A Survey of Presence and Related Concepts

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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 review several related constructs, including social presence, copresence, immersion, agency, transportation, reality judgment, and embodiment. In addition, we present a meta-analysis of existing presence models and propose a model 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, social presence, copresence, immersion, coherence, virtual reality, virtual environments

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1 INTRODUCTION

Since the early days of virtual environments (VE) research, *presence* has been a very important concept for VE creators, representing both the desired outcome of exposure to virtual experiences and a way to measure the quality of a given VE. Despite—or perhaps because of—its central importance, presence has been defined and measured in many different ways. This has also led to many related terms, such as *social presence*, being introduced to the VE literature. Our goals in this survey are to introduce the important terms used in the study of virtual experiences, to explore different definitions and models of presence and identify important commonalities and differences among them, to provide a single point of reference for the many methods that have been proposed for the measurement of presence, and to define or coin (where necessary) terms in such a way as to enable more effective—and less confusing—communication about virtual experiences.

This survey begins with an introduction to presence and related concepts to present the concepts and definitions that inform the analysis of the presence concept itself that makes up the bulk of this article. We then review many of the definitions of presence that appear in the literature. We

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group these definitions into categories and argue for a definition of presence that more closely matches how it is commonly used. We then review many of the models of the presence construct that have been proposed. We also present a meta-analysis of these presence models, identifying commonalities between them and presenting a new model informed by Slater's Place Illusion and Plausibility Illusion. We conclude with a review of existing presence measures, presenting and commenting on many of the self-report, behavioral, physiological, and psychophysical measures that have appeared in the VE literature.

2 EVALUATING THE EFFECTIVENESS OF VIRTUAL ENVIRONMENTS

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 those suggest different hardware and/or software implementations. Additionally, there is no consistent definition for what constitutes an effective VE, even within application domains. For these reasons, the identification of one or more *generalizable* constructs that can be used to determine the effectiveness of VEs has driven and continues to drive research in this area.

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, for example, 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 conducted, due to the time, effort, and cost required. That said, they are sometimes done, especially for training of mission critical personnel such as astronauts [79], shipboard firefighters [143], and surgeons [72, 74]. Even when such studies are performed, though, they do 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. The identification of potential constructs, such as presence, and the development of appropriate measures for said constructs have been driving VE research for decades, and continue to do so today.

2.1 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" [2]. *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" [157].

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 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 [87] and behavioral [47] measures, but these are also flawed, requiring addition to 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 such as 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 [87]. 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 measures are promising, they are not universal solutions.

Hendrix and Barfield proposed that a subjective measure of presence should be relevant, sensitive, convenient, nonintrusive, and reliable [63]. In Meehan's dissertation he posited that an ideal measurement of presence would be reliable, that is, producing repeatable results, both within and between subjects; valid, that is, demonstrated to correlate with the subjective feeling of presence; multi-level-sensitive; and objective [88]. These are standard principles of sound testing practices [1]. 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 regarding the use of presence as a universal VE effectiveness measure, 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 [151]. Experimental results linking presence and task performance are mixed [90, 124, 135, 157], and even so, it is difficult to distinguish whether any benefits would be due to increased presence or increased immersion.

2.2 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 [118]. 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" [157]. Lombard and colleagues refer to these different conceptions of immersion as *perceptual immersion* [16] and *psychological immersion*, respectively [81]. 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 VE literature. In addition, immersion is often used as a term synonymous with presence. (For some examples of such, see References [97, 153].) 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 [121].

We believe, again following Slater, that, "Immersion provides the boundaries within which [presence] can occur" [121]. However, studying the immersion of VE systems has significant utility beyond the fact that it enables presence. For example, Bowman and McMahan argue that, "Presence

might not be immersion's only benefit: Applications can take advantage of other side effects of high levels of immersion," such as spatial understanding or increased peripheral awareness [27].

2.3 Social Presence, Copresence, and Related Terms

One shortcoming in the common understanding of presence is that it does not include any notion of social interaction: The prevalent interpretations and uses of the term *presence* focus on a single user's interaction with an environment. In practice, a VE may contain other characters, controlled by computers or humans, with whom the user may (or may not) interact. To overcome this deficiency, researchers have adopted the terms *copresence* and *social presence* to discuss and reason about users' interactions with characters in virtual environments.

The term *copresence* was first coined by Goffman in the course of his describing human behavior in public places as, "exist[ing] when people sensed that they were able to perceive others and that others were able to actively perceive them...render[ing] persons uniquely accessible, available, and subject to one another" [56]. It has also been defined as, "a condition in which instant two-way human interactions can take place" [159], and even more succinctly as, "being there together" [107, 108]. Note that although these concepts are clearly related, there are important differences: The co-presence definitions from Goffman and Zhao refer to properties of a communication medium, and so are objective, immersive characteristics of a system; on the other hand, Schroeder's definition implies that copresence is a quale, the feeling of being together in a place.

The term *social presence* was first defined by Short et al. in their investigation of the social psychology of telecommunications as, "the degree of salience of the other person in the interaction and the consequent salience of the interpersonal relationships" [114]. It has also been defined as "when one person feels another person is 'there"' [31], "the perception of a medium's ability to connect people" [94], and "the awareness of being present with others in a mediated environment combined with a certain degree of attention to the other's intentional, cognitive, or affective states" [148]. Here, while all of these authors define social presence as a quale, the definitions again differ in important ways: The feeling described by Nowak and Biocca does not involve another being, but all the others do; the definition of van der Land and colleagues requires attention on the part of the user, while Bull's definition does not.

Note also that the terms copresence and social presence can have significant overlap, and in fact, are often used interchangeably [6, 19]. Additionally, the term social presence is used with multiple meanings, both as a system characteristic that is a prerequisite for copresence (Social presence is "[H]ow well a communications medium transmits verbal and nonverbal cues as well as the apparent distance or 'realness' of the communicators" [91].), and as a quale that is contingent upon copresence ("Mediated social presence is the moment-by-moment awareness of the co-presence of another sentient being accompanied by a sense of engagement with the other (i.e., human, animate, or artificial being)" [17].)

In this review, we follow Biocca et al. and define copresence as a quale that is required for a user to experience social presence [17]. Specifically, we define *copresence* as the sense of being together with another or others, and *social presence* as the moment-by-moment awareness of the copresence of another sentient being accompanied by a sense of engagement with them. Following Biocca et al., the difference between the two is the extent to which one's experience depends on the other or others. All that is required for copresence is the awareness that another being exists in the space; social presence, on the other hand, does not develop without some degree of interaction, wherein one's behavior and/or psychological state is affected by the other or vice versa.

At this point, we would like to coin and argue for the use of the term *Social Presence Illusion*, rather than the term *social presence*, to refer to the feeling of social presence engendered by characters in virtual or mediated environments. We have shown in this section that the terms

copresence and social presence have confusing and occasionally contradictory definitions. The use of the term Social Presence Illusion makes explicit that we are referring to the illusory (false) feeling of being together with and engaging with a real sentient being. To refer to the feeling of being together and interacting with a real person in the real world, we continue to endorse the term social presence. Similarly for the terms *Copresence Illusion* and *copresence*, which refer to the feeling of "being together" in a virtual or mediated space and the feeling of "being together" in a real space, respectively.

Note, however, that so defining copresence and social presence means that we no longer have a term to refer to the feeling that a medium provides the necessary affordances for social interaction. In the words of Sivunen and Nordbäck, "some researchers have separated copresence from social presence on the basis that the latter relates to the quality of the medium and users' perceptions of it, whereas copresence...addresses the psychological interaction of the individuals" [115]. For example, Lombard et al. used *social presence* to refer to "the extent to which a medium is perceived as sociable, warm, sensitive, personal or intimate when it is used to interact with other people" [80]. To address this shortcoming, we propose the term *communicative salience* to refer to this feeling, as well as the term *communicative immersion* to refer to the objective characteristics of the underlying medium that contribute to communicative salience.

As presence depends on immersion, and Plausibility Illusion on coherence (these are discussed in Sections 2.5 and 2.6), so Social Presence Illusion must be constrained by some characteristics of the underlying system. We argue that Social Presence Illusion depends on three things: (1) The *company* of another "sentient" being or beings in the virtual or mediated environment, (2) The ability of the medium to transmit communicative signals (voice, eye contact, posture, etc.), and (3) "Appropriate" behavior of the other sentient being or beings. (1) is the Copresence Illusion, (2) is what we previously defined as communicative immersion, and is a subset of the overall immersion of the VE, and (3) is a subset of coherence. (*Communicative coherence*, perhaps.)

Note that a medium can support Copresence Illusion and Social Presence Illusion without giving rise to the feeling of being in another place. Consider the case of speaking with someone on the telephone: "[F]or example, talking on a telephone with someone might give a strong sense of 'being with them' but not of being in the same place as them" [125]. Here, you are certainly aware of the person on the other end of the line (Copresence Illusion), and you can interact with that other person (Social Presence Illusion). However, you do not get the impression that you have been transported to another place.

2.4 Realism and Fidelity

Another potential shortcoming of presence as a generalizable measure is that it does not account for the realism of the scenario being presented. However, for some scenarios, such as military or surgical training, it may be important that the scenario correspond to reality to the maximum extent possible. Alexander et al. describe *fidelity* as "the extent to which the virtual environment emulates the real world," and identify several relevant subcategories of fidelity, including physical ("the physical simulation looks, sounds, and feels like the operational environment"), functional ("the simulation acts like the operational equipment in reacting to the tasks executed by the trainee"), and psychological ("the simulation replicates the psychological factors...experienced in the real-world environment") [3].

Stoffregen et al. describe *stimulus fidelity* as the extent to which sensory stimuli produced by a simulator are identical to those produced by the system being simulated. Stimulus fidelity is therefore an objective characteristic of a simulation, as it depends only on sensory stimuli, rather than perceptions of those stimuli. The authors also cite work by Riccio, who described *experiential fidelity* as "fidelity of subjective experience" and *action fidelity* as "fidelity of performance" [99].

Stimulus fidelity as so defined is akin to our definition of immersion; it is an objective characteristic of the simulator/VE. Experiential fidelity is similar to presence, in that it is a user's subjective experience of the reality of the scenario. (In fact, it is even more similar to Plausibility Illusion, defined in Section 2.5). Action fidelity is akin to, or perhaps a component of, training transfer: Do the actions a user takes in the simulator/VE match the actions that he or she would take in the real world?

In this document, we accept Alexander's definition of fidelity as "the extent to which the virtual environment emulates the real world" [3]. Fidelity as a construct is logically orthogonal to immersion. On the one hand, it is possible to create a high level of immersion in an unrealistic or fantastical scenario, and on the other, it is possible to have a high degree of fidelity in low-immersion media.

2.5 Place Illusion and Plausibility Illusion

To address some of the confusion relating to the presence construct (as explicated in Section 3), Slater proposed a theory that presence is composed of two logically orthogonal components, Place Illusion (PI) and Plausibility Illusion (Psi). 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)" [121]. PI, then, corresponds to the traditional conception of (spatial or place) 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, then that would reinforce your feeling of PI. If all the library patrons were being quiet, then that would reinforce your feeling of Psi. Contrarily, if you turned your head and the imagery didn't change, then that would break PI, and if patrons were yelling loudly in the library, then that would break Psi.

We believe that that there are several benefits to this theoretical framework. First, by introducing the terminology Place Illusion to replace spatial/place/tele/presence, Slater "make[s] it clear that we refer specifically and only to the strong illusion of being in a place and not to other multiple meanings that have since been attributed to the word 'presence"' [121]. Second, by introducing the concept of Plausibility Illusion and making it comparable in importance to Place Illusion, Slater reifies fidelity and correct behavior as important components of virtual experience.

2.6 Coherence

In the article that introduced Place Illusion and Plausibility Illusion, Slater stated that "Immersion provides the boundaries within which [Place Illusion] can occur" [121]. That is, the immersion of a system enables the feeling of Place Illusion. In his dissertation, Skarbez argues that there must be a construct parallel 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 [116].

Coherence can be thought of as a superset of realism or fidelity. Specifically, coherence makes no assumptions about a VE having to faithfully represent the real world. Rather, coherence depends on the internal logical and behavioral consistency of the virtual experience. If one has been led to believe that he or she is going to experience a virtual fantasy world, then the appearance of a character flying hundreds of feet in the air would be coherent behavior. On the other hand, if one has been led to believe that he or she is going to experience a realistic training scenario, the

very same behavior would be incoherent, and would likely decrease a user's feeling of Plausibility Illusion.

Gilbert independently proposed a very similar construct, that of *authenticity* [55]. He defines the authenticity of a VE as the degree to which it supports "(1) users' expectations based on their Bayesian priors for regularities in the real world and (2) the users' intentions in the VE." It "refers to whether the virtual environment provides the experience expected by the user, both consciously and unconsciously." As written, authenticity applies only to VEs that attempt to replicate some aspect of the real world, while coherence makes no such requirement. Gilbert's definition, however, does enable an alternative definition of reasonable circumstances, which can now be considered as those circumstances that align with users' Bayesian priors. We believe that authenticity and coherence are in fact different terms for the same construct; throughout this review, we will use the term coherence to refer to this construct.

An open question regarding coherence is whether it is truly an objective construct. Skarbez's original definition of a reasonable circumstance given previously raises the question, "Whose prior knowledge?" The redefinition prompted by Gilbert raises the question, "Whose Bayesian priors?"

As a thought experiment, one can imagine a VE in which every depicted action (or inaction) can be explained by information previously presented in the VE; that is, it requires no prior knowledge whatsoever. It seems to us, however, that the existence of such a VE would imply the existence of a perfect simulation of the history of the universe. Practically, every VE assumes some prior knowledge and set of experiences on the part of its users. If this is the case, then coherence cannot be purely objective.

That said, we believe that it is useful to treat coherence *as if* it were objective. A VE developer may not be able to control users' prior knowledge; however, he or she is able to control whether the events depicted in the VE are internally consistent, and he or she is able to minimize the extent to which the "reasonableness" of events depends on assumptions made by the user by explicitly priming the user to expect certain types of behavior—thereby altering the user's Bayesian priors (consider the flying example presented earlier). By doing so, the set of *objectively* reasonable circumstances—that is, states of affairs that are self-evident given prior knowledge *provided in the context of the virtual experience*—can be maximized. We therefore propose to redefine *coherence* as the set of objectively reasonable circumstances that can be demonstrated by the scenario without introducing objectively unreasonable circumstances.

2.7 Embodiment, Body Ownership, and Self-Presence

Within the computing literature, *embodiment* generally refers to the representation of a user (also known as an *avatar*) within a mediated or virtual environment. As examples, Gabbard states that, "Representing the user within a VE is known as *user embodiment*" [50], and Benford et al. state that, "User embodiment concerns the provision of users with appropriate body images to represent them to others (and also to themselves) in collaborative situations" [11].

In the psychology and philosophy fields, though, *embodiment* has a different meaning, that is, "The psychology of presence is related to the body and to the embodiment process" [102]. Blanke and Metzinger state that *embodiment* includes, "the subjective experience of using and 'having' a body" [18]. De Vignemont defines *embodiment* as follows: "E is embodied if and only if some properties of E are processed in the same way as the properties of one's body" [41]. Inspired by de Vignemont's definition of embodiment, Kilteni, Groten, and Slater define *Sense of Embodiment* as follows: "[Sense of Embodiment] toward a body B is the sense that emerges when B's properties are processed as if they were the properties of one's own biological body" [70]. De Vignemont's *embodiment* refers to a properties of a single body part or object being processed as if it were part of one's own body, while Kilteni et al.'s *Sense of Embodiment* refers to properties of a whole body

being processed in the same way. Kilteni et al. also provide a "working definition" for *Sense of Embodiment*, defining it as a combination of three subcomponents, "the sense of self-location, the sense of agency, and the sense of body ownership" [70].

Embodiment so defined can be measured by questionnaires and behavioral measures; for an example of such, see Botvinick and Cohen's presentation of the Rubber Hand Illusion [22].

Ownership is the sense that a body (or body part) is one's own. De Vignemont states that, "Embodiment is a necessary condition for the feeling of ownership" [41]. But the two are distinct. Embodiment can be felt with tools, for example, but that does not lead to a sense of ownership. Slater et al. have explored the illusion of body ownership with regard to a purely virtual body [127].

Related to embodiment and ownership is the feeling of *self-presence*.

> "*Self-presence* is defined as users' mental model of themselves inside the virtual world, but especially differences in self-presence due to the short term or long term effect of virtual environment on the perception of one's body (i.e., body schema or body image), physiological states, emotional states, perceived traits, and identity...*Self-presence* refers to the effect of embodiment in [a] virtual environment on mental models of the self" [13].

Alternatively, Lee defines *self-presence* as, "a psychological state in which virtual (para-authentic or artificial) self/selves are experienced in the actual self in either sensory or nonsensory ways" [77].

2.8 Other Concepts Related to Presence

The preceding sections address constructs frequently and specifically explored using or regarding virtual environments. There are other constructs from outside the VE literature that are related to presence, however. The following paragraphs provide an introduction to several of these constructs.

Involvement and Engagement. We group involvement and engagement under one heading as the terms are generally used interchangeably (as in, "the term 'engagement' [is] used as a generic indicator of game involvement" [28]), to mean something like a state of focused attention or interest. For example, Witmer and Singer define *involvement* as, "a psychological state experienced as a consequence of focusing one's energy and attention on a coherent set of stimuli or meaningfully related activities and events. Involvement depends on the degree of significance or meaning that the individual attaches to the stimuli, activities, or events" [157]. Böcking et al. define *involvement* as, "the intense cognitive engagement with a media environment that can be observed via processes of appraisal, elaboration, evaluations, and mental explorations...the active and intense processing of the world presented by the media" [20]. McQuarrie and Munson's Revised Product Involvement Inventory (RPII) identifies two facets of involvement: perceived importance and interest [86].

The Witmer-Singer Presence Questionnaire [157], the ITC-Sense of Presence Inventory (ITC-SOPI) [78], and the Igroup Presence Questionnaire (IPQ) [109] all contain subscales regarding involvement or engagement. In addition, the Game Engagement Questionnaire (GEQ) of Brockmyer et al. is an instrument specifically designed to measure the level of involvement/engagement in video games [28], although it has been adapted and used in the study of virtual environments as well [85].

We note that while some presence questionnaires, including those listed previously, explicitly consider involvement to be a component of the presence construct, we do not. As with some of the other constructs discussed previously, presence is logically orthogonal to involvement, as

illustrated by the following examples: "One can be present but not involved (as in many situations in everyday life). One can be involved but not present (e.g., watching a soap opera, reading a book)" [120], or "[A] user can feel spatially present in a VE designed to be boring without feeling engaged in it or cognitively involved" [39].

Flow. Flow is described as an optimal state of concentration, "the state in which individuals are so involved in an activity that nothing else seems to matter" [37]. Novak et al. describe Csikszentmihalyi's model of flow as follows:

> A good starting point is the comprehensive listing of eight components of flow provided by [38]: (1) a clear goal, (2) feedback, (3) challenges match skills, (4) concentration and focus, (5) control, (6) loss of self consciousness, (7) transformation of time, and (8) the activity becomes autotelic (that is, perceived as worth doing for its own sake). While structural relations among the constructs are not specified, the constructs are grouped according to whether they specify antecedent conditions of flow (1, 2, and 3), its characteristics (4 and 5), or the consequences of the experience (6, 7, and 8) [93].

In Novak et al.'s model of flow, telepresence appears as a contributing factor to flow [93]. This finding is supported by a study by Takatalo, who found a similar connection between presence and flow in a virtual environment [141]. (Novak et al.'s study regarded use of the World Wide Web.) Brockmyer et al. argue that flow, since it involves experiencing an altered state, may be a deeper state of engagement with media than presence [28]. Hoffman and Novak present a survey of existing literature on flow on the Web, as well as a discussion regarding flow and virtual worlds, in Reference [66].

Absorption. Absorption is described as, "the ability to get lost in the task at hand whether it is watching a movie, reading a book, or experiencing VR" [9], or as "the tendency to become fully involved in a perceptual, imaginative, or ideational experience" [144]. Brockmyer et al. argue that absorption is an even a deeper state of engagement with media than flow or presence [28].

The Tellegen-Atkinson Absorption Scale is an instrument consisting of six Likert-scale questions that measures openness to absorption [144]. Note that this is a measure of trait (a consistent and long-lasting tendency), not state (a temporary feeling based on one's situation); as such, it is a measure of individual differences, which will be discussed further elsewhere in this article.

Transportation. Broadly speaking, the concept of *transportation* is to narrative worlds as the concept of presence is to technology-mediated worlds [53]. 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" [58].

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 [157]. There are transportation and transportability questionnaires that are analogous to the PQ and ITQ, respectively [57, 58].

Agency. Agency [104] is, "the sense that I am the one who is causing or generating an action" [51], or "the satisfying power to take meaningful action and see the results of our decisions and choices" [92]. Agency has been identified as a concept that may share some features and factors with presence [65]. 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 [40, 112].

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 [7, 8]. Thus, reality judgment is roughly synonymous with Plausibility Illusion.

2.9 Analysis

As we've seen in this section, presence is not the only relevant construct in the evaluation of virtual environments, nor is it truly a universal measure of VE effectiveness. In particular, virtual environments that do not represent a particular place, such as visualization applications, are unlikely to benefit from a sense of "being there." They may, however, benefit from other side effects of increased immersion [27].

Even in the many VE applications for which presence is likely to be an effective measure, one or more of the other constructs discussed in this section may be equally or more relevant. For example, in applications that have the goal of predicting real world behavior, such as ergonomic evaluations, immersion and fidelity are likely most important [67, 96]. In telepresence or group training applications, Social Presence Illusion is likely at least as important as (spatial) presence. In applications where users are doing real work inside a VE, the ability to induce a state of involvement or flow might be more important. For applications whose goal is transfer of training to the real world, fidelity is likely to be important. For entertainment applications, or other applications that seek to elicit a feeling of absorption, coherence might be more important than immersion. (Or in terms of desired outcomes, Plausibility Illusion might be more important than Place Illusion.)

Even taking all of this into account, presence remains a centrally important idea in the development and evaluation of virtual environments. In this section, we introduced the presence construct, as well as several related constructs including immersion, social presence, copresence, fidelity, coherence, Place Illusion, and Plausibility Illusion. The remainder of this article focuses on the explication of presence, commenting on the many ways it is defined, its proposed models, and the methods that have been employed for its measurement.

3 DEFINING PRESENCE

Many definitions of presence have been 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 [150], presence as the perception of objects as real [77], presence as the feeling that the simulator is actually the simulated [140], or presence as the sense of feeling real [95].

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 publications in which the definitions appear are, in Table 1, sorted into these categories and subcategories.

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. The definitions are listed so the reader can better appreciate the important differences between the various definitions and to provide context for the analysis presented in Section 3.2.

Table 1. Sources of Definitions of Presence Sorted by Category

Being there		Non-mediation		Other
Active	Passive	External	Internal	Perceptual processing
Steuer, 1992 [139]	Witmer and Singer, 1998 [157]	Lombard and Ditton, 1997 [80]	Slater and Usoh, 1993 [131]	Waterworth and Waterworth, 2001 [150]
Schloerb, 1995 [106]	Sas and O'Hare, 2003 [105]	ISPR, 2000 [69]		
Flach and Holden, 1998 [46]	Spagnolli and Gamberini, 2004 [138]			Simulator is simulated
Zahorik and Jenison, 1998 [158]	Wirth et al., 2004 [155]			Stoffregen et al., 2003 [140]
Mantovani and Riva, 2001 [84]				
Biocca, 2001 [14]				Real objects
Slater, 2004 [120]				Lee, 2004 [77]
Carassa et al., 2005 [34]				
Witmer et al., 2005 [156]				Feeling real
Riva et al., 2006 [101]				Parola et al., 2016 [95]
Herrera et al., 2006 [65]				
Wirth et al., 2007 [154]				

3.1 Definitions

The notion of presence as it is used in the context of virtual reality can be traced to psychologist James Gibson, via Jonathan Steuer [139].

> Presence can be thought of as the experience of one's physical environment; it refers not to one's surroundings as they exist in the physical world, but to the perception of those surroundings as mediated by both automatic and controlled mental processes [54]: *Presence is defined as the sense of being in an environment.*

From Gibson comes the notion that, "The environment of animals and men is what they perceive. The environment is not the same as the physical world, if one means by that the world described by physics" [54]. 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: Presence 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.

The term *telepresence* can be traced back to Marvin Minsky's 1980 essay of the same name. Minsky does not explicitly provide a definition for the term, but does state that, "The biggest challenge to developing telepresence is achieving that sense of 'being there' [89].

3.1.1 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" [139]. 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," "mediated presence," or "virtual presence."

Schloerb introduced an "objective" definition of presence in Reference [106]. *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, then one is more present. This suggests a very natural method for measuring presence, however, we disagree with this conception of presence. For example, a professional baseball player would likely perform much better than an average person in a virtual baseball-hitting scenario, but to suggest that this means that the professional is more present seems inappropriate, especially if this difference in performance also applies in the real world.

Flach and Holden returned to Gibson's research as the basis of presence [46]. 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 (in particular, the characteristics of the world that are important for experiencing presence), then, are behavioral, rather than aesthetic.

Continuing that line of thinking, Zahorik and Jenison described *presence* as "tantamount to successfully supported action in the environment" [158]. 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 [84]. 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 it exists. 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.

These Gibsonian arguments (of Flach and Holden, Zahorik and Jenison, and Mantovani and Riva) are echoed in later conceptions of presence, such as Slater's *Place Illusion*, in which the illusion derives from the valid actions that are supported by the experience [121].

In the article that 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" [157].

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" [14]. 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 [158] and Flach and Holden [46]. 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" [120]. This is quite similar (albeit using very different terminology) to Zahorik and Jenison's conception of presence as being-in-the-world [158]. 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 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.

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 [105]. Here, as in Biocca [14], 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 is, that presence is binary. That consciousness can simultaneously have two foci seems unlikely.

Spagnolli and Gamberini, on the other hand, maintained the focus of presence on location [138]: "Whenever a person is qualified as 'present'...her location is the salient, characterizing feature." If one follows this line of thinking, then 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 in a mediated environment.

Wirth and colleagues defined *spatial presence* as "the subjective experience of being in the mediated environment" [155]. 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" [34]. 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 Reference [156]. 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." Witmer and Singer 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" [101]. This builds on Zahorik and Jenison's conception of presence as successfully supported action in the environment [158]. 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 [120].

Herrera et al. defined *presence* as the "conscious awareness of self, as both agent and experiencer, which characterizes the experiencing self of natural environments" [65]. 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" [154].

3.1.2 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" [131]. 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" [80]. 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 associated with 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 [121].

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 [69].

This definition is clearly indebted to Lombard and Ditton, as the focus is on the illusion of nonmediation 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.

3.1.3 Other. 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" [150]. In this article the authors 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.

Stoffregen et al. defined *presence* as, "[A]n illusory (false) perception that the simulator is the simulated" [140]. This echoes Schloerb's test for *subjective presence*, in which a person is asked to choose whether he or she is physically present in an environment, or interacting with the environment remotely, and their degree of subjective presence is equal to the probability that the person says that he or she is physically present when he or she is actually interacting remotely [106]. Also, note that Stoffregen et al. make it part of the definition that this is a *false* impression, following Lombard and Ditton [80] and foreshadowing Slater [121].

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" [77]. This is a new definition, that clearly puts the focus on things in the virtual world. If one experiences these things as actual objects, then he or she is present; if one doesn't, he or she isn'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.

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 [95]. This definition has more in common with Slater's Psi [121] or Baños's reality judgment [8] 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 [138].

3.2 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.) [111].

We do not agree with some aspects of presence that appear in the definitions in the previous section. First, 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 [137]. It seems clear in this case that the user is aware, at least on some level, that it is a mediated experience, since he or she is 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 [15] 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, he or she is always aware of the fact that he or she is 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 previously 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.

In addition, the definitions of Schloerb and Stoffregen et al., while conceptually clear, are of limited practical utility. In no known VE system would a user actually believe themselves to be "really in" the virtual environment, and it would be nearly impossible to conduct a study investigating presence as so defined, as it would have to be carried out in the absence, "not just of informed consent but of any consent at all" [140].

Definition of presence in this article. In this article, we follow Schubert in defining *(spatial) 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.

We, however, would also argue for the use of the term *Place Illusion*, rather than the term *presence*, to refer to this sensation in virtual or mediated environments. As this section has shown, the term *presence* has many definitions in the literature, and these describe a range of different constructs. The use of the term *Place Illusion* would make explicit that it is referring to the illusory (false) feeling of being in a remote or virtual place. To refer to the feeling of being in a *real* place, we recommend the term *placeness*.

Adopting the term Place Illusion for this construct also frees up the general term *presence* for other usage. It is already commonly in use to mean the overall "goodness" of a virtual experience. (For one example, see Reference [21], which describes *presence* as "a buzzword for what virtual reality can offer.") To that end, we propose a new definition of *presence* as, "The perceived realness of a mediated or virtual experience." Note that presence as so defined is a quale, with the focus on

perceived realness. *Actual* realness, on the other hand, would be a function of a system's ability to provide stimuli that match reality—that is, a function of immersion and coherence.

This section has focused on theoretical definitions of presence. In the following section, we focus on structural definitions of presence, as we present and analyze models that propose components that contribute to or compose the presence construct.

4 MODELS OF PRESENCE

In this section, we have grouped together those articles that posit a list of components asserted to contribute to presence. Some of these groupings are purely theoretical, and some are either the basis for questionnaires or factors derived from questionnaires in use. Therefore, some articles mentioned in this section will also appear in Section 6.1.1 where presence questionnaires are discussed. 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 2. There is no implied relationship among the data columns in Table 2: The components for each publication are listed across each row in the order they appear in the source publication. Figure 1 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 2, but they do appear as higher-order concepts in Figure 1.

4.1 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" [2]. 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) [60]. Note that here Heeter is using *presence* as a general term to refer essentially to the goodness or realness of a virtual experience, as we proposed in 3.2. Subjective personal presence is most like the traditional definition of presence as "being there," while social presence is akin to Biocca's definition of social presence (what we call Social Presence Illusion) and we consider environmental presence to be a component of Plausibility Illusion.

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 [113]. He also argues that presence is likely task-dependent, and that "fixed" characteristics of the experience (immersion factors and task properties) should affect dependent measures of user experience, such as presence, training efficiency, task performance, and so on. This supports the idea that different applications might require different aspects of user response, as discussed in 2.9.

Held and Durlach speculated on the value of telepresence, as well as its potential causal factors in [61]. 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." The authors 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

Table 2. List of Presence/Telepresence Models and Their Components

Source	Model components (order as listed in source)				
Akin et al., 1983 [2]	Ability to act in remote environment	Ability to sense in local environment			
Heeter, 1992 [60]	Subjective personal presence	Social presence	Environmental presence		
Sheridan, 1992 [113]	Extent of sensory information	Control of sensors	Ability to modify physical environment	Task dependent characteristics	
Held and Durlach, 1992 [61]	Sensory factors	Motor factors	Correlation between feedback and actions	Identification with the robot	Familiarity with the system
Kim and Biocca, 1997 [71]	Arrival	Departure			
Draper et al., 1998 [44]	Attention to mediated environment	Attention to ignoring distractors			
Witmer and Singer, 1998 [157]	Control	Sensory	Distraction	Realism	
Baños et al., 2000 [8]	Reality judgment	Presence	Emotional involvement	Interaction	Control
	Attention/Flow	Realism	Congruence/Continuity	Expectations	
IJsselsteijn et al., 2000 [68]	Extent and fidelity of sensory information	Match between sensors and display	Content factors	User characteristics	
Lombard et al., 2000 [81]	Social Richness	Realism (Social)	Realism (Perceptual)	Transportation	Immersion
	Social Actor in a Medium	Medium as Social Actor			
Sas and O'Hare, 2003 [105]	General cognitive factors	Task-specific cognitive factors	Technological factors	Media content	
Takatalo et al. 2008 [142]	Spatial	Action	Attention	Real[ness]	Arousal
Vorderer et al., 2004 [149]	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 [36]	Affective	Cognitive	Sensory	Active	Relational

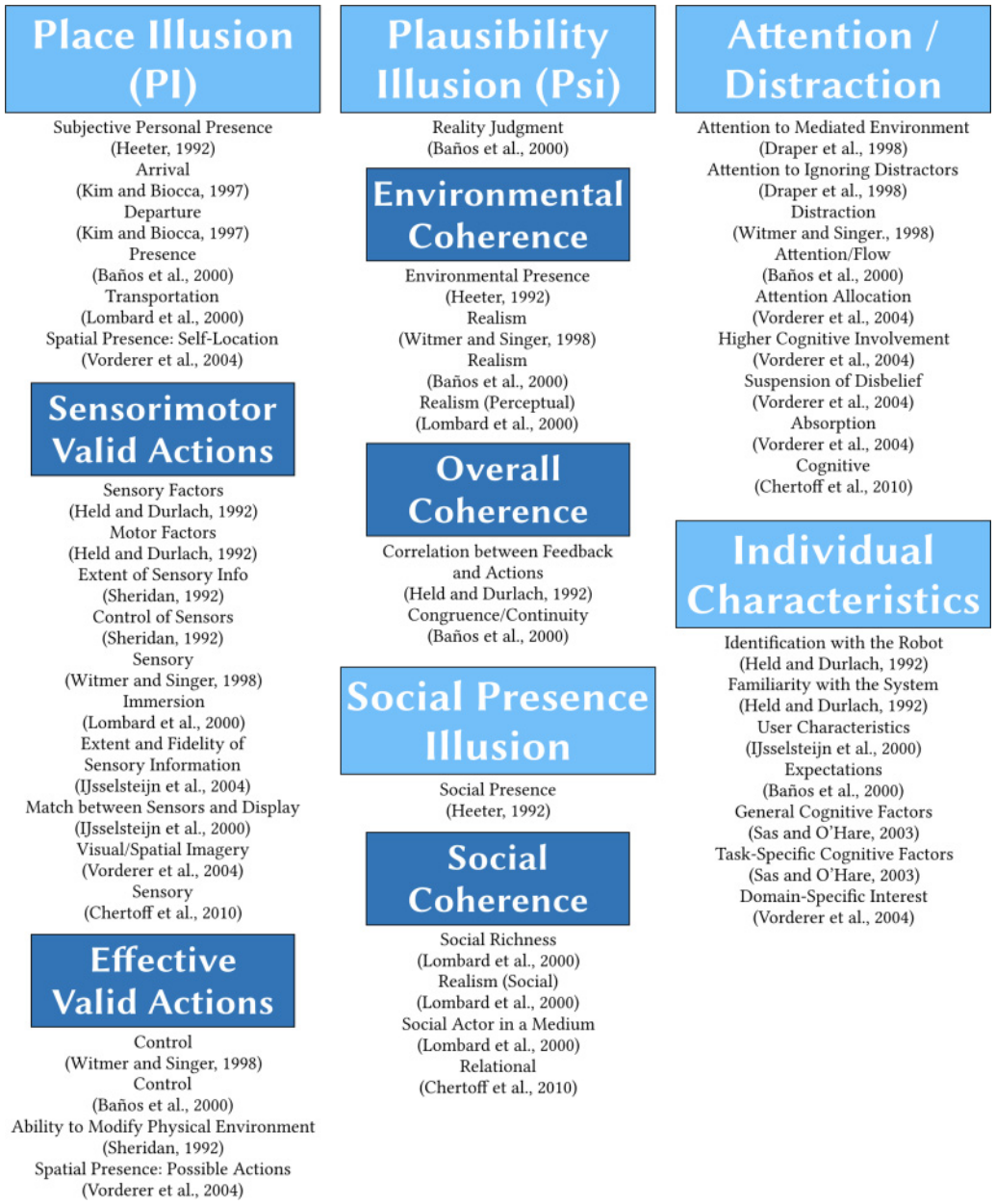

Fig. 1. Groupings of presence model components.

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 [71]. *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 Reference [44]. 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 [157]. They also claimed that factors may influence presence by acting on psychological immersion, involvement, or both. For example, Witmer and Singer 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 [33]. This is supported by a recent study from Skarbez et al. [117].

Bystrom et al. state that this model is based on the two models of presence proposed by Slater and colleagues [124, 134] and by Barfield and colleagues [63, 64]. 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. [35], Ellis et al. [45], Slater et al., [133], Towell and Towell [146], Witmer and Singer [157], and Regenbrecht et al. [98]. 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 [109, 110].

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 [68].

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 [81].

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 discussion regarding immersive vs. non-immersive VEs seems to indicate that they believe $c > a, b$. They argued for the use of a non-immersive VE for this experiment, because then any presence differences would be due to human factors rather than immersion [105].

Witmer and colleagues revisited their presence questionnaire with a factor analysis. 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 [156].

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), that is, 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" [154]. It seems to us that the SSM formalizes Held and Durlach's "cognitive representation of the operator's interaction with the world" [61].

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

Chertoff and colleagues presented a questionnaire developed to measure "holistic virtual environment experiences." The development of this questionnaire was guided by the five dimensions

of experiential design: affective (emotion), cognitive (engagement), sensory (immersion), active ("personal connection...to an experience"), and relational (social) [36].

Kent Bye proposed a theory of presence with a metaphor inspired by the four elements of natural philosophy: earth (embodied presence), fire (active presence), air (social and mental presence), and water (emotional presence) [32]. The similarity of these elements to the dimensions of experiential design used by Chertoff et al. is notable, as the two models were developed independently [36].

4.2 Analysis

Unlike the definitions of presence in Section 3.1, the models of presence are strikingly similar. Almost all can be transformed into one another, or into, for example, the PI/Psi/Social Presence Illusion/immersion/coherence framework endorsed in this review. 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 [2, 121]. (A *sensorimotor valid action* is any action a user can take that changes his or her perception of the virtual environment; an *effective valid action* is an action a user can take that changes the state of the VE itself.) 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 is Social Presence Illusion and environmental presence is similar to Plausibility Illusion [60]. 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 [113]. 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) [157].

IJsselsteijn et al., Sas and O'Hare, and Wirth et al. introduce individual differences to the discussion [68, 105, 154]. Specifically, Sas and O'Hare's presence equation (Equation (2)), consists of individual differences of both state and trait (*general cognitive factors* and *task-specific cognitive factors* both comprise both states and traits), 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

$$\begin{aligned} Presence = {} & \mathbf{A}[Vector\ of\ cognitive\ factors] + \mathbf{B}[Vector\ of\ task-specific\ cognitive\ factors] \\ & + \mathbf{C}[Vector\ of\ technological\ factors] + \mathbf{D}[Vector\ of\ media\ content\ factors], \end{aligned} \quad (3)$$

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

Grouping presence components. In Figure 1, we have grouped the presence components discussed in this section (and presented in Table 2). 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, Social Presence Illusion, 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. (Note that while we include Attention/Distraction as a heading in this diagram, since it appears in many of the models of presence discussed in this section, we do not believe that this is properly a component of the sense of presence. For our reasoning, refer to Section 2.8, under "Involvement and Engagement.")

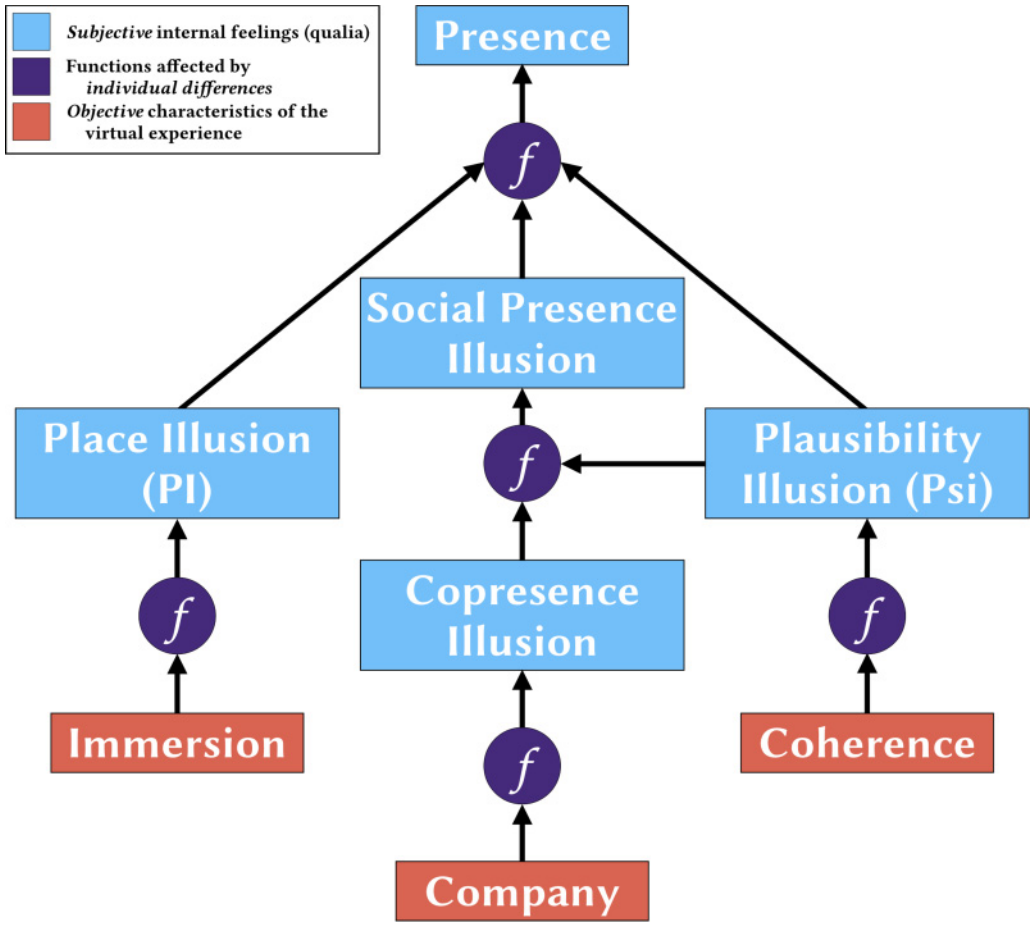

Fig. 2. Proposed relationships between presence concepts.

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).

Our model of presence. In Section 3.2, we proposed a new definition of presence, inspired by its common usage, as "The perceived realness of a mediated or virtual experience." In Sections 2.3 and 2.5, we discussed three illusions that are commonly experienced in virtual environments, those being Place Illusion, Plausibility Illusion, and Social Presence Illusion. In Figure 2, we present a conceptual model of presence based on these illusions and the environmental characteristics that give rise to them. Of note is the similarity of our model to that proposed by Heeter [60], with presence being a function of Place Illusion, Plausibility Illusion, and Social Presence Illusion. Specifically, we claim that presence arises from the immersion of the system (the sensorimotor and effective valid actions it supports), the coherence of the scenario, whether the virtual experience offers company to the user, and the individual characteristics of the user. That is, it arises naturally in a user who experiences Place Illusion, Plausibility Illusion, or Social Presence Illusion.

In this section, we have presented many proposed models of presence from the literature and have argued for these models being reconsidered in the light of the Place Illusion/Plausibility Illusion/Social Presence Illusion framework. The following section focuses on a special subset of models of presence, those that have been derived empirically via factor analysis.

5 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. [78, 109, 110, 156]. 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." Responses to these items seem to measure a user's overall affinity for the experience, rather than specifically relating to their feeling of 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 Slater-Usoh-Steed questionnaire does [147]), 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 immersion factors, and Involvement and Adaptation/Immersion as primarily coherence factors.

This concludes our discussion of definitions and models of presence. The following section focuses on *operationalizing* the sense of presence, and discusses the many questionnaires and other techniques that have been used to measure the sense of presence in virtual environments.

6 MEASURING PRESENCE

Welch and colleagues identified self-report, behavioral, and physiological measures as potential means of measuring presence [152]. We employ that categorization here in discussing the variety of presence measures that appear in the literature and add one more category of measure, psychophysical. The following sections list the various measures that have appeared in the literature; the purposes of providing this list are twofold. First, we seek to provide useful context for the analysis that appears in Section 6.5. Second, we hope to provide the reader with a toolbox of presence-measuring techniques. No single measure is perfect, and perhaps one or more of the measures referenced here may prove useful or inspirational to the reader.

In Section 2.1, we listed several desirable characteristics of presence measures. These include sensitivity, convenience, nonintrusiveness, reliability, validity, objectivity, contemporaneousness, continuousness, and generalizability. We will refer to these characteristics as we discuss and evaluate the measures that appear in the following sections.

6.1 Self-report

Self-report refers to all techniques in which users actively report some information about their experience to the experimenter. An important subset of self-report measures are post-experience questionnaires, which are discussed separately in the following.

6.1.1 Questionnaires. This section briefly describes several existing questionnaires designed to measure presence (typically referred to as *presence questionnaires*), discusses the history of use of the most popular questionnaires, and concludes with an analysis of questionnaire measures in light of the desired measure characteristics presented previously. These questionnaires are summarized in Table 3. (This table inspired by similar ones appearing in References [82] and [83].)

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 Reference [129] (later republished as Reference [130]). 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, Reference [147].

(Note that the SUS presence questionnaire discussed here and elsewhere in this review is not related to the System Usability Scale (also SUS) [30]. The usability SUS is a ten-item Likert-scaled questionnaire used to evaluate the usability of a system, and as such also appears in the VR literature on occasion.)

Kim and Biocca introduced a questionnaire based around the constructs of arrival and departure [71]. *Arrival* is the feeling of being there in a mediated environment; *departure* is the feeling of not being in the real environment.

Witmer and Singer introduced their Presence Questionnaire (PQ) in Reference [157]. 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 19 questions (reduced from 32) is designed to address some aspect of one of these four factors.

In the same article, 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 18 questions, reduced from 29.

Lombard et al. discussed their efforts to develop an instrument for presence based on their theoretical model of its components in Reference [81]. In the article, 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

Table 3. List of Presence/Telepresence Questionnaires

Questionnaire	# Items	Subscales	Intended use
Slater-Usoh-Steed (SUS) questionnaire [147]	6	No separate subscales	Virtual environments
Arrival/Departure [71]	8	Arrival; Departure	Cross-media
Witmer-Singer Presence Questionnaire (PQ) [157]	19	Involved/Control; Natural; Interface Quality	Virtual environments
Lombard et al. questionnaire [81]	103	Social richness; Realism; Transportation; Immersion; Social actor within a medium; Medium is a social actor	Cross-media
Reality Judgment and Presence Questionnaire (RJPQ) [8]	77	Reality judgment; Presence; Emotional involvement; Interaction; control; Attention/Flow; Realism, Congruence/Continuity; Expectations	Virtual environments
Swedish Viewer-User Presence (SVUP) questionnaire [75]	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) [78]	44	Sense of physical space; Engagement; Naturalness; Negative effects	Cross-media
Igroup Presence Questionnaire (IPQ) [109]	14	Presence; Spatial presence; Involvement; Realness	Virtual environments
Sas and O'Hare questionnaire [105]	34	Being there; Not being here; Reflective consciousness	Virtual environments
MEC-Spatial Presence Questionnaire (MEC-SPQ) [149]	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
Bouchard et al. questionnaire [24]	1	No separate subscales	Virtual environments
Experimental Virtual Environment-Experience Questionnaire (EVEQ) [141]	124	Physical presence; Situational involvement; Competence	Virtual environments
Temple Presence Inventory (TPI) [82]	42	Transportation; Immersion; Realism; Social actor within a medium; Social richness	Cross-media
Virtual Experience Test (VET) [36]	17	Affective; Cognitive; Sensory; Active; Relational	Cross-media

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, the authors say, willing suspension of disbelief) are separate constructs and should be treated as such [8]. They presented an initial 77-item questionnaire, the Reality Judgment and Presence Questionnaire (RJPQ), intended to measure both constructs. Baños et al. 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 [75]. In this experiment, they used 18 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 [78]. 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 Reference [109]. The authors follow Zahorik and Jenison in connecting presence to supported action in the VE [158]. This 14-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 34-item questionnaire for their experiment in Reference [105]. 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 Reference [149]. 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). The authors offer short, medium, and long versions of the MEC-SPQ, comprised of four, six, or eight questions, respectively, for each construct (36, 54, or 72 questions in total).

Bouchard et al. argued for the reliability and validity of a single item measure for presence in Reference [24]. The authors used the single question "To [what] [extent] do you feel present in the virtual environment, as if you were really there?" as a measure of presence, and subjected it to a content and face validity study, two test-retest reliability studies, a convergent and divergent validity study, and two sensitivity studies. Results show that the question is well-understood, reliable between tests for the same users, correlates better with the Witmer-Singer PQ than either the Perceived Realism Scale or the Witmer-Singer ITQ, and is sensitive between high and low levels of presence.

Takatalo and colleagues developed the Experimental Virtual Environment-Experience Questionnaire (EVEQ) [141]. The EVEQ consists of 124 questions drawn from other questionnaires and translated into Finnish. These were reduced into 19 subscales, five of which comprised the physical presence scale. These subscores were spatial, action, attention, real[ness], and arousal [142].

Lombard, Ditton, and Weinstein continued their efforts to develop a "conceptually comprehensive" (based on their literature-based model of presence put forward in Reference [81]) measure of presence with the Temple Presence Inventory (TPI) [82]. The TPI consists of 42 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 Reference [36]. 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 experiential 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* [103]. 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 primarily 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 article 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 [39]. Eighty-three studies were included in this meta-analysis, using many of the questionnaires discussed in this section. The purpose of the study was to examine the correlation between immersion and presence; the authors found a medium-sized effect of immersion on presence overall, with components of immersion varying in their effect sizes.

Analysis of questionnaires. Questionnaires are the most widely used means of measuring presence by a considerable margin. This is primarily due to their convenience and generalizability; it is very easy to ask users to complete a questionnaire (or many questionnaires) after an experience, and the questionnaires generally do not require substantial (or any) modification to be used with any type of experience. In addition, many questionnaires have been demonstrated to be valid, sensitive, and reliable. That said, questionnaires are intrusive, are not continuous, are generally not contemporaneous (questionnaires are most commonly conducted post-experience, but Bouchard's single-item measure is intended to be administered during an experience as well), are subjective, and rely on users' interpretations of potentially difficult concepts to generate meaningful results. (For a discussion regarding this last point, consult [119].)

6.1.2 Other Self-report Measures. Welch et al. reported the results of two studies where participants experienced a simulated driving scene [152]. 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 [136]. 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 [48]. They gave users a handheld slider that was continuously sampled during each trial. The experimenters 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 article [128], 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 [29].

Breaks in presence have also been investigated in combination with physiological measures [122, 123], 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 [52].

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 he or she reports as dominant [73].

Riener and Proffitt proposed a means of quantifying spatial presence by comparing the results of visual illusions (specifically the vertical-horizontal illusion and the Ponzo illusion) 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 [100].

Analysis of other self-report measures. These other self-report measures generally share both their strengths and weaknesses with questionnaire measures, discussed in the previous section. Notable exceptions are measures based on breaks in presence; these are contemporaneous measures, and it can be argued that they are minimally intrusive; since users are only asked to report when their presence breaks, the reporting does not cause additional breaks in presence. Sensory-conflict-based measures (such as proposed in Reference [73]) also have the benefit of being contemporaneous. The presence slider used in Reference [48] is potentially both continuous and contemporaneous but was not analyzed in that way by the authors.

6.2 Behavioral Measures

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) [113].

Slater, Usoh, and Chrysanthou used pointing to an ambiguous object as a measure of presence. Participants saw a radio in one location in the real world, and in a different location in the virtual world, and were told at various times during the experiment to point to "the radio." It was assumed that participants who pointed to the virtual radio were experiencing greater presence than participants who pointed to the location of the real radio. This was operationalized as a ratio of the differences between the actual pointing angle and the directions to the real and virtual angles. The authors observed a positive correlation between the number of shadows and this ratio [132].

Thie and van Wijk used "comeback rate" as a means to behaviorally evaluate presence. Participants were told before the experiment to bring something to read, then after the experiment were given the option of reading or re-entering the virtual environment after the experiment had "officially" ended. They found that users "came back" more often when the experience contained more social presence cues [145].

Regenbrecht, Schubert, and Friedmann demonstrated that fear increased with higher presence in a virtual environment designed to elicit fear of heights [98]. Presence was measured using Likert-style responses to 14 questions that included questions from References [62, 133]; anxiety was measured using the State-Trait Anxiety Index, a 20-item questionnaire [76]. We classify this with the behavioral measures rather than the self-report measures, 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 a behavioral measure for presence; specifically the magnitude of postural response for seated participants viewing a video [47]. 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.

Analysis of behavioral measures. Behavioral measures address one of the major shortcomings of the self-report measures in that they are objective measures (at least on the part of the user; they may require humans to score the behavior). They are generally contemporaneous, although not continuous. They are also nonintrusive, in that they attempt to capture users' "natural" behaviors. (They may require elements to be added to the virtual experience to trigger those behaviors, though; the examples from [113] previously would only apply in VEs where balls are thrown at users or other characters sneeze, respectively.)

6.3 Physiological Measures

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 [78] in a study where participants view a video stream presented either stereoscopically or monoscopically [43]. The results of that study are summarized in Reference [42], 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.

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 [87]. 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 [59, 123] and incidental [122].

More recently, Baumgartner et al. [10] and Bouchard et al. [23, 25, 26] 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.)

Analysis of physiological measures. Physiological measures address one of the major shortcomings of the self-report measures in that they are truly objective measures. Also, they are both contemporaneous and continuous. However, they are inconvenient and intrusive, and they are not generalizable. Rather, they can be collected in a very general way, but are only meaningful when collected during experiences that are known to affect physiological signals in certain ways. In addition, the collection of such measures requires the use of additional specialized equipment, which can encumber the user (and thereby reduce presence).

6.4 Psychophysical Methods

Slater, Spanlang, and Corominas demonstrated a method for evaluating the relative importance of different aspects of a virtual environment on participants' feelings of Place Illusion and Plausibility Illusion [126]. This method involved exposing each participant to a VE that was configured with the "highest levels" of various immersion and coherence factors, instructing the participant to remember how much PI or Psi he or she felt in that environment, then exposing the participant to various diminished versions of the virtual environment, and enabling the participant to improve the immersion or coherence factors in whatever order he or she saw fit. By so doing, the authors were able to generate an ordering of the experimental factors ranked by how important each factor was for generating a sense of PI or Psi in users. Similar methods were employed by Azevedo, Jorge, and Campos [4, 5], by Bergström et al. [12], and by Skarbez et al. [117].

Analysis of psychophysical methods. The psychophysical methods discussed here are notably unlike all the other measures discussed in this section in that they have not actually been used to measure presence. As such, the measure properties discussed elsewhere don't really apply here. Rather, what these psychophysical methods offer is a new way to measure how presence is impacted by changes to the immersion or coherence of a virtual experience.

6.5 Analysis

The proliferation of questionnaires adds complexity to presence research. Our experience with using multiple presence questionnaires following a single virtual experience suggests that the questionnaire scores are very highly correlated. Based on these observations, we believe that it is only necessary to use one questionnaire, although which to use may change based on the specific circumstances. For example, if one is particularly interested in reality judgment, or one or more of the subscores of the MEC questionnaire, one should consider using the RJPQ or MEC-SPQ, respectively. For a direct presence measure, we recommend either the SUS questionnaire or the Bouchard et al. single-item measure, as these are the shortest questionnaires in use (saving both experimenter and participant time) and they both directly measure the feeling of presence. In

particular, Bouchard et al.'s single-item measure is especially useful if a contemporaneous subjective measure of presence is desired.

We believe that behavioral measures represent a promising area of study that has so far been understudied. Physiological measures 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. However, these are not likely to be generalizable across scenarios. Per Reference [49]: "[C]ontent-dependency makes the development of a general behavioural metric unlikely." Thus, the identification of a universal measure of the quality of a virtual environment remains an open problem.

The psychophysical methods described previously are new and promising techniques for measuring presence or other qualia relating to the experience of virtual environments. If one's objective is the study of different factors of virtual experience and their effects on presence or other qualia, then we believe that one should absolutely consider using such psychophysical methods. However, the nature of these methods is such that they cannot be used to generate a single value corresponding to a level of presence in the way that self-report, physiological, and behavioral methods do. Furthermore, since such psychophysical methods require the ability to dynamically reconfigure the VE, they are ill-suited to the evaluation of production VEs.

All of the measures and methods discussed in this section have their applications, and none of them possess all the desirable characteristics that have been discussed. Because there is no "silver bullet," we recommend instead the use multiple measures of different types whenever feasible. If all the measures suggest the same interpretation, then the results can be used with greater confidence. This multiple measure technique, which is common in other fields of qualitative research, is called triangulation.

7 CONCLUSION

This article has reviewed the existing literature regarding presence and other concepts important in the study of virtual experiences. We first reviewed several of these other concepts, including social presence, copresence, immersion, agency, transportation, reality judgment, and embodiment. We also coined the term Social Presence Illusion to mean Biocca et al.'s definition of social presence, as well as several related terms, in an attempt to reduce the confusion in the literature regarding the terms social presence and co-presence. We then discussed many of the definitions for presence that have been proposed, grouped them into categories based on common factors (Table 1), and ultimately argued for the use of the term *Place Illusion* rather than the term *(spatial) presence*, and the re-definition of the word *presence* to match its common usage as "the perceived realness of a mediated or virtual experience." We presented many of the proposed models of presence (Table 2), grouped the factors of these models into categories informed by the Place Illusion/Plausibility Illusion/immersion/coherence framework (Figure 1), and presented a model of presence based on the feelings of Place Illusion, Plausibility Illusion, and Social Presence Illusion (Figure 2). Finally, we discussed a variety of measures of presence from the literature, categorized them as self-report, behavioral, physiological, or psychophysical, and argued for the use of short, direct instruments (such as the Slater-Usoh-Steed presence questionnaire or Bouchard et al.'s single-item measure) for measuring presence, the use of other questionnaires if their constructs or subscores are relevant to the research, the use of psychophysical methods to evaluate the importance of immersion and coherence factors on presence or related qualia, the development and use of appropriate behavioral measures, and the use of multiple measures of different types when feasible. We hope

that the results of the survey and analyses presented here have laid the groundwork for a more inclusive and less confusing literature regarding the study of virtual experiences.

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