Virtual Reality

A Survival Guide for the Social Scientist

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Abstract. In this article, we provide the nontechnical reader with a fundamental understanding of the components of virtual reality (VR) and a thorough discussion of the role VR has played in social science. First, we provide a brief overview of the hardware and equipment used to create VR and review common elements found within the virtual environment that may be of interest to social scientists, such as virtual humans and interactive, multisensory feedback. Then, we discuss the role of VR in existing social scientific research. Specifically, we review the literature on the study of VR as an *object*, wherein we discuss the effects of the technology on human users; VR as an *application*, wherein we consider real-world applications in areas such as medicine and education; and VR as a *method*, wherein we provide a comprehensive outline of studies in which VR technologies are used to study phenomena that have traditionally been studied in physical settings, such as nonverbal behavior and social interaction. We then present a content analysis of the literature, tracking the trends for this research over the last two decades. Finally, we present some possibilities for future research for interested social scientists.

Keywords: virtual reality, media effects, immersive virtual environments, computer-mediated communication, virtual worlds

Virtual reality (VR) was originally conceived as a digitally created space that humans could access by donning sophisticated computer equipment (Lanier, 1992; Rheingold, 1991; Sutherland, 1968). Once inside that space, people could be transported to a different world, a substitute reality in which one could interact with objects, people, and environments, the appearance of which were bound only by the limits of the human imagination. Images of people in bulky headgear, heavily wired gloves, and space age clothing became symbolic of the emergent technological revolution of computing and the possibilities of transforming the capabilities of the human mind and body. Futurists heralded VR as an imminent transition in the ways humans would experience media, communicate with one another, and even perform mundane tasks. In the early nineties, pioneering scientists began considering new ways this groundbreaking technology could be used to study social interaction and other psychological phenomena (Bente, 1989; Biocca 1992a,b; Loomis, 1992). In subsequent years, VR has continued to capture the imagination of scientists, philosophers, and artists for its ability to substitute our physical environment and our sensory experiences – what we understand as reality – with digital creations.

In the current paper, we seek to provide the reader not familiar with virtual reality technology with a fundamental understanding of its components and provide all readers with a comprehensive analysis of the role VR has played in social science. First, we define the nature of virtual reality and virtual environments. Next, we present an overview, designed for the nontechnical reader, of the hardware and equipment used to create virtual reality. Then, we discuss the history of VR research in the social sciences. From this literature, we delineate three ways in which social scientists have studied virtual reality: As a technology or medium in and of itself, wherein scientists pose questions about nature of the virtual experience and its effects; as an application, in which VR is used to create a more effective or efficient treatment or training environment to be implemented in a real world setting; and finally, as a method for studying social scientific phenomena in a novel, more effective, or more controlled manner. Next, we present our findings from a content analysis of this literature. Finally, we discuss future directions for VR research within the social sciences.

What Is a Virtual Environment?

A *virtual environment* (VE) is a digital space in which a user's movements are *tracked* and his or her surroundings *rendered*, or digitally composed and displayed to the senses, in accordance with those movements. For example, in a computer game, a user's joystick motions can be tracked and his or her character moves forward, rendering a new environment. Or, a Nintendo Wii player can physically swing the Wii remote, and the screen shows a bowling ball rolling down the lane. The goal of a virtual environment is to replace the cues of the real world environment with digital ones. According to Biocca and Levy (1995), "The blocking of sensory impressions from physical reality is a crucial part of the most compelling VR experiences. The senses are immersed in the virtual world; the body is entrusted to a reality engine" (p. 135). The psychological ex-

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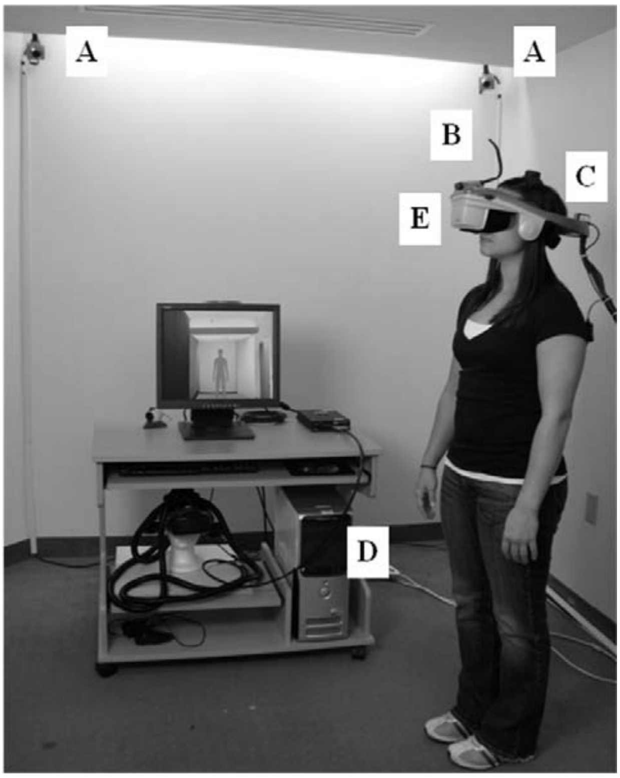

Figure 1. An example of a virtual environmental setup. Cameras (A) track an optical sensor (B) indicating the participant's position in the room. An accelerometer (C) gathers information about the participant's head movements. This information is relayed to the computer (D), which determines how the room is rendered and what the participant sees in the head-mounted display (E).

perience of losing oneself in the digital environment and shutting out cues from the physical world is known as *immersion* (Witmer & Singer, 1998). A VE can be implemented on any number of computer-based platforms, from a cellular telephone screen to a desktop monitor to a fully immersive virtual environment (IVE) in which a user can move around a physical space while wearing computer equipment. See Figure 1 for an example of a virtual environment.

The tracking and rendering process allows a much greater level of interactivity than traditional media. Unlike other media, a user in a virtual environment has a role within the medium, and his or her actions have an immediate and observable impact on the content of the medium. This interactivity may augment the effects of virtual environments because the user is typically active and cognitively engaged throughout the experience, in contrast to more passive media activities such as television viewing. Indeed, interactivity is one feature which contributes to making virtual reality so perceptually realistic because it reacts to our natural behaviors.

Because of the claims of many futurists in the early 1990s, when people hear the words "virtual reality," it is often with a dose of skepticism and technological trepidation: What happened to that bizarre world where everyone sits at home and experiences life in a funky helmet? The fact is that much of the high-end virtual reality technology featured in these futuristic fantasies has not diffused as quickly as other emergent technologies (e.g., cellular phones) because it remains too costly and cumbersome for everyday use. In the meantime, more simple virtual environments have become increasingly prevalent. People are generally unaware that low-end virtual reality using the cycle of tracking and rendering is a daily experience for many via computers, videogame consoles, and cellular phones. Considering that almost one of every four people worldwide (nearly 1.6 billion) uses the Internet (Internet World Stats, 2009), three of every five people use cellular phones (Jordans, 2009), and over 400 million videogames were sold last year (NPD Group, 2009), it is clear that low-immersive virtual environments are becoming a significant part of human existence around the world. The prevalence of exposure to VEs, and particularly their increasingly common use for social interaction, suggests that they are a necessary topic of social scientific study.

Why is VR of Interest to Social Scientists?

Many scholars have been involved in the introduction of VR to the social sciences, but three are notable for their contributions. Communication scholar Frank Biocca popularized the approach of studying VR as a medium through a series of influential journal articles (Biocca, 1992a,b; Lanier & Biocca, 1992) and the subsequent publication of *Communication in the Age of Virtual Reality*, coedited with Mark Levy, in 1995. Jack Loomis brought one of the first VR labs to a psychology department in the late eighties and published a landmark paper on the construct of presence in 1992 (Loomis, 1992). In the late nineties, Jim Blascovich joined Loomis and established a major research center at the University of California at Santa Barbara based on using immersive VR to study the social sciences. Blascovich and colleagues developed the theoretical and structural foundation to foster numerous research programs. It is worth noting that these scholars not only performed pioneering research in their own labs, but also focused their efforts on reaching out to other scholars in their respective disciplines and encouraging them to explore the possibilities of these new technologies.

As all three of these scholars argue, the utility of virtual reality for social science is inherent in the nature of the technology. One of the major goals driving the design and development of VR was to provide a space for people to interact without the constraints of the physical world (Lanier, 1992). As Biocca and Delaney (1995) noted, "VR is a medium for the extension of body and mind" (p. 58). Given the ability to recreate both real and fantasy environments and the multitude of sensory experiences within each, VR presents the opportunity to explore many social and psychological phenomena – both those that occur in the physical world as well as novel experiences unique to VR.

In addition, social scientists are taking interest in VR as an emergent medium that is playing a growing role in our everyday lives, facilitating both traditional mass media functions and interpersonal interactions. Although we have yet to enter an age where our communication occurs mostly in fully immersive virtual environments, the widespread adoption of the Internet and reliance on mobile media devices indicates that this transition may be imminent.

Hardware Setups

Virtual environments come in many forms, and often these are determined by the capabilities of the platform or hardware with which one is experiencing the VE. Virtual environment hardware may be something as simple as a cellular phone or as complex as a fully immersive virtual reality setup, which incorporates wearable equipment that allows the user to move in the physical environment.

The most rudimentary VEs are those available on desktop computers, mobile devices such as cellular telephones and handheld gaming devices, and traditional videogame consoles. These environments may be two- or three-dimensional. Typically, keypresses and mouse or joystick movements are employed by the user to move a viewpoint or a representation, thus providing a simple form of tracking. The monitor then reflects these changes via appropriate rendering. For example, a user may press the right arrow key or tilt a joystick to the right to move a videogame character from left to right on the screen and progress through a depicted virtual environment. New technologies have increased the tracking ability and movement veridicality in desktop setups via webcams and remotes (e.g., the Nintendo Wii). More immersive VEs often use a *head-mounted display* (HMD) to render virtual environments. An HMD is comprised of a helmet or headpiece with LCD screens affixed in front of the eyes to provide a wide, stereoscopic view of the computer-generated environment (Chung et al., 1989; Furness, 1987; Sutherland, 1968).

An HMD may be used in a simple, nonmobile setup, wherein the user's body remains stationary and only head movements are tracked. Head orientation is typically tracked through a device, such as an *accelerometer*, which provides feedback regarding the pitch, yaw, and roll of the user's head. If the user is in a fully immersive virtual environment and permitted to move around in the physical space, *optical* (light-based) or *magnetic trackers* may be attached to the user to send information about the user's x, y, and z position (Meyer, Applewhite, & Biocca, 1992; also see Welch, 2009, for a history of tracking technologies). Some recent developments, such as the HIVE (huge immersive virtual environment; Waller, Bachmann, Hodgson, & Beall, 2007), feature portable, untethered equipment that enables users to move around in much larger spaces. Another type of fully immersive environment, such as the CAVE® (computer-assisted virtual environment; Cruz-Neira, Sandin, DeFanti, Kenyon, & Hart, 1992; Sutcliffe, Gault, Fernando, & Tan, 2006), involves the use of multiple cameras and projection screens in an enclosed room to give users the impression that they are surrounded by the VE.

More complex VEs employ hardware that addresses different sensory modalities beyond visual stimuli (Turk & Robertson, 2000). For example, auditory aspects of a virtual environment can be transmitted through headphones or speakers. Sound is interpreted by the brain three-dimensionally, so the ability for a virtual environment to create spatialized sound (e.g., a virtual human's voice coming from the direction of the speaker and growing louder as the speaker approaches) enhances the realism of the VE experience (Kalawsky, 1993; Loomis, Hebert, & Cicinelli, 1990; Zahorik, 2002). Matching appropriate auditory cues with visual cues also enhances realism; for example, the sound of a door slamming should coincide with the visual depiction of the slamming door.

The sense of touch has also been incorporated in VEs through the use of sensory gloves and other haptic devices (Lanier, 1992, 1997; Salisbury & Srinivasan, 1997; Tan & Pentland, 1997). Some haptic devices may be employed to allow a user to exert touch and grasp or move a virtual object. Other haptic devices enable the user to feel the texture of a surface or receive *force feedback*, a felt reaction that can occur, for example, when trying to depress an object and having it bounce back (Basdogan, Ho, Srinivasan, & Slater, 2000; Tan & Pentland, 1997).

Inside the Virtual Environment

VEs are usually characterized by the same basic elements we observe in our physical environment: ground, sky, and other components of external landscapes; the floors, ceilings, and walls of internal spaces; and both realistic and fantastic objects.

From the perspective of social science, the most interesting virtual objects are representations of people. Representations of people in VEs can vary from a high-fidelity virtual human to an anthropomorphized animal in an online role-playing game (see Nowak & Rauh, 2006, for a review), and this representation can have effects on both the user and observers (Castronova, 2004, 2005; Schroeder, 2002; Schroeder & Axelsson, 2006; Yee & Bailenson, 2007; Yee, Bailenson, & Ducheneaut, 2009). Beyond their appearance, these representations are distinguished by who or what controls their actions. *Avatars* are controlled by a human user, whereas *agents* are controlled by an algorithm (Bailenson & Blascovich, 2004).

When a virtual human is controlled by an algorithm, it is referred to as an *embodied agent* (Cassell, 2000). This distinction is worth noting because research has shown that people react differently when they believe a virtual representation is controlled by a human as opposed to a computer. Notably, when people believe they are interacting with an avatar, their physiological responses and behaviors are more similar to how they would interact with a real person (Hoyt, Blascovich, & Swinth, 2003; Okita, Bailenson, & Schwartz, 2008)

According to Reeves and Nass's (1996) media equation, humans have a limited ability to distinguish between real and mediated representations, as the brain has not evolved in response to the latter. Additionally, advancements in photorealistic facial modeling (Bailenson, Beall, Blascovich, & Rex, 2004), computational emotional models (Badler, Phillips, & Webber, 1992; Gratch & Marsella, 2005), and artificial intelligence to direct conversation (Bickmore & Cassell, 2005; Cassell, 2000) have enabled the creation of increasingly lifelike and interactive virtual humans, which has been shown to have an impact on users' experiences within the virtual environment (Bailenson et al., 2005; Bailenson, Yee, Merget, & Schroeder, 2006). Thus, virtual humans are a particularly compelling subject to study because research indicates that participants often react to virtual humans similarly to how they react to real people (Donath, 2007; Garau, Slater, Pertaub, & Razzaque, 2005).

VEs may also provide sensory information beyond the visual; for example, sound effects and ambient noise are often implemented to bolster the user's feelings of immersion in the VE (Västfjäll, 2003). Social scientists may wish to use these cues to enhance the user's immersion, or they may wish to examine the role of such cues within the unique space of a VE. For example, Williams, Caplan, and Xiong (2007) found that in *collaborative virtual environments* (CVEs), VEs in which multiple people are networked and share tasks, participants' voices can have an effect on task outcomes as well as perceptions of others. Touch may also be incorporated in virtual interactions with haptic devices (Haans & Ijsselsteijn, 2005; Lanier, 1997). Like human touch, virtual touch may be used to apply force and move virtual objects (Tan & Pentland, 1997), to perform a collaborative task (Basdogan et al., 2000) or to communicate and express emotions (Bailenson, Yee, Brave, Merget, & Koslow, 2007). These technologies enable social scientists to create rich virtual environments in which they can study a range of multisensory phenomena.

VEs in Social Science

There are three primary ways virtual environments have been incorporated in the social sciences. First, VEs have been studied by social scientists as *objects* in and of themselves. What is the human experience like within a VE that is similar to or different from the experiences in the physical world? For example, researchers are interested in how VEs can be used to evoke emotional reactions. Secondly, VEs have been created with the intention of *application* outside of the laboratory in order to achieve real world goals. For example, surgical VEs have been developed to familiarize doctors with new medical procedures. Finally, VEs have been used as a *method* to study social scientific phenomena, enabling the replication and extension of real world experiments in a more controlled environment and also helping researchers create stimuli that may be too costly or impractical to achieve in the real world. For example, several researchers have used VEs to study how people react to certain forms of nonverbal communication or whether stereotyping of interactants occurs. These different categories of research present several angles from which a social scientist may be interested in studying or implementing VEs.

In our discussion here we focus predominantly on immersive virtual environments as opposed to online VEs or videogames (for these topics, see Anderson, Gentile, & Buckley, 2007; Barab, Hay, Barnett, & Squire, 2001; Cassell & Jenkins, 1998; Castronova, 2005; Dede, 2009; Vorderer & Bryant, 2006; Williams, 2006; Yee, 2006a,b), because there is no current literature that reviews the extent of social scientific work on and in IVEs.

Virtual Environments as Objects of Social Scientific Study

When virtual reality first emerged in social science, it was because researchers were interested in studying the different aspects of VR as a potential new medium. As with other media, research became focused on evaluating the form and content of VR and how variations in each affected the user (Petersen & Bente, 1991).

One variable of interest is *presence* (also referred to as *telepresence*), the user's feelings that the mediated environment is real and that the user's sensations and actions are responsive to the mediated world as opposed to the real, physical one (Biocca, Harms, & Burgoon, 2003; Lee, 2004; Lombard & Ditton, 1997; Loomis, 1992; Riva, Davide, & Ijsselsteijn, 2003; Slater & Steed, 2000; Steuer, 1992; Wirth et al., 2007; Witmer & Singer, 1998). The user experiences presence as "being there" or "losing oneself" in the mediated environment (Lombard & Ditton, 1997). Although presence has been examined in the context of other media such as television and books, because of the immersive nature of the virtual experience, it is of particular importance to VE researchers. Presence may be a result of characteristics of the technology used (Ijsselsteijn, de Ridder, Freeman, Avons, & Bouwhuis, 2001), aspects of the environment such as graphic realism (de Kort & Ijsselsteijn, 2006; Ivory & Kalyanaraman, 2007), or individual differences among users (Sacau, Laarni, & Hartmann, 2008). The examination of presence is important as previous studies have shown that the subjective experience of presence can impact the effectiveness of virtual treatments (Villani, Riva, & Riva, 2007) and the degree to which these stimuli translate into real world behavior (Fox, Bailenson, & Binney, in press; Persky & Blascovich, 2008; Price & Anderson, 2007). In a review of the research, Lee (2004) identified three different aspects of presence, including *physical, spatial*, or *environmental presence* (the feeling that you are in a particular virtual space; Lee, 2004), *social presence* (the feeling that another person is sharing the virtual space with you; Biocca et al., 2003), and *personal* or *self-presence* (the experience of a virtual self-representation as an extension of the self; Ratan, Santa Cruz, & Vorderer, 2008).

VEs can also be designed to evoke emotional responses. The EMMA project, for example, was created to explore the utility of VEs as "mood devices" to manipulate users' feelings while in a virtual space (Riva et al., 2007). A VE can be designed to evoke a particular emotion by depicting scenes such as a sad-looking park with an empty playground and a gloomy sky (Alcañiz, Baños, Botella, & Rey, 2003), a relaxing park with sunshine and soothing cues (Riva et al., 2007), or an anxiety-inducing room full of snakes (Bouchard, St-Jacques, Robillard, & Renaud, 2008). Virtual humans can also be used to influence users' emotions through their actions, dialog, and portrayed expressions (Gratch & Marsella, 2005; Kamada, Ambe, Hata, Yamada, & Fujimura, 2005; Nijholt, 2004; Rizzo, Neumann, Enciso, Fidaleo, & Noh, 2001).

In addition to the psychological effects of VEs, users may also experience physiological effects. One well-documented effect is *cybersickness* or simulator sickness. Some users, particularly those susceptible to light-based stimuli, may experience dizziness, light-headedness, and nausea after spending time in VEs, particularly if the VEs are fully immersive (Stanney & Salvendy, 1998). Several studies have demonstrated that beyond individual sensitivities (e.g., susceptibility to motion sickness or a history of migraines), the type of technology, its level of sophistication, and the time spent immersed may also play a role (Sharples, Cobb, Moody, & Wilson, 2008; Stanney, Hale, Nahmens, & Kennedy, 2003). For example, an increase in *lag*, or the time delay between the user's actual motions and the updating of the visual scene, is an issue of the technology that may cause illness. A recent longitudinal study, however, has demonstrated that cybersickness tends to decrease over time as participants become more familiar with the experience of immersion (Bailenson & Yee, 2006).

Beyond simulator sickness, researchers have also investigated other physiological responses to VEs, as they may be indicators of psychological states (Blascovich, 2000). Macedonio, Parsons, Diguiseppe, Weiderhold, and Rizzo (2007) successfully used virtual environments to induce anger, leading to increases in heart rate, blood pressure, galvanic skin response, respiration, and skin temperature. Bullinger et al. (2005) found that combining a provocative VE with a stressful cognitive task caused an increase in the generation of the stress hormone cortisol, whereas neither stimulus alone affected cortisol. Meehan, Razzaque, Insko, Whitton, and Brooks (2005) were able to increase participants' heart rate and skin conductance (i.e., perspiration) with a virtual height simulation, and also found that these increases served as good measures for participants' experience of presence. Slater, Guger et al. (2006) found that participants responded physiologically to interaction with a virtual human as if it were a real person. Additionally, Slater, Antley et al. (2006) found that heart rate and galvanic skin response can also be used to identify breaks in presence, or when participants are reminded of the fact that they are physically in the real world while they are immersed in the virtual world. Baumgartner, Valko, Esslen, and Jänke (2006) tracked brain activation as participants were exposed to a virtual roller coaster that made a continuous loop as well as a more realistic ride that made twists, turns, and dives. In addition to experiencing increased electrodermal activity, participants reported greater spatial presence in the realistic condition. An EEG also revealed greater activation of the brain areas related to spatial navigation during the realistic coaster. As the measurement of brain activity and physiological responses becomes increasingly accurate and mobile, it is likely that researchers will continue to explore these effects within the context of virtual environments using technologies such as fMRI (Baumann et al., 2003; Mraz et al., 2003).

The unique nature of virtual environments also led to the discovery of new theoretical constructs. Virtual technologies enable us to modify interpersonal communication in novel ways that we could not achieve in the real world, resulting in *transformed social interaction* (TSI; Bailenson, Beall, Loomis, Blascovich, & Turk, 2004; Bailenson, Beall et al., 2005). According to Bailenson, Beall, Loomis et al. (2004), TSI presents advantages over traditional forms of communication in three realms. First, TSI presents users with the opportunity to enhance their normal perceptual abilities (Bailenson & Beall, 2006). For example, participants might be able to see other participants' names, affiliations, or other relevant personal information hovering over their avatars. Participants can also view an environment from different points in the room through *multilateral perspective taking*. Second, VEs also enable manipulations of the context of the interaction including time and space (Bailenson & Beall, 2006); participants may choose to "rewind" a conversation to hear part of it again, or "pause" while they collect their thoughts. Third, and perhaps the most fruitful realm for TSI research, is controlling self-representation, namely "decoupling the rendered appearance of behaviors of avatars from the human driving the avatar" (Bailenson & Beall, 2006, p. 3). For example, *identity capture* entails obtaining the participant's image and using software to morph it with other individuals' images. Blending the two representations gives the other individual some of the more familiar features of the self; the resulting similarity and familiarity breeds more liking of this individual (Bailenson, Garland, Iyengar, & Yee, 2006).

The *Proteus effect* is a particular application of TSI in which a user's self-representation is modified in a meaningful way that is often dissimilar to the physical self. When the user then interacts with another person, the user's behavior conforms to the modified self-representation regardless of the true physical self or the other's impressions (Yee & Bailenson, 2007; Yee et al., 2009). For example, when participants embody attractive avatars, they disclose more personal information and approach another avatar more closely. When participants embody taller avatars, they are more confident in a negotiation task (Yee & Bailenson, 2007).

Another method of transforming the self-representation involves the use of a virtual human that is photorealistically similar to the physical self but behaves independently of the self. This representation can be modified to have an experience or perform a behavior that the user has not or currently cannot. After this exposure, users are more likely to imitate the behavior that the virtual self modeled. For example, Fox and Bailenson (2009) found that users who had seen their virtual selves exercise in a VE reported performing more exercise in the following 24 h than those who had not. Simply transforming the self-representation in the virtual world led to a desirable behavior in the real world.

As these studies have shown, the manipulation of different characteristics of a virtual environment can have a profound impact on the user, both psychologically and physiologically. Not only do these features of VEs have immediate effects within the environment, but these effects can carry over into the real world, indicating that VEs have the potential to become powerful tools in the applied realm.

Applications of Virtual Environments

As virtual reality has gained traction in the social sciences, innovative scholars have begun exploring its viability in the creation of novel stimuli, treatments, and learning environments for use outside of the laboratory. One of the most common applications of VEs is via virtual reality exposure therapy (VRET; Gregg & Tarrier, 2007; Parsons & Rizzo, 2008; Powers & Emmelkamp, 2008; Riva, 2005; Rothbaum, Hodges, & Kooper, 1997). Psychiatric researchers realized that VEs could be used to treat patients suffering from a specific anxiety or phobias. In the virtual environment, patients are gradually introduced to the negative stimulus in a virtual setting until they become desensitized or are able to cope with their fear or anxiety. VRET has been used to treat acrophobia (the fear of heights; Coelho, Santos, Silvério, & Silva, 2006), agoraphobia (fear of open spaces; Botella et al., 2007), arachnophobia (fear of spiders; Cote & Bouchard, 2005); aviophobia (fear of flying; Rothbaum, Hodges, Smith, Lee, & Price, 2000); public speaking anxiety (Harris, Kemmerling, & North, 2002), panic disorder (Botella et al., 2007) and social phobia (Roy et al., 2003). VRET has also been employed in the successful treatment of combat-related posttraumatic stress disorder (PTSD; Reger & Gahm, 2008; Rothbaum, Ruef, Litz, Han, & Hodges, 2003).

VEs have also been explored as a tool for cognitive behavioral therapy. Researchers have found that virtual cues can be used to stimulate alcohol cravings (Cho et al., 2008) and nicotine cravings in cigarette smokers (Baumann & Sayette, 2006). Thus, it is expected that these stimuli may be used therapeutically to teach addicts to cope with craving-inducing cues in a variety of situations. VEs have also been used in studying patients with eating disorders by exposing them to high-anxiety environments such as a kitchen filled with fattening foods and examining patients' emotional reactions (Gutiérrez-Maldonado, Ferrer-García, Caqueo-Urizar, & Letosa-Porta, 2006). Researchers expect that these environments will be incorporated in therapy in which patients learn to cope with anxiety-inducing situations in a healthy manner.

Another increasingly common application is the use of virtual reality therapy in physical rehabilitation (Schultheis & Rizzo, 2001; Sveistrup et al., 2003). Virtual environments have two features that uniquely facilitate physical rehabilitation: The ability to capture and review one's physical behavior three-dimensionally, thus enabling a close and interactive examination of one's progress and failures, and the ability to see one's own avatar rendered in real time from a third-person point of view (Bailenson et al., 2008). Additionally, virtual environments can be used to safely recreate real environments that might be challenges for those who have suffered an injury (e.g., crossing a busy intersection). VEs have been used to help stroke victims regain a sense of balance while walking (Deutsch & Mirelman, 2007) and help children with cerebral palsy develop muscular coordination (Bryanton et al., 2006). The visual nature of VEs has also facilitated novel treatments for children with amblyopia ("lazy eye"; Eastgate et al., 2006).

Aside from these applications, VEs have been employed in a variety of other medical contexts. VEs have been shown to be an effective distraction method for helping patients manage pain (Gold, Belmont, & Thomas, 2007; Hoffman et al., 2008). Children exposed to an interactive distraction in an HMD as opposed to other forms of distraction significantly increased their pain tolerance and pain thresholds (Dahlquist et al., 2007). Virtual models of the human body have become popular interactive tools for teaching medical students, nurses, and doctors the basics of human anatomy as well as complicated surgical procedures (O'Toole et al., 1998; Spitzer & Ackerman, 2008). VEs have also been used to teach medical personnel communication and decision-making skills because they can portray a variety of situations, from a regular checkup to the chaos of an emergency room, that practitioners may face (de Leo et al., 2003; Johnsen et al., 2006; Kenny, Rizzo, Parsons, Gratch, & Swartout, 2007; Mantovani, Castelnuovo, Gaggioli, & Riva, 2003).

The military has also taken an active interest in the development of training environments. One of the earliest applications of VR was the development of flight simulators, which provided pilots with a safer and less expensive way to learn flying skills (Furness, 1987; Pausch, Crea, & Conway, 1992). Virtual simulations of conflict scenarios have been used to teach soldiers how to make quick and effective decisions under stressful circumstances (Hill et al., 2003). VEs have also been used to help soldiers develop cross-cultural communication skills to prepare for their deployment to a different country (Deaton et al., 2005).

Aside from medical and military interests, several industries have taken interest in the ability to create VEs for training purposes and networked collaboration spaces. Although the initial development is rather involved, creating a VE for training employees is an overall less expensive, less risky, less variable, and possibly more effective method than hands-on training (which may interfere with productivity or present a safety issue) or traditional media (which do not permit interactivity or "hands on" practice; Brough et al., 2007). Another opportunity to incorporate VEs is through the development of virtual workplaces (Wilson & D'Cruz, 2006) or collaborative virtual environments that allow interaction via avatars (Benford, Greenhalgh, Rodden, & Pycock, 2001; Joslin, Di Giacomo, & Magnenat-Thalmann, 2004; Normand et al., 1999; Reeves, Malone, & O'Driscoll, 2008).

Because both training and collaboration can be facilitated by a virtual environment, it is unsurprising that a great deal of research energy is going toward the development of virtual classrooms (Moreno & Mayer, 2007). Digital enhancements offer unlimited opportunities for infusing the subject matter directly into the classroom, whether that entails making a Tyrannosaurus Rex appear next to the teacher during a science lesson or having Mark Twain lead a literature class about Huck Finn's adventures. Additionally, classroom variables can be manipulated to create the optimal learning environment. For example, sitting at the front of the classroom and receiving the majority of the teacher's eye gaze both enhance student learning, but these factors are not achievable for every student in a physical classroom as there are only so many seats and so much time a teacher can spend attending to a single student. In the virtual classroom, however, these factors can be manipulated so that every student receives these benefits; indeed, research has demonstrated that these virtual manipulations result in greater learning (Bailenson, Swinth et al., 2008).

VEs as a Method to Study Social Scientific Phenomena

The pioneering work of Jim Blascovich and colleagues led to the use of virtual environments to study social and psychological phenomena. Blascovich et al. (2002) cited several advantages to using VR in studies. First, VR allows the researcher to create experimental situations with more mundane realism, thus making participants' reactions to the stimuli more genuine than the typical combination of written vignettes and questionnaires (Blascovich et al., 2002). For example, rather than invoking fear by asking participants to imagine standing at the edge of a precipice or giving them a written passage describing the scenario, VR allows participants to be immersed in that situation and to see the precipice in front of them. VR and other networked technologies may also help alleviate the problem of nonrepresentative sampling (Blascovich et al., 2002). Rather than relying on immediately available participants, networked environments allow the inclusion of samples from distal locations, thus providing variation in the participant pool. Another issue VR helps resolve is the lack of exact replication of the experimental setting and stimulus (Blascovich et al., 2002). Consider, for example, the use of confederates. When the confederate stimulus is computer-programmed, the variability of that presentation is limited and precisely replicated down to the second and millimeter (Bailenson, Blascovich, Beall, & Loomis, 2001). In the real world, however, multiple confederates may vary on their demographic characteristics, appearance, or nonverbal behaviors in a way that causes unintentional variation in the stimulus. Even the same confederate may vary from day to day on eye contact, manner of dress, or degree of precision in adherence to the experimental script. VR can provide more control for such fluctuations to ensure that unintentional cues are avoided. Additionally, VR can be used to create a variety of environments (e.g., a shopping mall, a doctor's office, a movie theater, or an airplane cabin) in a controlled manner, thus providing the advantage of being able to study occurrences in these places without interference from other cues that might disrupt studies in corresponding real world environments (e.g., the smell of food or ringing cell phones). In the same vein, VR can be used to create stimuli that are unavailable or difficult to manage in the real world, such as large crowds, snakes, or children.

This ability to selectively craft stimuli is part of the reverse engineering approach (Bailenson et al., 2001; Bente, Krämer, Petersen, & de Ruiter, 2001; Bente, Petersen, Krämer, & de Ruiter, 2001). In the physical world it is very difficult to filter out the multitude of cues that contribute to any given experience. For example, if communication researchers want to study the effect of body posture on perceptions of a speaker's credibility, they must deal with several confounding cues, such as the speaker's natural facial expressions, head movements, and gestures. Using a virtual stimulus, however, these cues can all be removed or neutralized; also, the exact same stimulus can be created initially, with only a slight change in the programming to create the body posture manipulation. The main advantage of this approach is that the variable of interest is effectively isolated and can be examined without confounds.

Another benefit of the reverse engineering approach is the ability to replicate traditional theoretical studies in a more "pure" fashion given this control. Social scientists may take their pick of theories and put the relevant constructs to the test using VEs. For example, Fox and Bailenson (2009) implemented social cognitive theory (Bandura, 1977, 2001) in a study of exercise behavior modeling and were able to uniquely examine the concept of identification by using a virtual stimulus that varied only in the presentation of the model's face, which was either the self or an unknown other. Human models would have varied on other dimensions, such as height, weight, and body shape, which might have confounded the manipulation of interest.

Several methods for studying social scientific phenomena within virtual environments have been proposed (Blascovich et al., 2002; Loomis, Blascovich, & Beall, 1999; Schroeder, 2002; Schroeder, Heldal, & Tromp, 2006). Typical methods of assessment and data gathering such as survey responding, observation, and audiovisual recording work in VEs as easily as in other contexts, but VEs offer several advantages for data collection. Scripts for created virtual environments can be written to automatically record data regarding the user's movements, gaze, and gestures, alleviating the subjective and often painful process of having coders review videotape. These functions also gather data almost continuously, reporting at fractions of a second that are too minute for human coders to distinguish. VEs also enable this data to be integrated in real time with multiple networked participants (e.g., Bente, Rüggenberg, Krämer, & Eschenberg, 2008). Automatic data collection from online virtual worlds can provide information on task performance and social and economic exchange (Bainbridge, 2007). Additionally, many online environments permit the launch of specific modules that can be custom-built by computer programmers to record the exact data a researcher wants and filter out unwanted metrics (e.g., Friedman, Steed, & Slater, 2007; Yee & Bailenson, 2008; Yee, Bailenson, Urbanek, Chang, & Merget, 2007).

These advantages in stimulus creation and data collection have enabled researchers to examine a wide variety of sociopsychological phenomena. In the following section, we review in detail the findings of studies in virtual environments on nonverbal behavior, including eye gaze and proxemics; behavioral mimicry; interpersonal persuasion; social anxiety; social facilitation and inhibition; leadership; prosocial behavior; and prejudice and stereotyping.

Nonverbal behavior was one of the first subjects of social scientific study in virtual environments. Bente and colleagues (Bente, 1989; Bente, Feist, & Elder, 1996; Bente, Krämer et al., 2001; Bente, Petersen et al., 2001) were among the first to use computer animated humans to study nonverbals. The researchers videotaped dyadic interactions and then rendered the nonverbal behaviors of the participants using virtual humans. Participants were asked to judge their impressions of the interactions for the video and animation, and only marginal differences were identified between the two stimuli. Bailenson et al. (2001; Bailenson, Blascovich, Beall, & Loomis, 2003) replicated some work on proxemics using a VE. Similar to real world findings, the researchers observed that participants who approached a virtual human treated it like a real person and maintained its "personal space" by not getting too close. Also reflective of real world proxemic behavior, participants maintained more space in front of the avatar when facing it than when asked to walk around to its back side. The researchers also found support for equilibrium theory with virtual humans: That is, participants came closer to an avatar that was not looking at them, but when the avatar made eye contact and they shared gaze, participants maintained a greater distance. Friedman et al. (2007) reported that users of Second Life abided by proxemics that paralleled those in the real world when interacting with other avatars. Yee et al. (2007) found a replication of real world proxemics and eye gaze in a study conducted in Second Life: Male pairs exhibited larger interpersonal distances and less eye gaze, whereas female pairs maintained smaller distances and used more direct eye gaze. In another study on eye gaze, Bente, Eschenberg, and Krämer (2007) found that, similar to face-to-face interactions, participants evaluated those that gave longer gazes more favorably than those who gave shorter gazes.

Bailenson and Yee (2005, 2007) incorporated nonverbal communication in their VE-based studies examining Chartrand and Bargh's (1999) *chameleon effect*, the notion that an individual is more persuasive if he or she mimics the nonverbal behaviors of the target. They found that if a virtual human undetectably mimicked a participant's head movements, the participant rated the agent more positively and was more likely to agree with the persuasive message than if no mimicry occurred (Bailenson & Yee, 2005). This result was also replicated using another form of nonverbal communication, a virtual handshake (Bailenson & Yee, 2007).

These findings indicate that users can implement aspects of virtual technology to facilitate persuasive outcomes. Because of the prevalence of online persuasive environments such as shopping websites and political chatrooms, as well as the transition of many of our daily communications to digital venues such as email and instant messaging, it is natural that virtual social influence has been a growing area of study. Now that 3-D environments and more lifelike agents and avatars are being implemented in these interactions, we can expect that increasing numbers of these persuasive messages will be delivered using a virtual human (Nijholt, 2004). The model of social influence in immersive VEs proposed by Blascovich (2001; Blascovich et al., 2002) has provided the groundwork for a large number of such studies.

Several researchers have explored the use of virtual humans as mechanisms for social influence. Guadagno, Blascovich, Bailenson, and McCall (2007) found that same-sex in-group favoritism, a common effect in the real world, also occurred in a virtual persuasive environment. Participants demonstrated greater attitude change when they heard the persuasive message from a virtual human of the same sex as themselves. Skalski and Tamborini (2007) used interactive and noninteractive agents to deliver a persuasive health message. Participants who encountered an interactive agent demonstrated a greater change in attitudes and intentions: They placed greater importance on the value of getting one's blood pressure checked and were more likely to schedule an appointment for a blood pressure reading. Read et al. (2006) found that men who role-played in an interactive virtual environment in addition to receiving safe sex counseling reduced their risky sexual behaviors more than those who only received counseling. Eastwick and Gardner (2009) explored sequential request techniques in virtual worlds. As in the real world, using a foot-in-the-door or a door-in-the-face technique to gain compliance was more effective than merely making a direct request.

In addition to their use as agents of influence, virtual humans can be used to elicit the same psychological responses people experience in the presence of real humans, such as social anxiety. Garau et al. (2005) found that socially anxious people were more likely than nonanxious people to avoid contact with agents in an IVE, indicating that the virtual humans also evoked apprehension in socially anxious participants. Slater, Pertaub, Baker, and Clark (2006) put confident and phobic people in a public speaking IVE and had them deliver a speech to either an empty room or a group of people. Confident speakers showed no difference in self-reported anxiety or heart rate, whereas phobic speakers demonstrated significantly more psychological and physiological anxiety in the populated room than in the empty room.

Because virtual humans evoke such responses, several studies have used them to examine *social facilitation* and *social inhibition*, the effects that an audience may have on task performance. Hoyt et al. (2003) asked participants to complete easy or hard tasks in the presence of two avatars, in the presence of two agents, or alone. When people were told the virtual humans were human-controlled avatars rather than computer-controlled agents, the hypothesized social facilitation effects occurred: Avatars boosted participants' performance on easy tasks but hindered their performance on difficult tasks. Park and Catrambone (2007) presented participants with similar tasks and tested them alone, in the presence of another person, or in the presence of a virtual human. The easy tasks were completed significantly faster when in the company of another person or a virtual human compared to the alone condition, but the difficult tasks took longer when another person or virtual human was present as opposed to being alone. Zanbaka, Ulinski, Goolkasian, and Hodges (2007) performed the same manipulation and found that these effects occurred whether the virtual human was projected or presented in an immersive environment. Blascovich et al. (2002) reported a similar finding in a virtual card-playing scenario: Participants playing with virtual humans tended to conform more to the virtual humans' betting behavior when told the other players were human-controlled avatars as opposed to computer-controlled agents.

Other interpersonal and group processes have been explored using VR. Gilliath, McCall, Shaver, and Blascovich (2008) studied prosocial behavior. They found that approximately the same proportion of people help out or express concern for a virtual needy person as has been observed in real world studies. Slater, Sadagic, Usoh, and Schroeder (2000) compared face-to-face and virtual groups and found that, despite the rudimentary nature of the VE, natural group processes such as leadership emergence and embarrassment occurred in both environments. Hoyt and Blascovich (2003, 2007) examined leadership using virtual environments. They manipulated transactional and transformational leadership styles in an IVE and found that participants' group performance and cohesiveness were equivalent to those who engaged in the same activity in the physical world (Hoyt & Blascovich, 2003). In another study, the authors used an IVE to activate sex stereotypes regarding leadership abilities and found that women with high levels of efficacy experienced reactance and outperformed low efficacy women (Hoyt & Blascovich, 2007).

Stereotyping and prejudice have been explored in other studies as well. Fox and Bailenson (2009) found that participants exposed to a stereotype-confirming virtual female in an IVE later expressed more sexism and antiwoman attitudes than participants who encountered a nonstereotypical virtual female. Groom, Bailenson, and Nass (2009) found that participants embodied in Black avatars in an IVE expressed more negative implicit attitudes toward Blacks than participants embodied in White avatars. Dotsch and Wigboldus (2008) placed Dutch participants in a CAVE® in which they encountered a White or a Moroccan agent. Participants maintained more personal distance with a Moroccan agent. Also, participants showed an increase in skin conductance levels when approaching a Moroccan in contrast to a White virtual human. Eastwick and Gardner (2009) noted that the effects of race carried over to online virtual environments as well; in their experiment, Black avatars were less successful using the door-in-the-face compliance technique than White avatars.

In sum, VEs have been successfully implemented to investigate a wide range of phenomena. In addition to this detailed literature review, we conducted a study to determine how many articles had been published about VR and what trends could be observed.

A Content Analysis of Social Scientific Research on VEs

To get a better sense of the ways in which virtual environments have been used in the social sciences, we undertook a content analysis of a sample of empirical articles about VEs in social science research. For each article in our sample, we determined which of the three previously described categories the article fit into, i.e., whether the VE studied in the article was the *object* of basic research, an *application* intended for real world use, or a *method* for facilitating the observation of some psychological phenomena that were the main focus of study. We also captured the institutional affiliation of the first author of each article so that we could investigate trends regarding dispersion of VE research among various academic disciplines over time.

Criteria for Article Selection

We created a coding scheme by specifying that we wanted to limit our analysis to empirical articles about virtual environments (VEs) in social science research. This specification has three key elements, which we codified as follows. If the article did not meet these three criteria, they were coded as *false positives*. First, the study must be empirical and report the collection of data that have not been published elsewhere. An article that summarized or reviewed relevant literature would not be included, nor would an article that describes various properties of a new VE without reporting results about its use. Second, the environment reported in an article must render some sort of virtual space that is presented to the user (this is usually a visual representation, but some such representations might be auditory or haptic) and must include some tracking mechanism for updating its rendering based on user input. An environment that would not qualify for inclusion is one in which users watch movement through a virtual space as "passengers" without any ability to change the rendered space or perspective, such as in an online 3-D movie. Third, we focused solely on social scientific research; that is, the data must include the behavior of at least one person other than the researcher(s). Thus, qualitative accounts of an individual's experience in a VE were excluded. Also, an article about a new peer-to-peer multicast system that only reported network latency measurements would not count as social science, because no results of human participation are reported.

Coding Criteria

Articles that met our criteria were then placed into one of the following three categories:

1) *Object:* The research is centrally concerned with the nature of the user's experience regarding the VE itself and the possible effects of that experience.
2) *Application:* The research is centrally concerned with creating and using a VE outside of the laboratory, for example in a psychiatrist's office or a corporate training center, to change how people behave in the real world.
3) *Method:* The research is centrally concerned with using a VE to examine real world phenomena. Research in this category may use the VE to manipulate variables that are not easy to replicate in the laboratory (e.g., simulating a crowd of people), potentially harmful in the real world (e.g., a busy intersection), or hard to control (e.g., the number of cues in a shopping mall that might encourage smokers to crave a cigarette).

Sample

Having established criteria for inclusion and categorization of articles, we next needed a master data set of scholarly articles from which we would sample. To create the data set, we searched the Web of Science from the online academic database ISI Web of Knowledge (http://www.webofknowledge.com/) for all journal articles or proceedings papers published before 2009 that included any of the terms "virtual environment(s)," "virtual world(s)," or "virtual realit(y/ies)" in their title, abstract, or keywords. On Monday, 23 Feb 2009, this search returned 6,617 articles, which constituted our population of articles.

Method

Using a coding scheme and a data set, we recruited a team of nine undergraduate research assistants to serve as coders for our analysis. We then performed two rounds of reliability training with these coders, using random samples of articles from our master data set (50 articles in the first round and 100 in the second). In each round, we had all coders categorize all articles in the sample as *object*, *application*, or *method* (or as a *false positive* if the article was not empirical, did not involve a VE, or was not social science); we then debriefed and came to consensus about how to code articles for which there had been disagreement.

After our second round of training, we divided our team so that five coders could concentrate on categorizing articles while another four coders could concentrate on finding first-author institutional affiliations. We then conducted a third and final training round with another random sample of 133 articles from our master data set. By the end of this third round of training, we calculated intercoder reliability using Fleiss's extension to Cohen's κ[1] (Fleiss, 1971) for our five-person categorization team and found an estimate of reliability of 0.61, which although somewhat low has been described as a "substantial" level of agreement (Landis & Koch, 1977) and was determined to be high enough for our purposes.

Because we had debriefed and come to consensus for every article about which there was disagreement in the three rounds of training, we already had 283 articles categorized with 100% agreement. We then assigned to each member of our 5-person categorization team another random sample of 100 articles, bringing the tally of categorized articles to 783; of these, 553 were coded as *false pos-*

[1] We also calculated Krippendorff's α (Krippendorff, 1980) to assess intercoder reliability; because our estimates using Krippendorff's α were extremely close to those using Fleiss's extension to Cohen's κ, we report only the latter throughout.

itives, leaving 230 articles that were coded as either *object*, *application*, or *method*. We divided these up among the members of our four-person affiliation team to find first-author affiliations. We did not further examine false positives or include them in the subsequent analysis.

Results

Examining our data, we were able to identify some trends in publications about VR. To determine these values, the number of relevant articles was divided by the total number of articles (230) to yield the percentages. First, as can be seen in Figure 2, social scientific studies examining VR as an object were most popular (41.3%), followed closely by VR applications (38.7%); only 20% of articles concerned the use of VR as a method for studying existing social scientific phenomena. Figure 3 demonstrates that VR studies began to emerge in the social scientific literature in the early nineties. All three categories have increased steadily over time, although in the last decade object and application studies have grown more rapidly than method studies.

The first author affiliation coding, seen in Figure 4, demonstrates that medical affiliations, including medicine, surgery, and psychiatry, were the most common (33.5%). This finding may be due to the fact that medical studies involve applications that are actively implemented in the training of medical students and doctors (Burdea & Coiffet, 2003), and such implementations present additional opportunities to collect and report data on the effectiveness of a system. Social scientific affiliations (e.g., psychology, communication, or education) were the second most common (31.7%). Because we were searching for social scientific studies, this finding is not surprising. Engineering studies (including computer science) were the third most common (29.1%); however, if we had not required human subject participa-

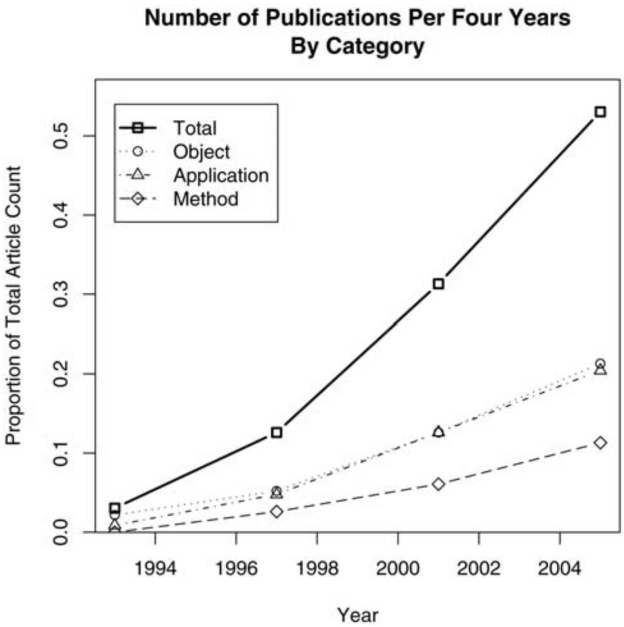

Figure 3. An examination of the three categories of VR studies over time.

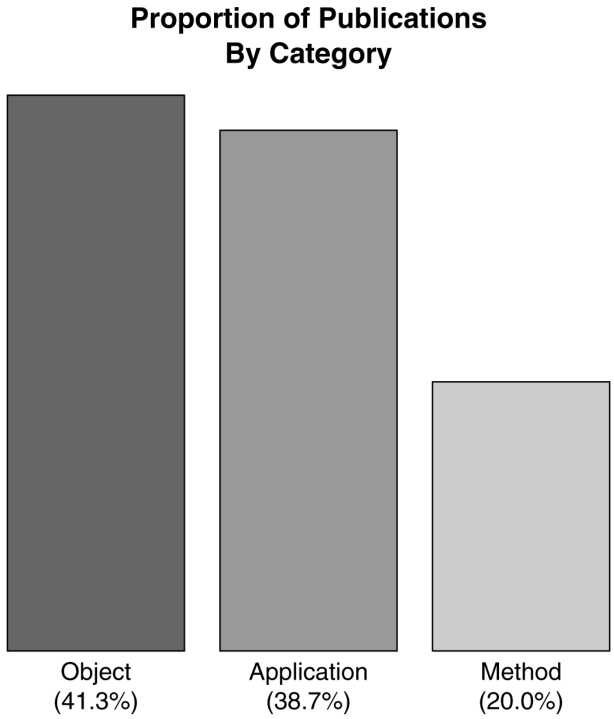

Figure 2. The distribution of articles categorized as object, application, and method.

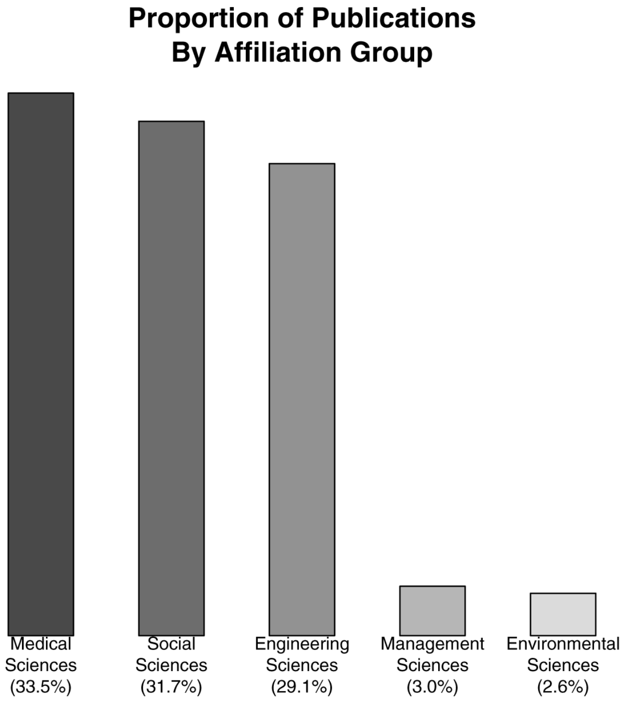

Figure 4. The first-author affiliations of our article sample.

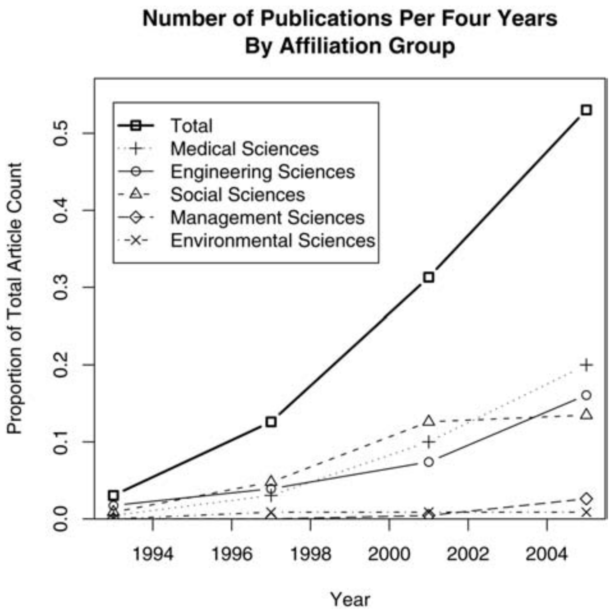

Figure 5. First-author affiliations over time.

tion, these studies would have likely predominated as engineering and computer science journals are rife with articles on emergent display, sensing, and tracking technologies. Since the early 1990s, all three of these categories have grown, although social sciences have remained steady since 2001 while engineering and medicine have continued to increase (see Figure 5). Finally, management sciences (e.g., business; 3%) and environmental sciences (2.6%) were represented in a couple of articles in our sample; however, they have not demonstrated much growth over time.

Future Directions: Where Can Social Scientists Go from Here?

We have seen that the social scientific study and implementation of virtual environments is becoming increasingly common. Because virtual technologies are still under development and testing, it is unsurprising that a large proportion of articles are devoted to the study of VEs as objects. We still have much to learn about the characteristics of the technology and their individual and cumulative sociopsychological impacts. The large number of application articles is also to be expected because the entities that wish to create VE applications, such as corporations and medical institutions, typically have more funding and personnel available to support such projects.

The results of the content analysis indicate that VEs are being underused as a method in the social sciences. The lack of usage is likely due to several factors. For example, many social scientists do not have a background in computers and technology. VEs are becoming increasingly user- and creator-friendly (Bartle, 2004), however, so a computer science degree is no longer necessary to understand and implement them. Computer literacy has become a fundamental aspect of education and essential to contemporary academia; thus, increasing numbers of scholars are emerging with the basic skill set needed for VE research. Another hindrance is that researchers are under the impression that VE research is cost-prohibitive. Although high-end equipment and fully immersive environments remain expensive, their costs are decreasing. Of greater interest is the availability of several online virtual environments, such as Second Life, that are free to use, accessible to any participant with an Internet connection, and relatively easy for researchers to modify.

With the technological and cost barriers removed, the individual scholar's question remains: "How can VEs benefit my line of research?" We can speculate about a number of future directions for the study of VEs as objects, the implementation of VEs as a method, and the application of VEs.

Communication researchers are presented with several different virtual media to explore as objects, perhaps implementing a traditional media effects paradigm and examining the characteristics of the medium, its content, and the cognitive, attitudinal, emotional, and behavioral effects on users (Bryant & Oliver, 2008). Although some basic questions have been addressed, little is known on the effects of different types of hardware setups on psychological and social outcomes. In the future, new explanatory models and theories for virtual experiences will emerge. Can we expect different effects on emotions, persuasive outcomes, aggression, and behavior from desktop VEs, physically tracked videogames like the Wii, and fully immersive virtual environments? What roles do interactivity and presence play in moderating or mediating these effects? It is possible that new theories and models addressing these specific aspects of new media will emerge, and VEs will be an effective platform with which to test them. Another issue is VE-specific content. What sort of trends in content are we seeing in existing VEs? Does this content reflect traditional media content, and will those trends continue with the emergence of new forms of VR technology? What novel forms of sensory content can we expect to emerge, and how will they be studied?

Media effects researchers should also consider transformed social interaction and the Proteus effect as fertile ground for examining how manipulations within the VE impact behaviors both inside and outside the virtual world. These concepts may be implemented to understand how traditional communication concepts may be altered in VEs. For example, CMC (computer-mediated communication) researchers have investigated the effects of different forms of self-presentation in online dating and social networking profiles (Gonzales & Hancock, 2008; Toma, Hancock, & Ellison, 2008; Walther, 2007; Walther, Van Der Heide, Kim, Westerman, & Tong, 2008). A study might investigate how transformed self-representations in IVEs affect others' perceptions of credibility or interpersonal trust.

We have demonstrated the utility of VEs for studying various social scientific phenomena. For researchers, the possibilities for replications of previously conducted studies are endless, or they may want to explore novel ways of testing existing theories. Social identity theory, for example, looks at the processes and strategies involved in establishing and bolstering one's group identity (Tajfel & Turner, 1986). An interesting study might involve experimentally manipulating various features of avatars, assigning them to participants, and observing if this affects how ingroups and outgroups develop in a collaborative virtual environment or an online VE such as Second Life. Conflicts and competition could then be introduced to see if virtual groups behave similarly to those observed in the real world. Persuasion theories could also be studied within VEs. Researchers have been plagued by the inconsistency between attitudes and behaviors (Ajzen & Fishbein, 1977, 1980), which is often observed in health initiatives (Armitage & Conner, 2000; Fishbein & Cappella, 2006). A treatment can be successful in shifting attitudes, and perhaps even behavioral intentions, but these effects often do not carry over to behavior. A VE may help resolve that link by providing participants with the opportunity to perform the behavior virtually.

Online and networked VEs also present opportunities to study macro-level behaviors on the community level. Some research has been conducted on economics (Castronova, 2005), the role of law (Lastowka & Hunter, 2004), task-oriented social networking (Williams, 2006), relationship formation (Yee, 2006a,b), and the potential for democratic processes (Noveck, 2003) within virtual communities. With the ability to collect vast amounts of data over time, researchers have the opportunity to explore a number of evolving and emergent phenomena that are difficult to trace in the real world, particularly in real time.

Beyond explorations of the technology itself, social scientists may also be interested in collaborating with educators, doctors, military personnel, or industry to help create effective applications for use in the real world. There are many opportunities to help create, test, and implement virtual treatments and training environments using social scientific constructs and theories. For example, VEs have been developed for medical students to practice their communication skills in patient-provider scenarios. A social scientist could contribute to this effort by incorporating persuasion techniques to facilitate patients' compliance with medical advice. Similarly, if a nonprofit organization were creating a virtual workplace, a social scientist might suggest ways to use a virtual environment's capabilities to enhance small group performance, perhaps by implementing a tracking system to decrease social loafing or a rewards structure to facilitate goal-setting.

In this article, we have provided an overview of the technological aspects of VR and laid out the possibilities for social scientific research using virtual environments. Although we have presented a rich body of literature that has begun to explore the nature and utility of VR, there are a multitude of questions and future directions for study that have yet to be addressed. As in virtual reality, the only limits are the researcher's imagination.

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References

Ajzen, I., & Fishbein, M. (1977). Attitude-behavior relations: A theoretical analysis and review of empirical research. *Psychological Bulletin, 84*, 888–918.

Ajzen, I., & Fishbein, M. (1980). *Understanding attitudes and predicting social behavior.* Englewood Cliffs, NJ: Prentice-Hall.

Alcañiz, M., Baños, R., Botella, C., & Rey, B. (2003). The EMMA Project: Emotions as a determinant of presence. *PsychNology Journal, 1,* 141–150.

Anderson, C.A., Gentile, D.A., & Buckley, K.E. (2007). *Violent videogame effects on children and adolescents: Theory, research, and public policy*. New York: Oxford University Press.

Armitage, C.J., & Conner, M. (2000). Social cognition models and health behavior: A structured review. *Psychology & Health, 15*, 173–189.

Badler, N.I., Phillips, C.B., & Webber, B.L. (1992). *Simulating humans: Computer graphics, animation, and control.* New York: Oxford University Press.

Bailenson, J.N. & Beall, A.C. (2006). Transformed social interaction: Exploring the digital plasticity of avatars. In R. Schroeder & A.-S. Axelsson (Eds.), *Avatars at work and play: Collaboration and interaction in shared virtual environments* (pp. 1–16). New York: Springer.

Bailenson, J.N., & Blascovich, J. (2004). Avatars. In W.S. Bainbridge (Ed.), *Encyclopedia of human-computer interaction* (pp. 64–68). Great Barrington, MA: Berkshire.

Bailenson, J.N., & Yee, N. (2005). Digital chameleons: Automatic assimilation of nonverbal gestures in immersive virtual environments. *Psychological Science, 16,* 814–819.

Bailenson, J.N., & Yee, N. (2006). A longitudinal study of task performance, head movements, subjective report, simulator sickness, and transformed social interaction in collaborative virtual environments. *PRESENCE: Teleoperators and Virtual Environments, 15*, 699–716.

Bailenson, J.N., & Yee, N. (2007). Virtual interpersonal touch: Haptic interaction and copresence in collaborative virtual environments. *International Journal of Multimedia Tools & Applications, 37*, 5–14.

Bailenson, J.N., Beall, A.C., Blascovich, J., & Rex, C. (2004). Examining virtual busts: Are photogrammetrically generated head models effective for person identification? *PRESENCE: Teleoperators and Virtual Environments, 13*, 416–427.

Bailenson, J.N., Beall, A.C., Loomis, J., Blascovich, J., & Turk, M. (2004). Transformed social interaction: Decoupling representation from behavior and form in collaborative virtual environments. *PRESENCE: Teleoperators and Virtual Environments, 13*, 428–441.

Bailenson, J.N., Beall, A.C., Loomis, J., Blascovich, J., & Turk, M. (2005). Transformed social interaction, augmented gaze, and social influence in immersive virtual environments. *Human Communication Research, 31,* 511–537.

Bailenson, J.N., Blascovich, J., Beall, A.C., & Loomis, J.M. (2001). Equilibrium theory revisited: Mutual gaze and personal space in virtual environments. *PRESENCE: Teleoperators and Virtual Environments, 10*, 583–598.

Bailenson, J.N., Blascovich, J., Beall, A.C., & Loomis, J.M. (2003). Interpersonal distance in immersive virtual environments. *Personality & Social Psychology Bulletin, 29*, 819–833.

Bailenson, J.N., Garland, P., Iyengar, S., & Yee, N. (2006). Transformed facial similarity as a political cue: A preliminary investigation. *Political Psychology, 27*, 373–386.

Bailenson, J.N., Patel, K., Nielsen, A., Bajscy, R., Jung, S.-H., & Kurillo, G. (2008). The effect of interactivity on learning physical actions in virtual reality. *Media Psychology, 11*, 354–376.

Bailenson, J.N., Swinth, K., Hoyt, C., Persky, S., Dimov, A., & Blascovich, J. (2005). The independent and interactive effects of embodied agent appearance and behavior on self-report, cognitive, and behavioral markers of copresence in immersive virtual environments. *PRESENCE: Teleoperators and Virtual Environments, 14*, 379–393.

Bailenson, J.N., Yee, N., Blascovich, J., Beall, A.C., Lundblad, N., & Jin, M. (2008). The use of immersive virtual reality in the learning sciences: Digital transformations of teachers, students, and social context. *Journal of the Learning Sciences, 17,* 102–141.

Bailenson, J.N., Yee, N., Brave, S., Merget, D., & Koslow, D. (2007). Virtual interpersonal touch: Expressing and recognizing emotions through haptic devices. *Human-Computer Interaction, 22,* 325–353.

Bailenson, J.N., Yee, N., Merget, D., & Schroeder, R. (2006). The effect of behavioral realism and form realism of real-time avatar faces on verbal disclosure, nonverbal disclosure, emotion recognition, and copresence in dyadic interaction. *PRESENCE: Teleoperators and Virtual Environments, 15*, 359–372.

Bainbridge, W.S. (2007). The scientific research potential of virtual worlds. *Science, 317,* 472–476.

Bandura, A. (1977). *Social learning theory.* Englewood Cliffs, NJ: Prentice-Hall.

Bandura, A. (2001). Social cognitive theory of mass communication. *Media Psychology, 3,* 265–299.

Barab, S.A., Hay, K.E., Barnett, M., & Squire, K. (2001). Constructing virtual worlds: Tracing the historical development of learner practices. *Cognition & Instruction, 19,* 47–94.

Bartle, R.A. (2004). *Designing virtual worlds.* San Francisco: New Riders.

Basdogan, C., Ho, C.-H., Srinivasan, M.A., & Slater, M. (2000). An experimental study on the role of touch in virtual environments. *ACM Transactions on Computer-Human Interaction, 7,* 443–460.

Baumann, S., Neff, C., Fetzick, S., Stangl, G., Basler, L., Vereneck, R. et al. (2003). A virtual reality system for neurobehavior and functional MRI studies. *CyberPsychology and Behavior, 6,* 259–266.

Baumann, S.B., & Sayette, M.A. (2006). Smoking cues in a virtual world provoke craving in cigarette smokers. *Psychology of Addictive Behaviors, 20,* 484–489.

Baumgartner, T., Valko, L., Esslen, M., & Jäncke, L. (2006). Neural correlate of spatial presence in an arousing and noninteractive virtual reality: An EEG and psychophysiology study. *CyberPsychology and Behavior, 9,* 30–45.

Benford, S., Greenhalgh, C., Rodden, T., & Pycock, J. (2001). Collaborative virtual environments. *Communications of the ACM, 44*(7), 79–85.

Bente, G. (1989). Facilities for the graphical computer simulation of head and body movements. *Behavior Research Methods, Instruments, & Computers, 21*, 455–462.

Bente, G., Eschenburg, F., & Krämer, N.C. (2007). Virtual gaze: A pilot study on the effects of computer simulated gaze in avatar-based conversations. In R. Schumaker (Ed.), *Virtual reality* (pp. 185–194). Berlin: Springer-Verlag.

Bente, G., Feist, A., & Elder, S. (1996). Person perception effects of computer-simulated male and female head movement. *Journal of Nonverbal Behavior, 20*, 213–228.

Bente, G., Krämer, N.C., Petersen, A., & de Ruiter, J.P. (2001). Computer animated movement and person perception: Methodological advances in nonverbal behavior research. *Journal of Nonverbal Behavior, 25,* 151–166.

Bente, G., Petersen, A., Krämer, N.C., & de Ruiter, J.P. (2001). Transcript-based computer animation of movement: Evaluating a new tool for nonverbal behavior research. *Behavior Research Methods, Instruments, & Computers, 33*, 303–310.

Bente, G., Rüggenberg, S., Krämer, N.C., & Eschenburg, F. (2008). Avatar-mediated networking: Increasing social presence and interpersonal trust in net-based collaborations. *Human Communication Research, 34,* 287–318.

Bickmore, T., & Cassell, J. (2005). Social dialog with embodied conversational agents. In J.C.J. Kuppevelt, L. Dybkjaer, & N.O. Bernson (Eds.), *Advances in natural multimodal dialog systems* (pp. 1–32). New York: Springer.

Biocca, F. (1992a). Communication within virtual reality: Creating a space for research. *Journal of Communication, 42*(4), 5–22.

Biocca, F. (1992b). Virtual reality technology: A tutorial. *Journal of Communication, 42*(4), 23–72.

Biocca, F., & Delaney, B. (1995). Immersive virtual reality technology. In F. Biocca & M.R. Levy (Eds.), *Communication in the age of virtual reality* (pp. 57–124). Hillsdale, NJ: Erlbaum.

Biocca, F., & Levy, M.R. (1995). Communication applications of virtual reality. In F. Biocca & M.R. Levy (Eds.), *Communication in the age of virtual reality* (pp. 127–157). Hillsdale, NJ: Erlbaum.

Biocca, F., Harms, C., & Burgoon, J.K. (2003). Toward a more robust theory and measure of social presence: Review and suggested criteria. *PRESENCE: Teleoperators and Virtual Environments, 12,* 456–480.

Blascovich, J. (2000). Using physiological indexes of psychological processes in social psychological research. In H.T. Reis & C.M. Judd (Eds.), *Handbook of research methods in social and personality psychology* (pp. 117–137). New York: Cambridge University Press.

Blascovich, J. (2001). Immersive virtual environments and social behavior. *Science Briefs: Psychological Science Agenda, 14,* 8–9.

Blascovich, J., Loomis, J., Beall, A.C., Swinth, K.R., Hoyt, C.L., & Bailenson, J.N. (2002). Immersive virtual environment technology as a methodological tool for social psychology. *Psychological Inquiry, 13,* 103–124.

Botella, C., García-Palacios, A., Villa, H., Baños, R.M., Quero, S., Alcañiz, M. et al. (2007). Virtual reality exposure in the treatment of panic disorder and agoraphobia: A controlled study. *Clinical Psychology & Psychotherapy, 14,* 164–175.

Bouchard, S., St-Jacques, J., Robillard, G., & Renaud, P. (2008). Anxiety increases the feeling of presence in virtual reality. *PRESENCE: Teleoperators and Virtual Environments, 17,* 487–502.

Brough, J.E., Schwartz, M., Gupta, S.K., Anand, D.K., Kavetsky, R., & Pettersen, R. (2007). Toward the development of a virtual environment-based training system for mechanical assembly operations. *Virtual Reality, 11*, 189–206.

Bryant, J., & Oliver, M.B. (Eds.). (2008). *Media effects: Advances in theory and research* (3rd ed.). New York: Routledge.

Bryanton, C., Bossé, J., Brien, M., McLean, J., McCormick, A., & Sveistrup, H. (2006). Feasibility, motivation, and selective motor control: Virtual reality compared to conventional home exercise in children with cerebral palsy. *CyberPsychology and Behavior, 9,* 123–128.

Bullinger, A.H., Hemmeter, U.M., Stefani, O., Angehrn, I., Mueller-Spahn, F., Bekiaris, E. et al. (2005). Stimulation of cortisol during mental task performance in a provocative virtual environment. *Applied Psychophysiology and Biofeedback, 30,* 205–216.

Burdea, G.C., & Coiffet, P. (2003). *Virtual reality technology* (2nd ed.). New York: Wiley.

Cassell, J. (2000). Embodied conversational interface agents. *Communications of the ACM, 43*(4), 70–78.

Cassell, J., & Jenkins, H. (1998). *From Barbie to Mortal Kombat: Gender and computer games.* Cambridge, MA: MIT Press.

Castronova, E. (2004). The price of bodies: A hedonic pricing model of avatar attributes in a synthetic world. *KYKLOS, 57,* 173–196.

Castronova, E. (2005). *Synthetic worlds: The business and culture of online games*. Chicago: University of Chicago Press.

Chartrand, T.L., & Bargh, J.A. (1999). The chameleon effect: The perception-behavior link and social interaction. *Journal of Personality & Social Psychology, 76,* 893–910.

Cho, S., Ku, J., Park, J., Han, K., Lee, H., Choi, Y.K. et al. (2008). Development and verification of an alcohol-craving induction tool using virtual reality: Craving characteristics in a social pressure situation. *CyberPsychology and Behavior, 11,* 302–309.

Chung, J.C., Harris, M.R., Brooks, F.P., Fuchs, H., Kelley, M.T., Hughes, J. et al. (1989). Exploring virtual worlds with head-mounted displays. *Proceedings of SPIE, 1083,* 42–52.

Coelho, C.M., Santos, J.A., Silvério, J., & Silva, C.F. (2006). Virtual reality and acrophobia: One-year follow-up and case study. *CyberPsychology and Behavior, 9,* 336–341.

Cote, S., & Bouchard, S. (2005). Documenting the efficacy of virtual reality exposure with psychophysiological and information processing measures. *Applied Psychophysiology & Biofeedback, 30,* 217–232.

Cruz-Neira, C., Sandin, D.J., DeFanti, T.A., Kenyon, R.V., & Hart, J.C. (1992). The CAVE: Audio visual experience automatic virtual environment. *Communications of the ACM, 35*(6), 64–72.

Dahlquist, L.M., McKenna, K.D., Jones, K.K., Dillinger, L., Weiss, K.E., & Ackerman, C.S. (2007). Active and passive distraction using a head-mounted display helmet: Effects on cold pressor pain in children. *Health Psychology, 26,* 794–801.

De Kort, Y.A.W., & Ijsselsteijn, W.A. (2006). Reality check: The role of realism in stress reduction using media technology. *CyberPsychology and Behavior, 9,* 230–233.

De Leo, G., Ponder, M., Molet, T., Fato, M., Thalmann, D., Magnenat-Thalmann, N. et al. (2003). A virtual reality system for the training of volunteers involved in health emergency situations. *CyberPsychology and Behavior, 6,* 267–274.

Deaton, J.E., Barba, C., Santarelli, T., Rosenzweig, L., Souders, V., McCollum, C. et al. (2005). Virtual environment cultural training for operational readiness (VECTOR). *Virtual Reality, 8*, 156–167.

Dede, C. (2009). Immersive interfaces for engagement and learning. *Science, 323,* 66–69.

Deutsch, J.E., & Mirelman, A. (2007). Virtual reality-based approaches to enable walking for people poststroke. *Topics in Stroke Rehabilitation, 14,* 45–53.

Donath, J. (2007). Virtually trustworthy. *Science, 317,* 53–54.

Dotsch, R., & Wigboldus, D.H.J. (2008). Virtual prejudice. *Journal of Experimental Social Psychology, 44,* 1194–1198.

Eastgate, R.M., Griffiths, G.D., Waddingham, P.E., Moody, A.D., Butler, T.K.H., Cobb, S.V. et al. (2006). Modified virtual reality for treatment of amblyopia. *Eye, 20,* 370–374.

Eastwick, P.W., & Gardner, W.L. (2009). Is it a game? Evidence for social influence in the virtual world. *Social Influence, 4,* 18–32.

Fishbein, M., & Cappella, J.N. (2006). The role of theory in developing effective health communications. *Journal of Communication, 56,* S1–S17.

Fleiss, J.L. (1971). Measuring nominal scale agreement among many raters. *Psychological Bulletin, 76,* 378–382.

Fox, J., & Bailenson, J.N. (2009). Virtual self-modeling: The effects of vicarious reinforcement and identification on exercise behaviors. *Media Psychology, 12,* 1–25.

Fox, J., & Bailenson, J.N. (2009). Virtual virgins and vamps: The effects of exposure to female characters' sexualized appearance and gaze in an immersive virtual environment. *Sex Roles, 61,* 147–157.

Fox, J., Bailenson, J.N., & Binney, J. (in press). Virtual experiences, physical behaviors: The effect of presence on imitation of an eating avatar. *PRESENCE: Teleoperators and Virtual Environments.*

Friedman, D., Steed, A., & Slater, M. (2007). Spatial social behavior in Second Life. In C. Pelachaud (Ed.), *Intelligent virtual agents* (pp. 252–263). New York: Springer.

Furness, T. (1987). Designing in virtual space. In W.B. Rouse & K.R. Boff (Eds.), *System design: Behavioral perspectives on designers, tools, & organization* (pp. 127–143). New York: North-Holland.

Garau, M., Slater, M., Pertaub, D.-P., & Razzaque, S. (2005). The responses of people to virtual humans in an immersive virtual environment. *PRESENCE: Teleoperators and Virtual Environments, 14*, 104–116.

Gilliath, O., McCall, C., Shaver, P.R., & Blascovich, J. (2008). What can virtual reality teach us about prosocial tendencies in real and virtual environments? *Media Psychology, 11,* 259–282.

Gold, J.I., Belmont, K.A., & Thomas, D.A. (2007). The neurobiology of virtual reality pain attenuation. *CyberPsychology and Behavior, 10,* 536–544.

Gonzales, A.L., & Hancock, J.T. (2008). Identity shift in computer-mediated environments. *Media Psychology, 11,* 167–185.

Gratch, J., & Marsella, S. (2005). Lessons from emotion psychology for the design of lifelike characters. *Applied Artificial Intelligence, 19,* 215–233.

Gregg, L., & Tarrier, N. (2007). Virtual reality in mental health: A review of the literature. *Social Psychiatry & Psychiatric Epidemiology, 42,* 343–354.

Groom, V., Bailenson, J.N., & Nass, C. (2009). The influence of racial embodiment on racial bias in immersive virtual environments. *Social Influence, 4,* 231–248.

Guadagno, R.E., Blascovich, J., Bailenson, J.N., & McCall, C. (2007). Virtual humans and persuasion: The effects of agency and behavioral realism. *Media Psychology, 10,* 1–22.

Gutiérrez-Maldonado, J., Ferrer-García, M., Caqueo-Urizar, A., & Letosa-Porta, A. (2006). Assessment of emotional reactivity produced by exposure to virtual environments in patients with eating disorders. *CyberPsychology and Behavior, 9,* 507–513.

Haans, A., & Ijsselsteijn, W. (2005). Mediated social touch: A review of current research and future directions. *Virtual Reality, 9,* 149–159.

Harris, S.R., Kemmerling, R.L., & North, M.M. (2002). Brief virtual reality therapy for public speaking anxiety. *CyberPsychology and Behavior, 5,* 543–550.

Hill, R.W., Jr., Gratch, J., Marsella, S., Rickel, J., Swartout, W., & Traum, D. (2003). Virtual humans in the mission rehearsal exercise system. *Künstliche Intelligenz, 17,* 5–12.

Hoffman, H.G., Patterson, D.R., Seibel, E., Soltani, M., Jewett-Leahy, L., & Sharar, S.R. (2008). Virtual reality pain control during burn wound debridement in the hydrotank. *Clinical Journal of Pain, 24,* 299–304.

Hoyt, C.L., & Blascovich, J. (2003). Transformational and transactional leadership in virtual and physical environments. *Small Group Research, 34,* 678–715.

Hoyt, C.L., & Blascovich, J. (2007). Leadership efficacy and women leaders' responses to stereotype activation. *Group Processes and Intergroup Relations, 10,* 595–616.

Hoyt, C.L., Blascovich, J., & Swinth, K.R. (2003). Social inhibition in virtual environments. *PRESENCE: Teleoperators and Virtual Environments, 12,* 183–195.

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

Internet World Stats. (2009). *World Internet usage and population stats.* Retrieved March 18, 2009, from http://www.internetworldstats.com/stats.htm

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

Johnsen, K., Dickerson, R., Rajj, A., Harrison, C., Lok, B., Stevens, A. et al. (2006). Evolving an immersive medical communication skills trainer. *PRESENCE: Teleoperators and Virtual Environments, 15,* 33–46.

Jordans, F. (2009, March 2). World's poor drive growth in global cell phone use. *Forbes Online.* Retrieved March 18, 2009, from http://www.forbes.com/feeds/ap/2009/03/02/ap6114172.html

Joslin, C., Di Giacomo, T., & Magnenat-Thalmann, N. (2004). Collaborative virtual environments: From birth to standardization. *IEEE Communications, 42*(4), 28–33.

Kalawsky, R.S. (1993). *The science of virtual reality and virtual environments*. Boston: Addison-Wesley.

Kamada, M., Ambe, M., Hata, K., Yamada, E., & Fujimura, Y. (2005). The effect of the emotion-related channel in 3D virtual communication environments. *PsychNology Journal, 3,* 312–327.

Kenny, P., Rizzo, A.A., Parsons, T.D., Gratch, J., & Swartout, W. (2007). A virtual human agent for training novice therapists clinical interviewing skills. *Annual Review of CyberTherapy and Telemedicine, 5,* 77–83.

Krippendorff, K. (1980). *Content analysis: An introduction to its methodology*. Beverly Hills, CA: Sage.

Landis, J.R., & Koch, G.G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33,* 159–174.

Lanier, J. (1992). Virtual reality: The promise of the future. *Interactive Learning International, 8,* 275–79.

Lanier, J. (1997). Beyond goggles and gloves. *Byte, 22*(9), 32.

Lanier, J., & Biocca, F. (1992). An insider's view of the future of virtual reality. *Journal of Communication, 42*, 150–172.

Lastowka, F.G., & Hunter, D. (2004). The laws of the virtual worlds. *California Law Review, 92*, 1–73.

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

Lombard, M., & Ditton, T. (1997). At the heart of it all: The concept of presence. *Journal of Computer-Mediated Communication, 3*(2). Retrieved on September 9, 2009, at http://jcmc.indiana.edu/vol3/issue2/lombard.html

Loomis, J.M. (1992). Distal attribution and presence. *PRESENCE: Teleoperators and Virtual Environments, 1,* 113–119.

Loomis, J.M., Blascovich, J.J., & Beall, A.C. (1999). Immersive virtual environment technology as a basic research tool in psychology. *Behavior Research Methods, Instruments, and Computers, 31,* 557–564.

Loomis, J.M., Hebert, C., & Cicinelli, J.G. (1990). Active localization of virtual sounds. *Journal of the Acoustical Society of America, 88,* 1757–1764.

Macedonio, M.F., Parsons, T.D., Diguiseppe, R.A., Weiderhold, B.K., & Rizzo, A.A. (2007). Immersiveness and physiological arousal within panoramic video-based virtual reality. *CyberPsychology and Behavior, 10*, 508–515.

Mantovani, F., Castelnuovo, G., Gaggioli, A., & Riva, G. (2003). Virtual reality training for health-care professionals. *CyberPsychology and Behavior, 6,* 389–395.

Meehan, M., Razzaque, S., Insko, B., Whitton, M., & Brooks, F.P., Jr. (2005). Review of four studies on the use of physiological reaction as a measure of presence in stressful virtual environments. *Applied Psychophysiology and Biofeedback, 30*, 239–258.

Meyer, K., Applewhite, H.L., & Biocca, F.A. (1992). A survey of position trackers. *PRESENCE: Teleoperators and Virtual Environments, 1*, 173–200.

Moreno, R., & Mayer, R. (2007). Interactive multimodal learning environments. *Educational Psychology Review, 19,* 309–326.

Mraz, R., Hong, J., Quintin, G., Staines, W.R., McIlroy, W.E., Zakzanis, K.K. et al. (2003). A platform for combining virtual reality experiments with functional magnetic resonance imaging. *CyberPsychology and Behavior, 6,* 359–368.

Nijholt, A. (2004). Where computers disappear, virtual humans appear. *Computers and Graphics, 28,* 467–476.

Normand, V., Babski, C., Raupp-Musse, A., Thalmann, D., Benford, S., Bullock, A. et al. (1999). The COVEN project: Exploring applicative, technical, and usage dimensions of collaborative virtual environments. *PRESENCE: Teleoperators and Virtual Environments, 8,* 218–236.

Noveck, B.S. (2003). Designing deliberative democracy in cyberspace: The role of the cyberlawyer. *Journal of Science and Technology Law, 9,* 1–91.

Nowak, K.L., & Rauh, C. (2006). The influence of the avatar on online perceptions of anthropomorphism, androgyny, credibility, homophily, and attraction. *Journal of Computer-Mediated Communication, 11,* 153–178.

NPD Group. (2009, February 2). *2008 videogame software sales across top global markets experience double-digit growth*. Retrieved on March 18, 2009, from http://www.npd.com/press/releases/press_090202.html

Okita, S.Y., Bailenson, J.N., & Schwartz, D.L. (2008). The mere belief in social interaction improves learning. In S. Barab, K. Hay, & D. Hickey (Eds.), *Proceedings of the 8th International Conference for the Learning Sciences.* Mahwah, NJ: Erlbaum.

O'Toole, R., Playter, R., Krummel, T., Blank, W., Cornelius, N., Roberts, W. et al. (1998). Assessing skill and learning in surgeons and medical students using a force feedback surgical simulator. In W. Wells, A. Colchester, & S. Delp (Eds.), *Proceedings of the International Conference for Medical Image Computing and Computer-Assisted Intervention (MICCAI).* Berlin: Springer-Verlag.

Park, S., & Catrambone, R. (2007). Social facilitation effects of virtual humans. *Human Factors, 49,* 1054–1060.

Parsons, T.D., & Rizzo, A.A. (2008). Affective outcomes of virtual reality exposure therapy for anxiety and specific phobias: A meta-analysis. *Journal of Behavior Therapy and Experimental Psychiatry, 39,* 250–261.

Pausch, R., Crea, T., & Conway, M. (1992). A literature survey for virtual environments: Military flight simulator visual systems and simulator sickness. *PRESENCE: Teleoperators and Virtual Environments, 1,* 344–363.

Persky, S., & Blascovich, J. (2008). Immersive virtual videogame play and presence: Influences on aggressive feelings and behavior. *PRESENCE: Teleoperators and Virtual Environments, 17,* 57–72.

Petersen, A., & Bente, G. (1991). Situative und technologische Determinanten des Erlebens virtueller Realität [Situational and technological determinants of virtual reality experience]. *Zeitschrift für Medienpsychologie, 13,* 138–145.

Powers, M.B., & Emmelkamp, P.M.G. (2008). Virtual reality exposure therapy for anxiety disorders: A meta-analysis. *Journal of Anxiety Disorders, 22,* 561–569.

Price, M., & Anderson, P. (2007). The role of presence in virtual reality exposure therapy. *Journal of Anxiety Disorders, 21,* 742–751.

Ratan, R., Santa Cruz, M., & Vorderer, P. (2008). Multitasking, presence, and self-presence on the Wii. In L. Moreno (Ed.), *Proceedings of the 10th Annual International Workshop on Presence* (pp. 167–190). Barcelona, Spain: Starlab Barcelona.

Read, S.J., Miller, L.C., Appleby, P.R., Nwosu, M.E., Reynaldo, S., Lauren, A. et al. (2006). Socially optimized learning in a virtual environment: Reducing risky sexual behavior among men who have sex with men. *Human Communication Research, 32,* 1–34.

Reeves, B., & Nass, C. (1996). *The media equation.* New York: Cambridge.

Reeves, B., Malone, T.W., & O'Driscoll, T. (2008). Leadership's online labs. *Harvard Business Review, 86*(5), 58–66.

Reger, G.M., & Gahm, G.A. (2008). Virtual reality exposure therapy for active duty soldiers. *Journal of Clinical Psychology, 64,* 940–946.

Rheingold, H. (1991). *Virtual reality.* New York: Simon & Schuster.

Riva, G. (2005). Virtual reality in psychotherapy: Review. *CyberPsychology and Behavior, 8,* 220–230.

Riva, G., Davide, F., & Ijsselsteijn, W.A. (Eds.). (2003). *Being there: Concepts, effects, and measurement of user presence in synthetic environments.* Amsterdam: Ios Press.

Riva, G., Mantovani, F., Capideville, C.S., Preziosa, A., Morganti, F., Villani, D. et al. (2007). Affective interactions using virtual reality: The link between presence and emotions. *CyberPsychology and Behavior, 10,* 45–56.

Rizzo, A.A., Neumann, U., Enciso, R., Fidaleo, D., & Noh, J.Y. (2001). Performance-driven facial animation: Basic research on human judgments of emotional state in facial avatars. *CyberPsychology and Behavior, 4,* 471–487.

Rothbaum, B.O., Hodges, L.F., & Kooper, R. (1997). Virtual reality exposure therapy. *Journal of Psychotherapy Practice and Research, 6,* 219–226.

Rothbaum, B.O., Hodges, L., Smith, S., Lee, J.H., & Price, L. (2000). A controlled study of virtual reality exposure therapy for the fear of flying. *Journal of Consulting and Clinical Psychology, 68,* 1020–1026.

Rothbaum, B.O., Ruef, A.M., Litz, B.T., Han, H., & Hodges, L. (2003). Virtual reality exposure therapy of combat-related PTSD: A case study using psychophysiological indicators of outcome. *Journal of Cognitive Psychotherapy, 17,* 163–177.

Roy, S., Klinger, E., Legeron, P., Lauer, F., Chemin, I., & Nugues, P. (2003). Definition of a VR-based protocol to treat social phobia. *CyberPsychology and Behavior, 6,* 411–420.

Sacau, A., Laarni, J., & Hartmann, T. (2008). Influence of individual factors on presence. *Computers in Human Behavior, 24,* 2255–2273.

Salisbury, J.K., & Srinivasan, M.A. (1997). Phantom-based haptic interaction with virtual objects. *IEEE Computer Graphics and Applications, 17*(5), 6–10.

Schroeder, R. (Ed.). (2002). *The social life of avatars: Presence and interaction in shared virtual environments*. London: Springer-Verlag.

Schroeder, R., & Axelsson, A.-S. (Eds.). (2006). *Avatars at work and play: Collaboration and interaction in shared virtual environments*. New York: Springer.

Schroeder, R., Heldal, I., & Tromp, J. (2006). The usability of collaborative virtual environments and methods for the analysis of interaction. *PRESENCE: Teleoperators and Virtual Environments, 15,* 655–667.

Schultheis, M.T., & Rizzo, A.A. (2001). The application of virtual reality technology in rehabilitation. *Rehabilitation Psychology, 46,* 296–311.

Sharples, S., Cobb, S., Moody, A., & Wilson, J.R. (2008). Virtual reality induced symptoms and effects (VRISE): Comparison of head mounted display (HMD), desktop, and projection display systems. *Displays, 29,* 58–69.

Skalski, P., & Tamborini, R. (2007). The role of social presence in interactive agent-based persuasion. *Media Psychology, 10,* 385–413.

Slater, M., & Steed, A. (2000). A virtual presence counter. *PRESENCE: Teleoperators and Virtual Environments, 9,* 413–434.

Slater, M., Antley, A., Davison, A., Swapp, D., Guger, C., Barker, C. et al. (2006). A virtual reprise of the Stanley Milgram obedience experiments. *PLoSONE 1*(1): e39. doi: 10.1371/journal.pone.0000039

Slater, M., Guger, C., Edlinger, G., Leeb, R., Pfurtscheller, G., Antley, A. et al. (2006). Analysis of physiological responses to a social situation in an immersive virtual environment. *PRESENCE: Teleoperators and Virtual Environments, 15,* 553–569.

Slater, M., Pertaub, D.-P., Baker, C., & Clark, D.M. (2006). An experimental study on fear of public speaking using a virtual environment. *CyberPsychology and Behavior, 9,* 627–633.

Slater, M., Sadagic, A., Usoh, M., & Schroeder, R. (2000). Small group behavior in a virtual and real environment: A comparative study. *PRESENCE: Teleoperators and Virtual Environments, 9,* 37–51.

Spitzer, V.M., & Ackerman, M.J. (2008). The Visible Human® at the university of Colorado 15 years later. *Virtual Reality, 12,* 191–200.

Stanney, K., & Salvendy, G. (1998). Aftereffects and sense of presence in virtual environment: Formulation of a research and development agenda. *International Journal of Human-Computer Interaction, 10,* 135–187.

Stanney, K.M., Hale, K.S., Nahmens, I., & Kennedy, R.S. (2003). What to expect from immersive virtual environment exposure: Influences of gender, body mass index, and past experience. *Human Factors, 45,* 504–520.

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

Sutcliffe, A., Gault, B., Fernando, T., & Tan, K. (2006). Investigating interaction in CAVE virtual environments. *ACM Transactions on Computer-Human Interaction, 13,* 235–267.

Sutherland, I.E. (1968). A head mounted three dimensional display. *Proceedings of the Fall Joint Computer Conference, 33,* 757–764.

Sveistrup, H., McComas, J., Thornton, M., Marshall, S., Finestone, H., McCormick, A. et al. (2003). Experimental studies of virtual reality-delivered compared to conventional exercise programs for rehabilitation. *CyberPsychology and Behavior, 6,* 245–249.

Tajfel, H., & Turner, J.C. (1986) . The social identity theory of intergroup behavior. In S. Worchel & W. Austin (Eds.), *Psychology of intergroup relations* (pp. 7–24). Chicago: Nelson-Hall.

Tan, H.Z., & Pentland, A. (1997). Tactual displays for wearable computing. *Personal Technologies, 1,* 225–230.

Toma, C.L., Hancock, J.T., & Ellison, N.B. (2008). Separating fact from fiction: An examination of deceptive self-presentation in online dating profiles. *Personality and Social Psychology Bulletin, 34,* 1023–1036.

Turk, M., & Robertson, G. (2000). Perceptual user interfaces. *Communications of the ACM, 43*(3), 33–34.

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

Villani, D., Riva, F., & Riva, G. (2007). New technologies for relaxation: The role of presence. *International Journal of Stress Management, 14,* 260–274.

Vorderer, P., & Bryant, J. (Eds.). (2006). *Playing videogames: Motives, responses, and consequences.* Mahwah, NJ: Erlbaum.

Waller, D., Bachmann, E., Hodgson, E., & Beall, A.C. (2007). The HIVE: A huge immersive environment for research in spatial cognition. *Behavior Research Methods, 39,* 835–843.

Walther, J.B. (2007). Selective self-presentation in computer-mediated communication: Hyperpersonal dimensions of technology, language, and cognition. *Computers in Human Behavior, 23,* 2538–2557.

Walther, J.B., Van Der Heide, B., Kim, S.-Y., Westerman, D., & Tong, S.T. (2008). The role of friends' appearance and behavior on evaluations of individuals on Facebook: Are we known by the company we keep? *Human Communication Research, 34,* 28–49.

Welch, G.F. (2009). History: The use of the Kalman filter for human motion tracking in virtual reality. *PRESENCE: Teleoperators and Virtual Environments, 18,* 72–91.

Williams, D. (2006). Why study games now? Gamers don't bowl alone. *Games & Culture, 1,* 13–16.

Williams, D., Caplan, S., & Xiong, L. (2007). Can you hear me now? The impact of voice in an online gaming community. *Human Communication Research, 33,* 427–449.

Wilson, J.R., & D'Cruz, M. (2006). Virtual and interactive environments for work of the future. *International Journal of Human-Computer Studies, 64,* 158–169.

Wirth, W., Hartmann, T., Böcking, S., Vorderer, P., Klimmt, C., Schramm, H. et al. (2007). A process model of the formation of spatial presence experiences. *Media Psychology, 9,* 493–525.

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

Yee, N. (2006a). The demographics, motivations and derived experiences of users of massively multiuser online graphical environments. *PRESENCE: Teleoperators and Virtual Environments, 15,* 309–329.

Yee, N. (2006b). The psychology of MMORPGs: Emotional investment, motivations, relationship formation, and problematic usage. In R. Schroeder & A. Axelsson (Eds.), *Avatars at work and play: Collaboration and interaction in shared virtual environments* (pp. 187–207). New York: Springer.

Yee, N., & Bailenson, J.N. (2007). The Proteus effect: Self transformations in virtual reality. *Human Communication Research, 33,* 271–290.

Yee, N., & Bailenson, J.N. (2008). A method for longitudinal behavioral data collection in Second Life. *PRESENCE: Teleoperators and Virtual Environments, 17,* 594–596.

Yee, N., Bailenson, J.N., & Ducheneaut, N. (2009). The Proteus effect: Implications of transformed digital self-representation on online and offline behavior. *Communication Research, 36,* 285–312.

Yee, N., Bailenson, J.N., Urbanek, M., Chang, F., & Merget, D. (2007). The unbearable likeness of being digital: The persistence of nonverbal social norms in online virtual environments. *CyberPsychology and Behavior, 10,* 115–121.

Zahorik, P. (2002). Assessing auditory distance perception using virtual acoustics. *Journal of the Acoustical Society of America, 111,* 1832–1846.

Zanbaka, C., Ulinski, A., Goolkasian, P., & Hodges, L.F. (2007). Responses to virtual humans: Implications for future interface design. *Proceedings of the Conference on Computer-Human Interaction (CHI) 2007,* 1561–1570.

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