two models of presence proposed by Slater and colleagues [Slater et al. 1996] [Slater and Wilbur 1997] and by Barfield and colleagues [Hendrix and Barfield 1996a] [Hendrix and Barfield 1996b]. The Slater model as outlined here described presence as, "determined not only by... aspects of displays... but also mediated by the sorts of sensory information required to perform the task at hand... and individual differences in preferences for information". The Barfield model described presence as "dependent on the degree to which... transformations of objects in a virtual environment are similar to... transformations of objects in the real world."

Schubert et al. presented the results of a factor analysis on an experiment in which 246 participants answered a 75-item survey of new questions and questions taken from Carlin et al. [Carlin et al. 1997], Ellis et al. [Ellis et al. 1997], Slater et al., [Slater et al. 1994], Towell and Towell [Towell and Towell 1997], [Witmer and Singer 1998], and Regenbrecht et al. [Regenbrecht et al. 1998]. The authors extracted eight factors that combined express 50.27% of the total variance. These factors, in decreasing order of importance, were spatial presence, quality of immersion, involvement, drama, interface awareness, exploration of the VE, predictability and interaction, and realness. The authors then performed a second order factor analysis to see how the factors grouped together. In a two-factor solution, the first factor grouped spatial presence, quality of immersion, involvement, drama, and realness, and the second factor grouped interface awareness, exploration, and predictability and interaction. In a three-factor solution, the first factor grouped spatial presence, involvement, and realness, the second factor grouped interface awareness, predictability and interaction, and exploration, and the third factor grouped drama and quality of immersion [Schubert and Regenbrecht 1999] [Schubert et al. 2001].

IJsselsteijn et al. reviewed the existing presence literature to summarize research into the factors contributing to presence and the methods for measuring it. The authors identified four determinants of presence: (1) the extent and fidelity of sensory information, (2) the match between sensors and display, (3) content factors (a broad category covering most anything else that is part of the virtual scenario), and (4) user characteristics [IJsselsteijn et al. 2000].

Lombard et al. discussed their efforts to develop an instrument for presence based on their theoretical model of its components. In the literature, they identified six "dimensions" of presence: presence as social richness, presence as realism (both social and perceptual), presence as transportation, presence as immersion, presence as a social actor within a medium, and presence where the medium is a social actor. The authors claim that the common element among these types of presence is a perceptual illusion of nonmediation [Lombard et al. 2000].

Sas and O'Hare presented a "presence equation", where 45% of presence variation can be predicted as

$$0.37 \times Willingness\ to\ Suspend\ Disbelief + 0.29 \times Creative\ Imagination/Absorption. \quad (1)$$

They later presented a more general form of the presence equation,

$$Presence = a \times (General\ cognitive\ factors) + b \times (Task\ specific\ cognitive factors) + c \times (Technological\ factors) + d \times (Media\ content). \quad (2)$$

Note that *general cognitive factors* is the only term that is entirely dependent on the participant, whereas *technological factors* and *media content* are entirely dependent on the specific VE, and *Task specific cognitive factors* is at least partially dependent on the specific VE. Furthermore, Sas and O'Hare's own previous discussion regarding immersive vs. non-immersive VEs seems to indicate

that they believe $c > a, b$. They argue for the use of a non-immersive VE for their experiment because then presence differences will be due to human factors rather than immersion [Sas and O'Hare 2003].

Witmer and colleagues revisited their presence questionnaire with a factor analysis [Witmer et al. 2005]. They identified four factors of their presence questionnaire, which combined account for 52.2% of the variance. These factors are Involvement (accounting for 31.9% of variance), Sensory Fidelity, Adaptation/Immersion, and Interface Quality.

Wirth and colleagues presented a theoretical model of how spatial presence might be generated in a participant. They proposed a two-stage model. In the first stage, one constructs a spatial situation model (SSM), i.e., a mental model of the spatial environment that one constructs based on (1) spatial cues that one processes and (2) relevant personal spatial memories and cognitions. In the second stage, one defines his or her primary egocentric reference frame (PERF), which is either the SSM representing the mediated environment, in which case one is present in the virtual environment, or the SSM representing the real world, in which case one is not present in the VE. Specifically, the authors claim that "spatial presence occurs when the medium-as-PERF hypothesis is confirmed repeatedly through processed information and is thus stabilized over time" [Wirth et al. 2007]. It seems to us that the SSM formalizes Held and Durlach's "cognitive representation of the operator's interaction with the world" [Held and Durlach 1992].

For Wirth et al., then, an individual's sense of presence in any mediated environment is dependent on both characteristics of the environment—e.g., richness, salience, consistency—and of the individual user—e.g., attention, involvement, suspension of disbelief.

7.2. Analysis

Unlike the definitions of presence in Section 5.1, the models of presence are strikingly similar. Almost all can be transformed into one another, or into, for example, the more recently developed PI/Psi framework. Akin et al.'s conception of telepresence being composed of the ability to act in the remote environment plus the ability to display sense data in the local environment is very similar to Slater's conception of immersion being composed of effective and sensorimotor valid actions [Akin et al. 1983]. Those authors do not consider coherence, but they have no need to, since they are explicitly talking about remote real environments as opposed to virtual ones. Heeter's subjective personal presence is precisely Place Illusion, while social presence and environmental presence are components of Plausibility Illusion [Heeter 1992]. Sheridan's factors contributing to telepresence are, again, sensorimotor and effective valid actions, plus the extent of sensor information, which is also an aspect of immersion [Sheridan 1992]. Witmer and Singer's conception of presence as arising from control factors, sensory factors, distraction factors, and realism factors can be restated as immersion (control and sensory) plus coherence (distraction and realism) [Witmer and Singer 1998].

IJsselsteijn et al., Sas and O'Hare, and Wirth et al. introduce individual differences to the discussion [IJsselsteijn et al. 2000] [Sas and O'Hare 2003] [Wirth et al. 2007]. Specifically, Sas and O'Hare's presence equation

$$\begin{aligned} Presence = a \times (General\ cognitive\ factors) + b \times (Task\ specific\ cognitive factors) \\ + c \times (Technological\ factors) + d \times (Media\ content) \end{aligned} \quad (3)$$

consists of individual differences of state and trait (*general cognitive factors* and *task specific cognitive factors*), immersion (*technological factors*), and coherence (*media content*). It also consists of the respective coefficients on each of these terms, which might be better restated as

$$\begin{aligned} Presence = \mathbf{A}[Vector\ of\ cognitive\ factors] + \mathbf{B}[Vector\ of\ task\ specific\ cognitive\ factors] \\ + \mathbf{C}[Vector\ of\ technological\ factors] + \mathbf{D}[Vector\ of\ media\ content\ factors] \end{aligned} \quad (4)$$

to more accurately represent the difficulty involved in computing a "presence equation."

In Figure 3, we have grouped the presence components discussed in this section (and presented in Table III). This grouping demonstrates that most of the components that have previously been proposed as making up the presence construct can in fact be grouped as components of PI, Psi, immersion, or coherence. Several others can be grouped under the heading of attention or distraction, and another subset can be grouped under individual differences. Taken together, these categories account for the overwhelming majority of components that have been proposed as part of the presence construct.

While immersion and coherence (and therefore PI and Psi) are largely under the control of the VE developer, attention and individual differences are generally not. Many of these models of presence, then, take into consideration the impact of individual differences on presence (at least implicitly).

8. FACTOR ANALYSES

There have been three significant factor analyses of presence and presence questionnaires in the literature: Schubert et al., Lessiter et al., and Witmer et al. [Schubert and Regenbrecht 1999] [Schubert et al. 2001] [Lessiter et al. 2001] [Witmer et al. 2005]. Schubert et al. identified eight factors—spatial presence, quality of immersion, involvement, drama, interface awareness, exploration of the VE, predictability and interaction, and realness—that then grouped into three second-order factors—spatial presence, involvement, and realness. Lessiter et al. identified four factors—sense of physical space, engagement, naturalness, and negative effects. Witmer et al. identified four factors as well, which were involvement, sensory fidelity, adaptation/immersion, and interface quality.

An inherent limitation of factor analyses is that they can only group based on the items that were actually used in the measure. So if a questionnaire does not include questions about the coherence of social interactions, for example, there cannot be a factor that addresses that construct. On the other hand, if a questionnaire does ask questions about a construct that others do not—as with the ITC-SOPI and negative effects—that construct is likely to be represented by a factor. The initial selection of items, then, inherently biases the factor analysis that follows.

That said, it is enlightening to look at the similarities and differences among these factor lists. All three include a factor they call *involvement* or *engagement*. (We will use *involvement* going forward.) However, a look at the questions that make up these factors reveals that they may actually represent different constructs. For Lessiter et al., this factor is represented by items such as, “I enjoyed myself”, and “My experience was intense”. These items seem to represent an overall affinity for the experience, rather than specifically relating to presence. For Witmer et al., the involvement factor contains items including “How much were you able to control events?”, “How much did the visual aspects of the environment involve you?”, and “How much did your experiences in the virtual environment seem consistent with your real world experiences?”, which don’t on face seem to represent any one construct. On the other hand, for Schubert et al., involvement is represented by items including “I concentrated only on the virtual space”, and “I was completely captivated by the virtual world”, which seems clearly to represent an attentional component. This discussion demonstrates that these factors are not as similar as one would assume from the names.

From Schubert et al., we classify the Spatial Presence factor as a sub-questionnaire asking directly about the feeling of spatial presence (as the SUS questionnaire asks directly about the feeling of presence), Involvement as an attentional component, Predictability and Interaction, Realness, and Drama as coherence factors, and Quality of Immersion, Interface Awareness, and Exploration as immersion factors.

From Lessiter et al. we classify the Sense of Physical Space factor as a sub-questionnaire asking directly about the feeling of spatial presence, Engagement as an affinity component, Naturalness as a coherence factor, and Negative Effects as a (reverse-coded) immersion factor.

From Witmer et al. we classify their Interface Quality and Sensory Fidelity factors as being immersion factors, and Involvement and Adaptation/Immersion to be primarily coherence factors.

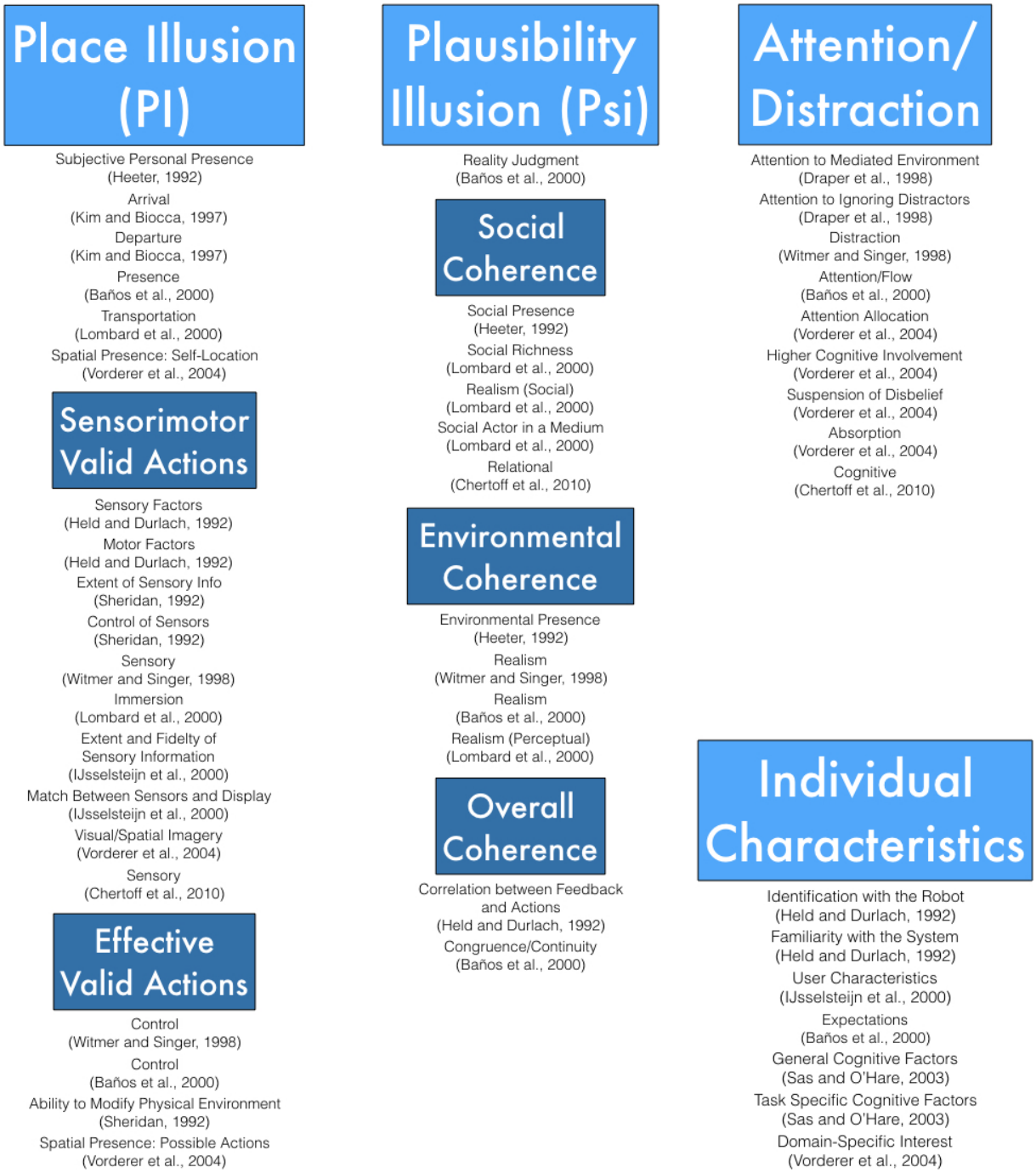

Fig. 3. Clustering of presence model components

9. RELATED CONCEPTS

9.1. Transportation

Broadly speaking, the concept of *transportation* is to narrative worlds as the concept of presence is to technology-mediated worlds [Gerrig 1993]. In a state of transportation, "[T]he reader loses access to some real-world facts in favor of accepting the narrative world that the author has created... transported readers may experience strong emotions and motivations, even when they know the events in the story are not real" [Green and Brock 2000].

Transportability refers to a person's inherent ability to be transported by a narrative. There is not an equivalent term in the field of presence research, although this idea was explored in the form of Witmer and Singer's Immersive Tendencies Questionnaire [Witmer and Singer 1998]. There are transportation and transportability questionnaires that are analogous to the PQ and ITQ, respectively [Green and Brock 2000] [Green 1996].

9.2. Agency

Agency [Russell 1996] is "the sense that I am the one who is causing or generating an action," [Gallagher 2000] or "the satisfying power to take meaningful action and see the results of our decisions and choices" [Murray 1997]. Agency has been identified as a concept that may share some features and factors with presence [Herrera et al. 2006]. There is some speculation that the brain mechanisms that give rise to the sense of agency may be related to those that give rise to presence [David et al. 2008] [Seth et al. 2012].

9.3. Reality Judgment

Baños and colleagues argue for the existence of *reality judgment* as a construct separate from presence. They point out that one can attribute reality to something without feeling a sense of presence, for example, when watching a news broadcast; or vice versa, as when playing a fantasy video game. So reality judgment (the belief that our experiences are real) should be treated as related to, but distinct from, presence [Baños et al. 2000][Baños et al. 2004].

9.4. Analysis

Oftentimes virtual reality researchers focus primarily on the research published in their specific subfield. Virtual reality researchers are computer scientists, media theorists, and both clinical and experimental psychologists, to name only some of the more prominent disciplines. These researchers then tend to publish in the conferences and journals that they are most familiar with, which may not be frequently read by researchers in other disciplines.

Transportation, for example, is directly analogous to presence, and may become even more relevant as research explores narrative and coherence factors of virtual environments that have previously gone understudied. Agency, likewise, is a close cousin of presence, particularly if one accepts that presence is inherently connected to one's ability to act in virtual environments. Reality judgment represents the most direct effort any researchers have made to study the value of realism in virtual environments, at least prior to the introduction of Plausibility Illusion.

10. CONCLUSION

This article has reviewed the existing presence literature in order to provide background and context for the development of theory regarding Place Illusion and Plausibility Illusion. We first reviewed many of the definitions of presence in the literature. As a synthesis of these definitions, we recommend the definition of presence as the cognitive feeling of being in a place. Notably, this feeling does not arise only from immersion, but also from coherence and both state and trait characteristics of the individual user. Secondly, we reviewed existing methods for measuring presence, categorizing them as self-report (predominantly, but not only, post-experiment questionnaires), physiological, and behavioral. We recommend the use of the SUS questionnaire in combination with appropriate physiological or behavioral measures. Thirdly, we reviewed models of presence in the literature, ar-

guing that most of these models are remarkably similar to the Place Illusion and Plausibility Illusion model, albeit using different terms. Finally, we reviewed some related concepts, namely transportation, agency, and reality judgment, and argued for a more inclusive cross-disciplinary VE literature.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Ben Lok, Dr. Abigail Panter, Dr. Mel Slater, and Dr. Gregory Welch for their guidance and helpful feedback during the writing of the dissertation from which this work is derived.

REFERENCES

AERA/APA/NCME. 2014. *Standards for educational and psychological testing*. AERA, Washington, DC.

David L. Akin, Marvin L. Minsky, Eric D. Thiel, and Clifford R. Kurtzman. 1983. *Space applications of automation, robotics, and machine intelligence systems, (ARAMIS) phase II, vol. 3: Executive summary*. Technical Report. Massachusetts Institute of Technology, Cambridge, MA, USA.

Rosa M Baños, Cristina Botella, Mariano Alcañiz, Víctor Liaño, Belén Guerrero, and Beatriz Rey. 2004. Immersion and emotion: Their impact on the sense of presence. *CyberPsychology & Behavior* 7, 6 (February 2004), 734–741.

Rosa M Baños, Cristina Botella, A García-Palacios, H Villa, C Perpiña, and Mariano Alcañiz. 2000. Presence and reality judgment in virtual environments: A unitary construct. *CyberPsychology & Behavior* 3, 3 (July 2000), 327–335.

Thomas Baumgartner, Dominique Speck, Denise Wettstein, Ornella Masnari, Gian Beeli, and Lutz Jäncke. 2008. Feeling present in arousing virtual reality worlds: prefrontal brain regions differentially orchestrate presence experience in adults and children. *Frontiers in Human Neuroscience* 2 (2008), 8. DOI: http://dx.doi.org/10.3389/neuro.09.008.2008

Frank Biocca. 2001. Inserting the presence of mind into a philosophy of presence: A response to Sheridan and Mantovani and Riva. *Presence: Teleoperators and Virtual Environments* 10 (2001), 554–556.

Frank Biocca. 2002. Presence working group research targets. Presentation at the "Presence Info Day" of the European Commission. (January 2002).

Frank Biocca and Ben Delaney. 1995. Immersive virtual reality technology. In *Communication in the age of virtual reality*, Frank Biocca and Mark R. Levy (Eds.). Lawrence Erlbaum Associates Inc., Hillsdale, NJ, 57–124.

Stéphane Bouchard, Stéphanie Dumoulin, Jeanne Talbot, André-Anne Ledoux, Jennifer Phillips, Johana Monthuy-Blanc, Geneviève Labonté-Chartrand, Geneviéve Robillard, Matteo Cantamesse, and Patrice Renaud. 2012. Manipulating subjective realism and its impact on presence: Preliminary results on feasibility and neuroanatomical correlates. *Interacting with Computers* 24, 4 (2012), 227–236. DOI: http://dx.doi.org/10.1016/j.intcom.2012.04.011 Special Issue on Presence and Interaction.

Stéphane Bouchard, Jeanne Talbot, André-Anne Ledoux, Jennifer Phillips, Matteo Cantamasse, and Geneviève Robillard. 2009. The meaning of being there is related to a specific activation in the brain located in the parahypocampus. In *Proceedings at the 12th Annual International Workshop on Presence (Los Angeles (CA), 2009)*, Vol. 2.

Stéphane Bouchard, Jeanne Talbot, André-Anne Ledoux, Jennifer Phillips, Matteo Cantamesse, and Geneviéve Robillard. 2010. Presence is just an illusion: using fMRI to locate the brain area responsible to the meaning given to places. *Annual Review of Cybertherapy and Telemedicine: Advanced Technologies in the Behavioral, Social, and Neurosciences. 2010* 154 (2010), 193–196.

Andrea Brogni, Mel Slater, and Anthony Steed. 2003. More breaks less presence. In *PRESENCE 2003 - 6th Annual International Workshop on Presence*.

Karl-Erik Bystrom, Woodrow Barfield, and Claudia Hendrix. 1999. A Conceptual Model of the Sense of Presence in Virtual Environments. *Presence: Teleoperators and Virtual Environments* 8 (April 1999), 241–244. Issue 2. DOI: http://dx.doi.org/10.1162/105474699566107

Antonella Carassa, Francesca Morganti, and Maurizio Tirassa. 2005. A situated cognition perspective on presence. In *Proceedings of the 27th Annual Conference of the Cognitive Science Society: 2005; Stresa, Italy*. Sheridan Printing, 384–389.

Albert S. Carlin, Hunter G. Hoffman, and Suzanne Weghorst. 1997. Virtual reality and tactile augmentation in the treatment of spider phobia: a case report. *Behaviour Research and Therapy* 35, 2 (February 1997), 153–158.

Dustin B. Chertoff, Brian Goldiez, and Joseph J. LaViola Jr. 2010. Virtual Experience Test: A virtual environment evaluation questionnaire. In *Virtual Reality*. 103–110. DOI: http://dx.doi.org/10.1109/VR.2010.5444804

James J. Cummings and Jeremy N. Bailenson. 2016. How Immersive Is Enough? A Meta-Analysis of the Effect of Immersive Technology on User Presence. *Media Psychology* 19, 2 (2016), 272–309. DOI: http://dx.doi.org/10.1080/15213269.2015.1015740

Nicole David, Albert Newen, and Kai Vogeley. 2008. The "sense of agency" and its underlying cognitive and neural mechanisms. *Consciousness and Cognition* 17, 2 (2008), 523 – 534. DOI: http://dx.doi.org/10.1016/j.concog.2008.03.004

Cath Dillon, Edmund Keogh, and Jonathan Freeman. 2002. "It's been emotional": Affect, physiology, and presence. In *Proceedings of the 5th Annual International Conference on Presence*.

Cath Dillon, Edmund Keogh, Jonathan Freeman, and Jules Davidoff. 2000. Aroused and immersed: The psychophysiology of presence. In *Proceedings of the 3rd International Workshop on Presence*. Goldsmiths College / Independent Television Commission, London, UK.

John V. Draper, David B. Kaber, and John M. Usher. 1998. Telepresence. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 40, 3 (1998), 354–375. DOI: http://dx.doi.org/10.1518/001872098779591386

Stephen R. Ellis, Nancy S. Dorighi, Brian M. Menges, Bernard D. Adelstein, and Richard H. Jacoby. 1997. In Search of Equivalence Classes in Subjective Scales of Reality. In *Human-Computer Interaction*, Vol. 2. 873–876.

John M. Flach and John G. Holden. 1998. The Reality of Experience: Gibson's Way. *Presence: Teleoperators and Virtual Environments* 7 (1998), 90–95. DOI: http://dx.doi.org/10.1162/105474698565550

Jonathan Freeman, Steve E. Avons, Ray Meddis, Don E. Pearson, and Wijnand IJsselsteijn. 2000. Using behavioral realism to estimate presence: a study of the utility of postural responses. *Presence: Teleoperators and Virtual Environments* 9, 2 (April 2000), 149–164.

Jonathan Freeman, Steve E. Avons, Don E. Pearson, and Wijnand A. IJsselsteijn. 1999. Effects of Sensory Information and Prior Experience on Direct Subjective Ratings of Presence. *Presence: Teleoperators and Virtual Environments* 8 (February 1999), 1–13. Issue 1. DOI: http://dx.doi.org/10.1162/105474699566017

Shaun Gallagher. 2000. Philosophical conceptions of the self: implications for cognitive science. *Trends in Cognitive Sciences* 4, 1 (2000), 14 – 21. DOI: http://dx.doi.org/10.1016/S1364-6613(99)01417-5

Maia Garau, Doron Friedman, Hila Ritter Widenfeld, Angus Antley, Andrea Brogni, and Mel Slater. 2008. Temporal and spatial variations in presence: Qualitative analysis of interviews from an experiment on breaks in presence. *Presence: Teleoperators and Virtual Environments* 17 (June 2008), 293–309. Issue 3. DOI: http://dx.doi.org/10.1162/pres.17.3.293

Richard J. Gerrig. 1993. *Experiencing narrative worlds*. Yale University Press, New Haven, CT.

James J. Gibson. 1979. *The ecological approach to visual perception*. Houghton-Mifflin, Boston, MA.

Melanie Colette Green. 1996. *Mechanisms of narrative-based belief change*. Master's thesis. The Ohio State University. http://rave.ohiolink.edu/etdc/view?acc_num=osu1235579429

Melanie C Green and Timothy C Brock. 2000. The role of transportation in the persuasiveness of public narratives. *Journal of Personality and Social Psychology* 79, 5 (November 2000), 701–721.

Cristoph Guger, Guenter Edlinger, Robert Leeb, and Gert Pfurtscheller. 2004. Heart-Rate Variability and Event-Related ECG in Virtual Environments. *7th International Conference on Presence* (2004), 240–245.

Carrie Heeter. 1992. Being there: the subjective experience of presence. *Presence: Teleoperators and Virtual Environments* 1 (May 1992), 262–271. Issue 2. http://portal.acm.org/citation.cfm?id=196564.196589

Richard M. Held and Nathaniel I. Durlach. 1992. Telepresence. *Presence: Teleoperators and Virtual Environments* 1, 1 (Jan. 1992), 109–112. http://dl.acm.org/citation.cfm?id=128947.128954

Claudia Hendrix and Woodrow Barfield. 1995. Presence in virtual environments as a function of visual and auditory cues. In *Proceedings of the Virtual Reality Annual International Symposium (VRAIS'95) (VRAIS '95)*. IEEE Computer Society, Washington, DC, USA, 74–82. http://dl.acm.org/citation.cfm?id=527216.836011

Claudia Hendrix and Woodrow Barfield. 1996a. Presence within virtual environments as a function of visual display parameters. *Presence: Teleoperators and Virtual Environments* 5, 3 (1996), 274–289.

Claudia Hendrix and Woodrow Barfield. 1996b. The sense of presence within auditory virtual environments. *Presence: Teleoperators and Virtual Environments* 5, 3 (1996), 290–301.

Gerardo Herrera, Rita Jordan, and Lucí Vera. 2006. Agency and presence: a common dependence on subjectivity? *Presence: Teleoperators and Virtual Environments* 15, 5 (2006), 539–552.

Wijnand A. IJsselsteijn, Huib de Ridder, Jonathan Freeman, and S.E. Avons. 2000. Presence: Concept, determinants and measurement. In *Storage and Retrieval for Image and Video Databases*.

International Society for Presence Research. 2000. The concept of presence: explication statement. (2000).

Taeyong Kim and Frank Biocca. 1997. Telepresence via Television: Two Dimensions of Telepresence May Have Different Connections to Memory and Persuasion. *Journal of Computer-Mediated Communication* 3, 2 (1997). DOI: http://dx.doi.org/10.1111/j.1083-6101.1997.tb00073.x

Martin Kuschel, Franziska Freyberger, Martin Buss, and Berthold Färber. 2007. A Presence Measure for Virtual Reality and Telepresence Based on Multimodal Conflicts. In *Proceedings of the 10th International Workshop on Presence*.

Pontus Larsson, Daniel Västfjäll, and Mendel Kleiner. 2001. The Actor-Observer Effect in Virtual Reality Presentations. *CyberPsychology & Behavior* 4, 2 (2016/09/18 2001), 239–246. DOI: http://dx.doi.org/10.1089/109493101300117929

Lothar Laux, Peter Glanzmann, Paul Schaffner, and Charles D. Spielberger. 1981. *State-Trait-Angstinventar [State-Trait Anxiety Inventory]*. Beltz, Weinheim, Germany.

Kwan Min Lee. 2004. Presence, Explicated. *Communication Theory* 14, 1 (2004), 27–50. DOI: http://dx.doi.org/10.1111/j.1468-2885.2004.tb00302.x

Jane Lessiter, Jonathan Freeman, Edmund Keogh, and Jules Davidoff. 2001. A cross-media presence questionnaire: The ITC-Sense Of Presence Inventory. *Presence: Teleoperators and Virtual Environments* 10 (2001), 282–297. DOI: http://dx.doi.org/10.1162/105474601300343612

Matthew Lombard and Theresa Ditton. 1997. At the Heart of It All: The Concept of Presence. *Journal of Computer-Mediated Communication* 3, 2 (1997). DOI: http://dx.doi.org/10.1111/j.1083-6101.1997.tb00072.x

Matthew Lombard, Theresa B. Ditton, Daliza Crane, Bill Davis, Gisela Gil-Egui, Karl Korvath, and Jessica Rossman. 2000. Measuring presence: A literature-based approach to the development of a standardized paper-and-pencil instrument. In *PRESENCE 2000 - 3rd International Workshop on Presence*.

Matthew Lombard, Theresa B. Ditton, and Lisa Weinstein. 2009. Measuring presence: The Temple Presence Inventory. In *Twelfth International Workshop on Presence*. Los Angeles, California.

Matthew Lombard, Lisa Weinstein, and Theresa B. Ditton. 2011. Measuring telepresence: The validity of the Temple Presence Inventory (TPI) in a gaming context. In *Annual conference of the International Society for Presence Research (ISPR)*. Edinburgh, Scotland.

Giuseppe Mantovani and Giuseppe Riva. 2001. Building a bridge between different scientific communities: On Sheridan's eclectic ontology of presence. *Presence: Teleoperators and Virtual Environments* 10, 5 (October 2001), 537–543.

Rory McGloin, Kirstie Farrar, and Marina Krcmar. 2013. Video games, immersion, and cognitive aggression: does the controller matter? *Media psychology* 16, 1 (2013), 65–87.

Michael Meehan, Brent Insko, Mary Whitton, and Frederick P. Brooks, Jr. 2002. Physiological measures of presence in stressful virtual environments. In *Proceedings of the 29th annual conference on Computer graphics and interactive techniques (SIGGRAPH '02)*. ACM, New York, NY, USA, 645–652. DOI: http://dx.doi.org/10.1145/566570.566630

Michael John Meehan. 2001. *Physiological reaction as an objective measure of presence in virtual environments*. Ph.D. Dissertation. The University of North Carolina at Chapel Hill.

David Modjeska and John A. Waterworth. 2000. Effects of desktop 3D world design on user navigation and search performance. In *Proceedings of IV2000, the IEEE International Conference on Information Visualization, 2000.* 215–220. DOI: http://dx.doi.org/10.1109/IV.2000.859758

Dinah K.C. Murray. 1997. Autism and information technology: Therapy with computers. In *Autism and learning: A guide to good practice*, S. Powell and R. Jordan (Eds.). David Fulton, London, UK.

Max Parola, Samuel Johnson, and Ruth West. 2016. Turning Presence Inside-Out: MetaNarratives. *Electronic Imaging* 2016, 4 (February 2016), 1–9.

Holger T. Regenbrecht, Thomas W. Schubert, and Frank Friedmann. 1998. Measuring the Sense of Presence and its Relations to Fear of Heights in Virtual Environments. *International Journal of Human-Computer Interaction* 10, 3 (1998), 233–249. DOI: http://dx.doi.org/10.1207/s15327590ijhc1003_2

Cedar Riener and Dennis Proffitt. 2002. Quantifying spatial presence. In *Proceedings of the 5th Annual International Conference on Presence*.

Giuseppe Riva, M Teresa Anguera, Brenda K Wiederhold, and Fabrizia Mantovani (Eds.). 2006. *From communication to presence*. Emerging Communication: Studies in New Technologies and Practices in Communication, Vol. 9. IOS Press, Amsterdam.

Christine Rosakranse and Soo Youn Oh. 2014. Measuring presence: The use trends of five canonical presence quesionnaires from 1998-2012. In *Proceedings of the International Society for Presence Research 2014*. International Society for Presence Research.

James Russell. 1996. *Agency: its role in mental development*. Psychology Press, East Sussex, UK.

Corina Sas and Gregory MP O'Hare. 2003. Presence equation: an investigation into cognitive factors underlying presence. *Presence: Teleoperators and Virtual Environments* 12, 5 (2003), 523–537.

David W. Schloerb. 1995. A Quantitative Measure of Telepresence. *Presence: Teleoperators and Virtual Environments* 4 (1995), 64–80.

Thomas Schubert, Frank Friedmann, and Holger Regenbrecht. 2001. The experience of presence: Factor analytic insights. *Presence: Teleoperators and Virtual Environments* 10, 3 (June 2001), 266–281. DOI: http://dx.doi.org/10.1162/105474601300343603

Thomas Schubert and Holger Regenbrecht. 1999. Decomposing the Sense of Presence: Factor Analytic Insights. In *2nd International Workshop on Presence*.

Thomas W. Schubert. 2009. A New Conception of Spatial Presence: Once Again, with Feeling. *Communication Theory* 19, 2 (2009), 161–187. DOI: http://dx.doi.org/10.1111/j.1468-2885.2009.01340.x

Anil K. Seth, Keisuke Suzuki, and Hugo D. Critchley. 2012. An interoceptive predictive coding model of conscious presence. *Frontiers in Psychology* 2, 395 (2012). DOI: http://dx.doi.org/10.3389/fpsyg.2011.00395

Thomas B. Sheridan. 1992. Musings on telepresence and virtual presence. In *Papers from SRI's 1991 Conference on Virtual Reality on Virtual worlds : real challenges: real challenges (SRI '91)*. Meckler Corporation, Westport, CT, USA, 55–65. http://portal.acm.org/citation.cfm?id=166761.166779

Richard Skarbez. 2016. *Plausibility illusion in virtual environments*. Ph.D. Dissertation. The University of North Carolina at Chapel Hill.

Richard Skarbez, Jr. Frederick P. Brooks, and Mary C. Whitton. 2016. Immersion and coherence in a visual cliff environment. *IEEE Transactions on Visualization and Computer Graphics (in submission)* (2016).

Mel Slater. 1999. Measuring presence: A response to the Witmer and Singer Presence Questionnaire. *Presence: Teleoperators and Virtual Environments* 8 (1999), 560–565. DOI: http://dx.doi.org/10.1162/105474699566477

Mel Slater. 2004. A note on presence terminology. In *Presence Connect*, Vol. 3.

Mel Slater. 2009. Place illusion and plausibility can lead to realistic behavior in immersive virtual environments. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 364 (2009), 3549–3557.

Mel Slater, Andrea Brogni, and Anthony Steed. 2003. Physiological responses to breaks in presence: A pilot study. In *PRESENCE 2003 - 6th Annual International Workshop on Presence*.

Mel Slater, Christoph Guger, Guenter Edlinger, Robert Leeb, Gert Pfurtscheller, Angus Antley, Maia Garau, Andrea Brogni, and Doron Friedman. 2006. Analysis of Physiological Responses to a Social Situation in an Immersive Virtual Environment. *Presence: Teleoperators and Virtual Environments* 15 (2006), 553–569. DOI: http://dx.doi.org/10.1162/pres.15.5.553

Mel Slater, Vasilis Linakis, Martin Usoh, Rob Kooper, and G Street. 1996. Immersion, presence, and performance in virtual environments: An experiment with tri-dimensional chess. In *ACM Virtual Reality Software and Technology (VRST)*. 163–172.

Mel Slater and Anthony Steed. 2000. A Virtual Presence Counter. *Presence: Teleoperators and Virtual Environments* 9 (October 2000), 413–434. Issue 5. DOI: http://dx.doi.org/10.1162/105474600566925

Mel Slater, Anthony Steed, and Martin Usoh. 1993. The Virtual Treadmill: A Naturalistic Metaphor for Navigation in Immersive Virtual Environments. In *First Eurographics Workshop on Virtual Environments*, Martin Goebel (Ed.). 71–83.

Mel Slater, Anthony Steed, and Martin Usoh. 1995. The Virtual Treadmill: A Naturalistic Metaphor for Navigation in Immersive Virtual Environments. In *Selected Papers of the Eurographics Workshops on Virtual Environments '95 (VE '95)*. Springer-Verlag, London, UK, UK, 135–148. http://dl.acm.org/citation.cfm?id=237121.237143

Mel Slater and Martin Usoh. 1993. Representations systems, perceptual position, and presence in virtual environments. *Presence: Teleoperators and Virtual Environments* 2, 3 (1993), 221–233.

Mel Slater, Martin Usoh, and Anthony Steed. 1994. Depth of Presence in Virtual Environments. *Presence: Teleoperators and Virtual Environments* 3 (1994), 130–144.

Mel Slater and Sylvia Wilbur. 1997. A Framework for Immersive Virtual Environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators and Virtual Environments* 6, 6 (2016/02/18 1997), 603–616. DOI: http://dx.doi.org/10.1162/pres.1997.6.6.603

Michael Potter Snow. 1998. *Charting presence in virtual environments and its effects on performance*. Ph.D. Dissertation. Virginia Polytechnic Institute, Blacksburg, VA, USA. UMI Order No. GAX97-24047.

Michael P. Snow and Robert C. Williges. 1998. Empirical Models Based on Free-Modulus Magnitude Estimation of Perceived Presence in Virtual Environments. *Human Factors* (1998), 386–402.

Anna Spagnolli and Luciano Gamberini. 2002. Immersion/Emersion: Presence in hybrid environments. In *Proceedings of the 5th Annual International Conference on Presence*. Universitade Fernando Pessoa Press, Porto, Portugal, 421–434.

Anna Spagnolli and Luciano Gamberini. 2004. The Sense of Being 'There': a Model for the Space of Presence. In *Proceedings of the 7th Annual International Workshop on Presence*. Editorial Universidad Politécnica de Valencia, Valencia, Spain, 48–53.

Jonathan Steuer. 1992. Defining Virtual Reality: Dimensions Determining Telepresence. *Journal of Communication* 42, 4 (1992), 73–93. DOI: http://dx.doi.org/10.1111/j.1460-2466.1992.tb00812.x

Jari Takatalo. 2002. Presence and flow in virtual environments: An explorative study. *Master's thesis, University of Helsinki* (2002).

Jari Takatalo, Göte Nyman, and Leif Laaksonen. 2008. Components of human experience in virtual environments. *Computers in Human Behavior* 24, 1 (2008), 1 – 15. DOI: http://dx.doi.org/10.1016/j.chb.2006.11.003

John Towell and Elizabeth Towell. 1997. Presence in text-based networked virtual environments or "MUDS". *Presence: Teleoperators and Virtual Environments* 6, 5 (1997), 590–595.

Martin Usoh, Ernest Catena, Sima Arman, and Mel Slater. 2000. Using Presence Questionnaires in Reality. *Presence: Teleoperators and Virtual Environments* 9 (2000), 497–503. DOI: http://dx.doi.org/10.1162/105474600566989

Peter Vorderer, Werner Wirth, Feliz Ribiero Gouveia, Frank Biocca, Timo Saari, Lutz Jäncke, Saskia Böcking, Holger Schramm, Andre Gysbers, Tilo Hartmann, Cristoph Klimmt, Jari Laarni, Niklas Ravaja, Ana Sacau, Thomas Baumgartner, and Petra Jäncke. 2004. *MEC Spatial Presence Questionnaire (MEC-SPQ): Short documentation and instructions for application*. Technical Report. Report to the European Community, Project Presence: MEC (IST-2001-37661).

Eva L Waterworth and John A Waterworth. 2001. Focus, locus, and sensus: The three dimensions of virtual experience. *CyberPsychology & Behavior* 4, 2 (July 2001), 203–213.

Robert B. Welch. 1999. How Can We Determine if the Sense of Presence Affects Task Performance? *Presence: Teleoperators and Virtual Environments* 8, 5 (Oct. 1999), 574–577. DOI: http://dx.doi.org/10.1162/105474699566387

Robert B. Welch, Theodore T. Blackmon, Andrew Liu, Barbara A. Mellers, and Lawrence W. Stark. 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 (2016/03/06 1996), 263–273. DOI: http://dx.doi.org/10.1162/pres.1996.5.3.263

Werner Wirth, Tilo Hartmann, Saskia Böcking, Peter Vorderer, Christoph Klimmt, Holger Schramm, Timo Saari, Jari Laarni, Niklas Ravaja, Feliz Ribeiro Gouveia, Frank Biocca, Ana Sacau, Lutz Jäncke, Thomas Baumgartner, and Petra Jäncke. 2007. A Process Model of the Formation of Spatial Presence Experiences. *Media Psychology* 9, 3 (2007), 493–525. DOI: http://dx.doi.org/10.1080/15213260701283079

Werner Wirth, Susanne Wolf, Ursina Mögerle, and Saskia Böcking. 2004. Measuring the subjective experience of presence with think-aloud method: Theory, instruments, implications, In PRESENCE 2004 - 7th Annual International Workshop on Presence. *PRESENCE 2004* (2004), 351–358.

Bob G. Witmer, Christian J. Jerome, and Michael J. Singer. 2005. The factor structure of the presence questionnaire. *Presence: Teleoperators and Virtual Environments* 14, 3 (June 2005), 298–312.

Bob G. Witmer and Michael J. Singer. 1998. Measuring Presence in Virtual Environments: A Presence Questionnaire. *Presence: Teleoperators and Virtual Environments* 7 (1998), 225–240. DOI: http://dx.doi.org/10.1162/105474698565686

Pavel Zahorik and Rick L. Jenison. 1998. Presence as Being-in-the-World. *Presence: Teleoperators and Virtual Environments* 7 (1998), 78–89. DOI: http://dx.doi.org/10.1162/105474698565541

Received November 2016; revised November 2016; accepted November 2016