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Interfaces That Heal: Coupling Real and Virtual Objects to Treat Spider Phobia

Hunter G. Hoffman
Human Interface Technology Laboratory
University of Washington

Azucena Garcia-Palacios
Human Interface Technology Laboratory, University of Washington
Universidad Jaume I, Castellon, Spain

Albert Carlin
Thomas A. Furness III
Human Interface Technology Laboratory
University of Washington

Cristina Botella-Arbona
Universidad Jaume I

Tactile augmentation is a simple, safe, inexpensive interaction technique for adding physical texture and force feedback cues to virtual objects. This study explored whether virtual reality (VR) exposure therapy reduces fear of spiders and whether giving patients the illusion of physically touching the virtual spider increases treatment effectiveness. Eight clinically phobic students were randomly assigned to one of 3 groups—(a) no treatment, (b) VR with no tactile cues, or (c) VR with a physically "touchable" virtual spider—as were 28 nonclinically phobic students. Participants in the 2 VR treatment groups received three 1-hr exposure therapy sessions resulting in clinically significant drops in behavioral avoidance and subjective fear ratings. The tactile augmentation group showed the greatest progress on behavioral measures. On average, participants in this group, who only approached to 5.5 ft of a live spider on the pretreatment Behavioral Avoidance Test (Garcia-Palacios, 2002), were able to approach to 6 in. of the spider after VR exposure treatment and did so with much less anxiety (see www.vrpain.com for details). Practical implications are discussed.

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Requests for reprints should be sent to Hunter G. Hoffman, Human Interface Technology Laboratory, University of Washington, Seattle, WA 98195. E-mail: hunter@hitL.washington.edu

1. INTRODUCTION

The essence of "immersive" virtual reality (VR) is the illusion users have of going inside the computer-generated environment (Laurel, 1995). The extent to which people experience this sensation of presence is limited, especially when virtual environments are entirely computer generated. When the typical VR user touches a virtual object, the object they reach for is not solid, has no mass or "cyberheft" when lifted, and does not feel fuzzy. As computers and graphics cards continue to become more powerful, human–computer interface techniques that make interactions with graphics more realistic and natural will prove valuable for some applications.

Tactile augmentation can be used as a technique for interacting with three-dimensional (3-D) graphics in VR. Real objects can be used as props to enhance the quality of the virtual world (Hoffman, 1998a). For example, Hoffman, Hollander, Schroder, Rousseau, and Furness (1998) showed that physically touching one virtual object influenced user's predictions about the properties of other unexplored virtual objects and the "laws of nature" obeyed in a virtual kitchen. Tactile experiences with a virtual plate (using tactile augmentation) influenced participants' expectations about other virtual objects in the virtual kitchen despite the fact that the participants had not interacted with the other objects. Participants in the see-and-touch condition predicted the teapot, walls, and countertop were more solid and predicted the teapot was heavier and more likely to obey the laws of gravity than participants in the no-touch condition. Tactile augmentation, a form of mixed reality (Milgram & Kishino, 1994), can increase the realism of the virtual experience, can increase how present the individual feels in the virtual environment, and can help blur the distinction between real and virtual objects (Hoffman, 1998a, 1998b; Hoffman, Garcia-Palacios, Thomas, & Schmidt, 2001). In this study, we applied the tactile augmentation technique to treating spider phobics with immersive VR.

Clinical spider phobics have a persistent fear of spiders, an immediate anxiety response on exposure to spiders, and avoid spiders. These symptoms can interfere with the patient's normal social routines, activities, and interpersonal relationships and can produce distress about having the fear. The person typically recognizes that his or her fear is excessive or unreasonable (American Psychiatric Association, 1994). Desensitization, a treatment based on gradually and systematically exposing the phobic person to the feared object or situation and calming them, has proved to be an effective treatment for a wide range of phobias (Marks & Gelder, 1965). Exposure therapy has been involved in the successful treatment of claustrophobia (Ost, Alm, Brandberg, & Breitholtz, 2001); fear of public speaking (Kozasa & Leite, 1998); fear of flying in airplanes (Ost, Brandberg, & Alm, 1997); spider phobia (Ost, Ferebee, & Furmark, 1997); fear of blushing, sweating, or trembling (Scholing & Emmelkamp, 1996); fear of getting blood draws (Bernstein, Peterson, Perwien, Borchardt, & Kushner, 1996); panic attacks (Williams & Falbo, 1996); insects (McGlynn, Rose, & Lazarte, 1994); childhood water phobia (Menzies & Clarke, 1993), other phobias not mentioned here; and obsessive–compulsive disorder (Jenike, 2001).

Exposure is a technique that belongs to a therapeutic approach known as cognitive-behavioral therapy. Regardless of the origins of how patients became phobic in the first place, spider phobics have one thing in common—they avoid spiders. For example, if they go into a room and see a large spider scurry across the room, they typically leave the room. When they leave the room, their anxiety goes down. This leads to a stimulus–response association between anxiety reduction and avoidance behavior (operant conditioning). Each time they avoid a spider, their tendency to leave the room when they encounter a spider becomes a little stronger, and little by little their phobia gets worse. Exposure therapy involves exposing the patient to the situation or object that elicits a fear/anxiety response, but instead of fleeing the room, patients "hold their ground." This technique uses response prevention to keep the operant avoidance response from occurring. When done correctly, the anxiety "fight-or-flight" response naturally declines/habituates after a short time, the racing heart slows down, the sweaty palms become dryer, the feeling of losing control diminishes, and the patient is ready to approach closer to the spider and start the cycle again (i.e., move closer to the spider, experience anxiety, habituate). In addition to the behavioral aspects (i.e., fear reduction via stimulus–response dissociation), cognitive-behavioral therapy involves changing the way the patient thinks about spiders (i.e., cognition), changing the patient's memory about spiders, and changing the meaning of stimulus–response associations (Foa & Kozak, 1986). For example, many patients explain that they are afraid they will not be able to handle an encounter with a spider. Patients may erroneously think that if they stay in the presence of the spider, their anxiety will just get higher and higher until they lose control or lose their minds. The therapist corrects this misconception. Patients are told, for example, that if they just stand there, gradually and slowly they will habituate. Their heart will stop racing, and anxiety will go down. As patients see themselves approaching closer and closer to the spider with less and less anxiety during exposure treatment, they begin to realize that they are stronger and better able to face their fear than they previously thought.

As another example, some patients think the spider senses their vulnerability and is going to deliberately stalk them, perhaps even bringing other spiders into the attack (Carlin, Hoffman, & Weghorst, 1997). To change such counterproductive irrational trains of thought, the therapist and the patient reach more rational interpretations by means of cognitive therapy; for example, the therapist reminds the patient that spiders tend to "run in fear" from huge humans, and spider brains are extremely small. Instead of concocting elaborate schemes for how to terrify people, the spider is likely thinking much simpler thoughts (if any).

Cognitive dissonance (Festinger, 1957) may also help progress. As the patient observes that they are behaving less and less like someone who is afraid of spiders, they may change their attitudes to be more consistent with their behavior (cognitive dissonance) to reduce internal conflict (i.e., "Gee, I am acting like someone who is not afraid of spiders, I am able to walk right up to this spider, I can't believe I am able to do this. I must not be afraid of spiders anymore"). Behavioral theory and cognitive theory can be combined when using exposure therapy (Zinbarg, Barlow, Brown, & Hertz, 1992).

Recent researchers have found the application of VR exposure therapy to be effective for treating posttraumatic stress disorder (Difede & Hoffman, 2002; Rothbaum, Hodges, Ready, Graap, & Alarcon, 2001), fear of heights (Rothbaum et al., 1995), fear of flying (Rothbaum, Hodges, Anderson, Price, & Smith, 2002), and claustrophobia (Botella et al., 1998), to name a few, suggesting that a VR exposure therapy may also be effective for the treatment of other phobias such as spider phobia (Carlin et al., 1997). One potential advantage of VR over other techniques lies in the greater ability of the patient or therapist to control the feared stimulus. Unlike a real spider, virtual spiders obey commands, can be placed in various positions and orientations by the patient or therapist, can have sound effects, and can be touched without danger. VR allows an unprecedented amount of patient–spider interaction and active participation. Also, these interactions can be performed repeatedly until the patient habituates. VR helps the experimenter control how frightening the spiders appear.

To be effective, the virtual environment must elicit an anxiety response similar to the response elicited by the feared object or situation (i.e., a spider), and VR appears to do this quite well. Tactile augmentation may lead to better emotional processing of the phobia-related information by facilitating access to the patient's fear memory structure (Foa & Kozak, 1986) during therapy. The strength of the illusion of presence in VR may be associated with the amount of attention drawn into the virtual world. In fact, the amount of attention drawn into VR is so high, it can distract severe burn patients from their pain during wound care (Hoffman, Doctor, Patterson, Carrougher, & Furness, 2000; Hoffman, Patterson, & Carrougher, 2000). Also, recent medical research studying VR analgesia (pain distraction) has shown that manipulations that increase the illusion of presence increase the effectiveness of the treatment (Hoffman et al., 2003). Increasing the amount of emotion evoked by the stimulus can improve recall. For instance, emotionally arousing events typically draw more attention (as measured by eye fixations) and are better remembered than emotionally neutral events (Christianson, Loftus, Hoffman, & Loftus, 1991). Thus, there is reason to predict that tactile augmentation will improve phobia treatment effectiveness.

Carlin et al. (1997) treated the first spider phobic with VR exposure therapy, a 37-year-old woman with severe and incapacitating fear of spiders code named "Miss Muffet." After several preliminary VR exposure therapy sessions, Miss Muffet physically touched the virtual spider using tactile augmentation. Doing so elicited a dramatic anxiety response: dryness of the mouth, uncontrolled shaking of the hands and legs, and profuse sweating (often visible) and reports of being on the verge of tears. After approximately eight more 1-hr VR exposure therapy sessions, the mixed reality spider no longer evoked a strong emotional reaction; the same mixed-reality stimulus that had once been rated 10 (she actually responded "15," "off the scale") on a scale ranging from 1 (*no anxiety*) to 10 (*panic-level anxiety*) now evoked a rating of only 3, with no physical symptoms. She demonstrated dramatic drops in subjective and objective measures of fear of spiders and she speculated in a postexperimental interview that the tactile augmentation experience had played an important role in the success of her therapy (Carlin et al., 1997).

This study is the first controlled experiment to test the hypothesis that tactile augmentation improves the outcome of immersive VR exposure therapy. People with a high fear of spiders were randomly assigned to one of three groups. One group received no treatment, one group received three 1-hr VR exposure therapy sessions with no tactile cues, and one group received three VR exposure therapy sessions with tactile cues (i.e., using a real toy spider as a prop). We predicted that VR exposure therapy would reduce participants' fear of spiders and that exposure therapy with tactile augmentation would reduce fear of spiders even more, as measured with both subjective and objective fear-of-spiders measures. In other words, we predicted that making the user's technique of interacting with the graphics more realistic and touchable would improve the effectiveness of the treatment. We discuss the practical implications of the results.

2. METHOD

2.1. Participants

During a survey in an introductory psychology class, 444 students filled out a reduced version of a Fear of Spiders Questionnaire (Szymanski & O'Donohue, 1995). Students scoring over 1 *SD* above the class mean in fear of spiders were invited. Thirty-six students responded to an invitation to participate. These 36 students received extra credit in their class for participating. Twenty-nine of the participants were women (80.6%) and 7 were men (19.4%). The mean age of these 36 students was 18.66 years old. The mean reported duration of their fear was 12 years (*SD* = 3.11; range 5 to 20 years). Eight of the students (22.2%) met the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed. [*DSM–IV*]; American Psychiatric Association, 1994) criteria of specific phobia, animal type. That is, 8 were clinically phobic. None of the participants had received former treatment for their fear of spiders. After participating in the experiment, all participants were offered the opportunity to continue their treatment if they liked (or to start treatment if they were in the control group).

2.2. Equipment

A Silicon Graphics Octane MXE with Octane Channel Option (allowing stereo vision; www.sig.com) coupled with a wide field of view (40° vertical × 105° horizontal with 40° overlap) head-mounted visual display (Division dVisor) was used to create an immersive, 3-D, interactive, computer-simulated environment (see Figure 1). A Polhemus™ Fastrak position tracking system (www.polhemus.com) was used to measure the position of the user's head and hand position and the location of the virtual spider. The patient experienced SpiderWorld (Hoffman, Hollander, Rousseau, & Hendrickson, 1996), a modified version of KitchenWorld (Hamilton, 1992).

2.3. Measures

Diagnostic interview. During this interview, the patient was asked about each criteria of *DSM–IV* (American Psychiatric Association, 1994) specific phobia,

FIGURE 1 An experimenter treating a spider phobic with virtual reality SpiderWorld. Photo on left copyright UW/Mary Levin. Reprinted with permission.

animal type. Information on demographic and clinical variables was also obtained: the duration of the problem, severity of the phobia as perceived by the patient, former treatments (if any), and presence of other psychological or physical problems.

Fear of Spiders Questionnaire (Szymanski & O'Donohue, 1995), reduced version. Six fear of spider questions chosen from a set of 18 questions (Szymanski & O'Donohue, 1995) were used to assess the efficacy of VR treatment. The full set of questions should be used when possible, to maximize validity. Previous researchers have found the full questionnaire to have excellent split half reliability and internal consistency, good test–retest consistency, convergent validity due to its highly significant correlations with a Behavioral Avoidance Test ($r = .65$, $p < .001$), and construct validity in its ability to discriminate phobics from nonphobics as measured by a Behavioral Avoidance Test (O'Donohue & Szymanski, 1993; Szymanski & O'Donohue, 1995; see also Muris, & Merckelbach, 1996). These questions are designed to measure the patient's anxiety about spiders. Both before and after VR exposure treatment, the participants responded to the following items:

1. I now would do anything to avoid a spider.
2. If I came across a spider now, I would leave the room.
3. If I saw a spider now, I would ask someone else to kill it.
4. If I saw a spider now, I would be afraid of it.
5. If I saw a spider now, I would feel panicky.
6. I would feel very nervous if I saw a spider now.

Patients were asked to rate each item on a scale ranging from 1 (*does not apply to me*) to 7 (*very much applies to me*). There were six questions worth 7 points each, for a possible 42 points. Also, in a recent study by Garcia-Palacios, Hoffman, Carlin, Furness, and Botella-Arbona (2002), nearly identical results were achieved (in that study) when the full questionnaire was used versus when only the preceding six questions were used.

Behavioral Avoidance Test. The Behavioral Avoidance Test is a popular objective measure of clinical progress in overcoming phobias (e.g., Mineka, Mystkowski, Hladek, & Rodriguez, 1999). Participants were informed that the Behavioral Avoidance Test was an objective measure of how afraid they are of spiders and not part of the therapy. A live tarantula was presented, housed in a terrarium from which it could not escape. Patients were asked to walk as close as they could to the live tarantula. When the participants approached as close to the spider as they could, the distance in feet from the participant to the spider was measured, and participants rated their anxiety level on a scale ranging from 1 (*no anxiety*) to 10 (*panic-level anxiety*) using subjective units of discomfort scales (Wolpe, 1969), which were also used during the exposure sessions. The Behavioral Avoidance Test was administered in a room separate from the treatment room. The living tarantula was never in the room where the patient received VR treatment.

Presence Questionnaire. The Presence Questionnaire was composed of three questions about how present participants felt in VR (Questions 5 and 6 were adapted from the three presence questions used by Slater, Usoh, & Steed, 1994; Question 7 is from Carlin et al., 1997, p. 155). Hendrix and Barfield (1995) described several studies showing the reliability of a similar subjective measure of presence.[1] The participants rated their answers using 0 mm to 100 mmVisual Analog scales (Gift, 1989; Huskisson, 1974). Following are the questions:

1. Rate your anxiety during the last 5 minute period (endpoints = *no anxiety, highest anxiety*).
2. To what extent did you feel increased nausea as a result of experiencing the virtual world? (endpoints = *not at all, very much so*).
3. How real did the virtual world seem to you? (endpoints = *about as real as an imagined world, indistinguishable from a real world*).
4. How real did the virtual spider seem to you? (endpoints = *about as real as an imaginary spider, indistinguishable from a real spider*).
5. To what extent were there times when you felt that the virtual world became "reality" for you, and you almost forgot about the real world outside? (endpoints = *at no time, almost all of the time*).
6. Did the virtual world seem more like something you saw, or some place you visited? (endpoints = *something I saw, some place I visited*).
7. "In the virtual world, I felt more like: I was standing in the laboratory wearing a helmet vs. I was in the virtual world (endpoints = *I was standing in the laboratory wearing a helmet, I was in the virtual room*)."

[1]We chose to use our Presence Questionnaire instead of the Presence Questionnaire proposed by Witmer and Singer (1998) because the latter is not a Presence Questionnaire at all (Slater, 1999), and the validity of the Witmer and Singer Questionnaire has been questioned (Slater, 1999). Also, rather than Kennedy, Lane, Lilienthal, Berbaum, and Hettinger's (1992) Full Simulator Sickness Questionnaire, we used a single question about "simulator nausea" because nausea was our most serious concern for this application.

2.4. Procedure

During the pre-treatment assessment, participants were interviewed to determine if they met criteria for specific phobia, animal type, spiders (*DSM–IV;* APA, 1994). Then they filled out a questionnaire assessing their fear of spiders and were given the Behavioral Avoidance Test. Eight of the participants met *DSM–IV* criteria of specific phobia, animal type (spiders). These phobic participants were randomly assigned to one of the three conditions: ordinary VR (3 phobics), VR with tactile augmentation (3 phobics), and no treatment (2 phobics). Twenty-eight other nonclinical phobic participants scored high in fear of spiders but were not clinically phobic by *DSM–IV* criterion. These participants were also randomly assigned to the three treatment conditions.

During the posttreatment assessment, participants were given the same measures used at pretreatment except the diagnostic interview. Participants in the control group went through the two assessment sessions within a week, and during the first session, they spent about 15 min in a VR scenario without spiders (virtual kitchen) and filled out the Presence Questionnaire.

The 12 participants who received ordinary VR (i.e., with no tactile augmentation) and the 12 participants with tactile augmentation all received 3 one-on-one clinical VR exposure therapy sessions for treatment of spider phobia. Although in everyday practice, the number of therapy sessions would likely vary depending on how quickly the patient responds to treatment, three sessions were always used in this study based on findings in the literature that most people would show progress after 3 hr of "in vivo" exposure therapy (e.g., Ost, 1996). Each session lasted approximately 1 hr and each participant completed all three sessions and the posttreatment assessment within 1 week of beginning treatment. After each treatment session, participants also answered the presence and nausea ratings. Treatment consisted of a standardized exposure protocol delivered by an experienced clinical psychologist trained in experimental psychology (Azucena Garcia-Palacios). In Session 1, participants saw a virtual spider in a virtual kitchen and approached as closely as they could using their 3-D mouse to navigate through the virtual world. The goal of this session was to come within arms reach of the virtual spider. During the second therapy session, participants picked up a "spider bucket" with their "cyberhand." When they let go of the virtual bucket, an animated spider with wiggly legs drifted to the floor of the virtual kitchen accompanied by a brief scary sound effect. During the second therapy session, participants repeated this spider bucket routine until habituated. During the third therapy session, the two groups of participants getting treated (i.e., ordinary VR and VR + tactile augmentation) were encouraged to touch the virtual spider image with their cyberhand. The only difference between those two groups was the nature of their interaction with the virtual spider when they touched it (i.e., the nature of the human–computer interface). Participants in the ordinary VR condition reached out their cyberhand and touched the visual image of the wiggly legged, virtual Guyana bird-eating tarantula (see Figure 1). Their "cyberfingers" went right through the virtual image. In contrast, participants in the tactile augmentation condition physically groped the plump furry body of the same virtual spider. This was accomplished using tactile augmentation (Hoffman, 1998a). As the patients reached out with their cyberhand to explore the virtual spider, their real hand explored the toy spider attached to a stationary Polhemus position sensor. The virtual spider then felt furry and solid.

3. RESULTS

Alpha was initially set at .05.

3.1. Pretreatment Tests

As expected, a one-way analysis of variance (ANOVA) showed no significant difference between the three groups with respect to behavioral avoidance of spiders prior to clinical VR treatment, $F(2, 33) = 2.67$, $p > .05$, *ns*. Similarly, no difference was found in the level of anxiety reported during the behavioral avoidance pretreatment, $F(2, 33) < 1$, *ns*. Finally, as expected, no differences between the three groups were found in the subjective measure of fear of spiders at pretreatment, $F(2, 33) < 1$, *ns*.

3.2. Distance to Spider on Behavioral Avoidance Test

As shown in Figure 2, on the Behavioral Avoidance Test a 3 (group) × 2 (time = pretreatment vs. posttreatment) mixed model ANOVA regarding avoidance showed

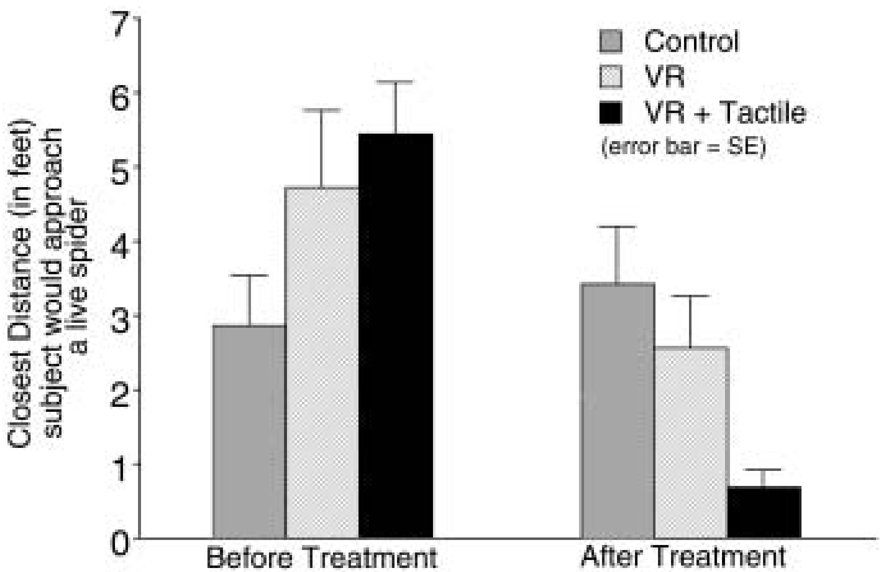

FIGURE 2 Distance participants approached a live spider before and after treatment. VR = virtual reality; SE = standard error.

no significant group effect, $F(1, 33) < 1$, *ns;* a significant time effect, $F(1, 33) = 57.25$, $p < .001$ (mean square error [*MSE*] = 1.46); and a significant Group × Time interaction, $F(2, 33) = 30.27$, $p < .001$ (*MSE* = 1.46). The interaction indicates that the three groups differed in amount of improvement. Follow-up ANOVAs revealed that the ordinary VR group showed greater improvement than the control group, $F(1, 22) = 23.76$, $p < .001$ (*MSE* = .94). The VR with tactile augmentation group also showed more improvement than the control group, $F(1, 22) = 58.60$, $p < .001$ (*MSE* = 1.50). Furthermore, compared to the ordinary VR exposure group, participants in the tactile augmentation condition showed a significantly larger pretreatment to posttreatment improvement (reduction in behavioral avoidance), $F(1, 22) = 11.32$, $p < .003$ (*MSE* = 1.93).

3.3. Anxiety During the Behavioral Avoidance Test.

Anxiety during the Behavioral Avoidance Test is shown in Figure 3. The mixed model ANOVA showed no significant group effect, $F(2, 33) = 1.01$, *ns;* a significant time effect, $F(1, 33) = 36.35$, $p < .001$ (*MSE* = 109.76); and a significant Group × Time interaction, $F(2, 33) = 11.51$, $p < .001$ (*MSE* = 109.77). The interaction indicates that the three treatment groups differed in the amount of improvement from pretest to posttest on anxiety. Follow-up ANOVAs revealed that when compared to ordinary VR, VR with tactile augmentation resulted in a greater reduction in anxiety, $F(1, 22) = 9.93$, $p < .005$ (*MSE* = 96.09). The VR tactile augmentation group showed significantly more reduction in anxiety than the control group, $F(1, 22) = 22.09$, $p < .001$

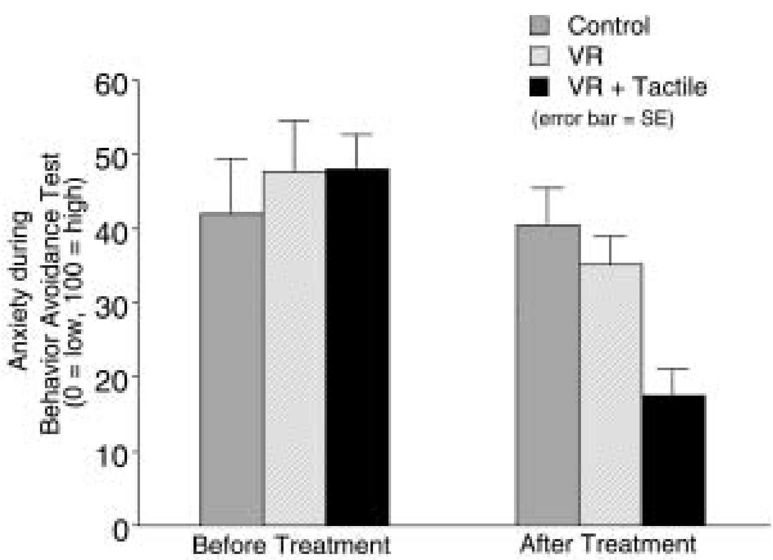

FIGURE 3 Anxiety experienced during the Behavioral Avoidance Test (approaching a live spider) before and after treatment. VR = virtual reality; SE = standard error.

(*MSE* = 112.26). Although, as predicted, anxiety was lower than the control group after ordinary VR treatment, the amount of anxiety reduction was not statistically significant, $F(1, 22) < 1$, *ns.*

3.4. The Influence of Treatment on the Subjective Fear of Spiders

The influence of treatment on the subjective fear of spiders is shown in Figure 4. A mixed model ANOVA regarding this measure showed a significant group effect, $F(2, 33) = 4.32$, $p < .05$ ($MSE = 49.27$); a significant time effect (pretreatment vs. posttreatment), $F(2, 33) = 174.69$, $p < .001$ ($MSE = 17.41$); and a significant Group × Time interaction, $F(2, 33) = 21.72$, $p < .001$ ($MSE = 17.41$). The interaction reveals that the amount of anxiety reduction was not the same for each group. Follow-up ANOVAs showed that each treatment group achieved greater improvement (more reduction in subjective ratings of fear of spiders) than the no treatment control group; ordinary VR versus control, $F(1, 22) = 35.59$, $p < .001$ ($MSE = 15.74$); and VR with tactile augmentation versus control, $F(1, 22) = 29.02$, $p < .001$ ($MSE = 19.78$). Although in the predicted direction, there were no differences in improvement in subjective fear of spiders comparing ordinary VR and VR with tactile augmentation, $F(1, 22) < 1$, *ns.* However, both groups achieved large reduction in their fear of spiders. Although fear of spiders scores were high prior to treatment, after treatment fear of spiders scores were much lower (approximately 50% lower) and more similar to the general population sample of 444 undergraduate students ($M = 18.38$, $SD = 10.96$). Patients achieved a clinically meaningful improvement according to well-established criteria (Jacobson, Follette, & Revenstorf, 1984).

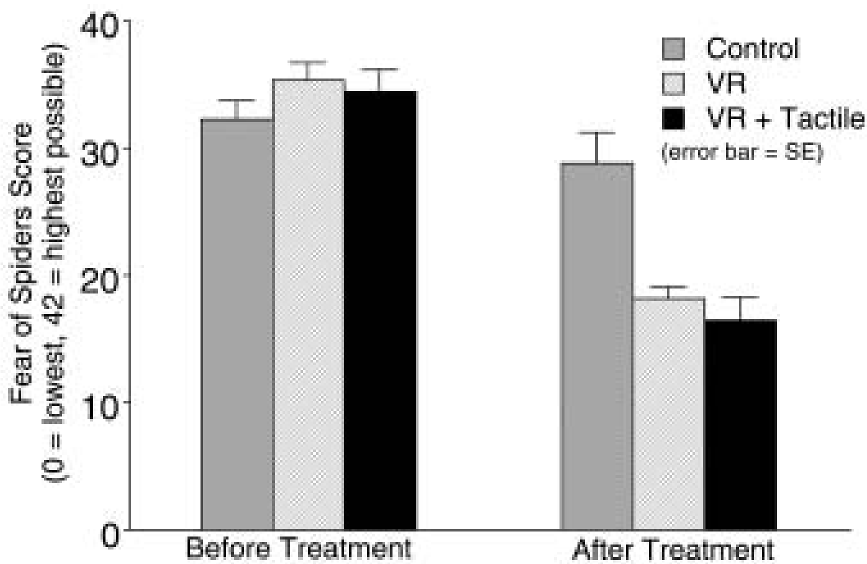

FIGURE 4 Subjective ratings of fear of spiders before and after treatment. VR = virtual reality; SE = standard error.

3.5. Presence

Comparison using *t* tests between the ordinary VR group and the VR with tactile augmentation group revealed a significant difference for the presence measure, "To what extent… [did you forget] about the real world outside" (ordinary VR, M = 40.17, SD = 21.73; VR with tactile, M = 64.83, SD = 4.64), $t(22) = 3.16$, $p = .005$ (MSE = 7.80), and a significant difference trend for the presence question asking, "Did the virtual world seem more like something you saw, or some place you visited" (ordinary VR, M = 43.42, SD = 24.37, compared to VR with tactile, M = 65.16, SD = 20.01), $t(22) = 2.39$, $p < .05$ (MSE = 9.10). Although in the predicted direction, no significant differences were found in "wearing a helmet vs. I was in the virtual room" (VR, M = 50.00, SD = 22.73; VR with tactile, M = 63.58, SD = 17.61), $t(22) = 1.56$, $p > .05$, *ns.*

3.6. Realism

The *t* tests comparing ordinary VR and VR with tactile augmentation showed significant differences between the groups in the two realism measures: "How real did the virtual world seem to you?" (VR, M = 45.33, SD = 19.51; VR with tactile, M = 63.00, SD = 19.42), $t(22) = 2.223$, $p < .05$ (MSE = 7.95), and "How real did the virtual spider seem to you?" (VR, M = 59.16, SD = 22.26; VR with tactile, M = 75.75, SD = 14.99), $t(22) = 2.14$, $p < .05$ (MSE = 7.75).

In all cases, presence and realism ratings were higher in the VR plus tactile augmentation group than in the ordinary VR group. Simulator nausea was very low in both treatment conditions (VR, M = 11.42, SD = 16.53; VR with tactile, M = 11.66, SD = 10.14) and did not differ between the two treatment groups, $t(22) < 1$, *ns.* Also, although in the predicted direction, no significant difference between groups was found for anxiety level achieved during treatment (VR, M = 50.50, SD = 16.87; VR with tactile, M = 61.00, SD = 14.74), $t(22) = 1.33$, $p > .05$, *ns.*

3.7. Treatment Outcome of Participants Who Met DSM–IV Criteria for Specific Phobia, Animal Type (Spiders)

The pattern of results for clinically phobic and nonclinically phobic patients are very similar (see Table 1). The eight clinically phobic participants were analyzed separately using Wilcoxon signed rank tests. For clinical phobics, the control group showed no change from pretest to posttest in any of the three outcome measures: the Behavioral Avoidance Test, $z = .45$, $p = .66$; anxiety during the Behavioral Avoidance Test, $z = .45$, $p = .66$; and fear of spiders, $z = 1.00$, $p = .32$. Collapsing across VR and VR plus tactile augmentation, clinically phobic participants in the two treatment conditions combined showed statistically significant drops in the pretest to posttest outcome variables: behavioral avoidance measure, $z = 2.20$, $p < .05$; anxiety during the Behavioral Avoidance Test, $z = 2.20$, $p < .05$; and fear of spiders, $z = 2.20$, $p < .05$. After VR treatment, the fear of spiders scores were similar to the mean score of the general populations sample, suggesting a clinically significant improvement (see Jacobson et al., 1984).

Table 1: Outcome Measures at Each Assessment for Participants Who Met *DSM-iv* Criteria of Specific Phobia, Animal Type (Spiders; Phobics) Versus Participants Who Did Not Meet Those Criteria (Nonclinical Phobics)

	Non-clinical phobics[a]			*Phobics*[b]		
Measure	*Control*	*VR*	*VR + T.A.*	*Control*	*VR*	*VR + T.A.*
Fear of Spiders Questionnaire (FSQ) pretreatment						
M	31.20	33.78	32.56	37.50	40.00	40.00
SD	4.32	4.27	5.61	6.36	2.00	3.46
(FSQ) posttreatment						
M	27.30	17.89	15.89	36.50	19.00	18.33
SD	7.54	3.70	6.50	7.78	1.00	6.70
Behavioral Avoidance Test (Avoidance) pretreatment						
M	1.95	3.93	5.17	7.41	7.11	6.30
SD	1.15	3.61	2.72	0.35	2.71	0.50
(Avoidance) posttreatment						
M	2.42	2.20	0.65	8.45	3.67	0.78
SD	1.11	2.33	0.80	2.54	2.85	1.07
Behavioral Avoidance Test (Anxiety) pretreatment						
M	38.00	39.67	41.67	62.50	71.67	66.67
SD	25.84	20.46	11.72	3.54	16.07	14.43
(Anxiety) posttreatment						
M	38.00	31.67	16.11	52.50	45.33	21.67
SD	17.35	12.50	14.09	17.68	10.50	7.64

Note. VR = virtual reality; T.A. = tactile augmentation; FSQ = Fear of Spiders Questionnaire.
[a]$n = 28$. [b]$n = 8$.

Although the sample of clinical phobics was too small to make a statistical comparison between the two treatment groups (three phobics in each VR condition), the pattern was as predicted: Improvement was higher in the VR plus tactile augmentation condition than in the ordinary VR group for the Behavioral Avoidance Test, both avoidance and anxiety (but not on the Fear of Spiders Questionnaire).

3.7. Dropout

None of the participants refused treatment, and none of them dropped out of the study.

4. DISCUSSION

Using both objective and subjective measures of fear, ordinary VR and VR plus tactile augmentation treatments each significantly reduced fear of spiders after only three 1-hr therapy sessions. Although only 8 clinically phobic people participated in the study when only clinical phobics were analyzed, they also showed a marginally statistically significant and clinically meaningful drop in fear after only three 1-hr treatment sessions.

Tactile augmentation is a simple, safe, inexpensive interaction technique for adding physical texture and force-feedback cues to virtual objects (Hoffman, 1998a, 1998b). In this study, we explored whether adding tactile feedback increased the effectiveness of VR exposure therapy for spider phobia. Tactile augmentation made the interface between the human and the computer touchable and led to higher presence and realism. On average, patients who stopped 5.5 ft away from a living tarantula on a Behavioral Avoidance Test prior to 3 hr of tactile augmentation VR therapy could approach to within 6 in. of the living tarantula after treatment. On average, patients in the ordinary VR group who stopped 5 ft away from a living tarantula could only approach to 2.5 ft after treatment. The advantage of treatment effectiveness of tactile augmentation over ordinary VR on the Behavioral Avoidance Test was statistically significant and large. Furthermore, even though the tactile augmentation group approached more closely to the spider on the posttreatment Behavioral Avoidance Test, their anxiety during this test was significantly lower than participants in the ordinary VR group. Why this large advantage of tactile augmentation over ordinary VR on the objective measure of fear was not reflected on the subjective Fear of Spiders Questionnaire is unknown. Although desirable and often the case that subjective and objective measures of clinical success do converge, there are a number of studies in which one measure indicated improvement, whereas the other type of measure did not (e.g., Hellstrom & Ost, 1996).

Being able to physically touch the virtual spider during therapy heightened the degree of realism, the sense of presence, and the amount of anxiety experienced by the participants during treatment. This finding could help explain the higher effectiveness of VR plus tactile augmentation in this study because successful exposure therapy involves evoking (and habituating to) the fear response.

Only 8 participants in this study met (*DSM–IV*) criteria for specific phobia. However, the improvement achieved by these patients were similar to the rest of the sample and were so large that statistically significant treatment effects were observed even with such a small sample size. Because results from small samples should be interpreted with caution, it would be valuable to replicate this study with a larger clinical population. Garcia-Palacios et al. (2002) recently provided converging evidence for our conclusion that VR exposure therapy is effective in the treatment of spider phobia. Garcia-Palacios et al. (2002) compared a treatment condition versus a waiting list control condition in a between-group design with 23 clinical spider phobics. VR exposure with tactile augmentation was effective in treating spider phobia compared to a nontreatment control condition as measured with a Fear of Spiders Questionnaire (the full validated Fear of Spiders Questionnaire), a Behavioral Avoidance Test, and severity ratings made by the clinician and an independent assessor. None of the patients in the control group showed clinically significant improvement, whereas 83% of patients in the VR treatment group showed clinically significant improvement after an average of four 1-hr sessions. Recidivism rates have tended to be very low for both VR exposure (Rothbaum et al., 2002) and in vivo exposure treatments (Ost, 1996).

Future research might explore ways that tactile augmentation (or other means of introducing tactile feedback, such as the computer-controlled force feedback

Phantom[2]) can be used to increase the effectiveness of VR exposure therapy for other types of phobias. Although not referred to as such, Rothbaum et al. (1995) used tactile augmentation in their pioneering research showing that VR exposure therapy works for treating fear of heights. Patients in a virtual elevator held a mixed reality handrail. That research group is also using tactile augmentation to treat fear of flying. Participants in the Hodges, Rothbaum, Watson, Kessler, and Opdyke (1996) study sat in a real chair they could also see in VR. "Woofer" speakers under the flying phobic's mixed reality chair provided vibrations at takeoff in a virtual airplane. In a new study, Anderson, Hodges, and Rothbaum (as cited in Hodges, Anderson, Burdea, Hoffman, & Rothbaum, 2001) allowed patients to touch a real podium during immersive VR treatment for fear of public speaking. Prior to our study, the contribution of these tactile cues to the treatment success of VR exposure therapy has never been isolated. This study is the first controlled study to experimentally demonstrate that such mixed reality techniques are valuable for maximizing the effectiveness of VR exposure therapy. The results of this study suggest that tactile augmentation should be used in future clinical applications of VR when possible. For example, Botella et al. (1998) used VR exposure therapy to treat claustrophobia or fear of closed spaces. Among other things, their patients stood in a room, and the walls got closer and closer. If patients were allowed to physically lean against one of the walls, which remained stationary in the virtual world (using a real wall/tactile augmentation), patients would likely have inferred that the other walls were also solid and would likely have found the experience more realistic (Hoffman 1998a). Furthermore, patients getting tactile augmentation would likely have shown more effective/efficient progress on objective measures of clinical success, as in this study.

In this study, desensitization to the virtual spider generalized to real spiders. Tactile augmentation blurs the distinction between what is real and what is virtual. This likely helped increase transfer of training from the virtual world to the real world (Carlin et al., 1997; Hoffman, 1998a). Tactile augmentation appears to have promise as a technique for increasing the effectiveness of VR exposure therapy at little or no additional cost compared to ordinary VR. Results of this study provide converging evidence for a growing literature showing the value of adding physical qualities to virtual objects (Burdea, 1996; Burdea, Richard, & Coiffet, 1996). Tactile augmentation allows a more naturalistic means of interacting with computer graphics, broadening the bandwidth of information flow to include more senses.

Why use VR when in vivo exposure therapy is so effective? VR gives the patient and therapist the ability to control the feared object. VR allows patients to confront fears that are not easily accessible. For example, in vivo exposure of fear of flying can be an expensive project. Therapists have reported difficulty with numerous logistic problems and expenses, such as getting to the airport and renting a commercial jet for treating patients and having to buy airline tickets (e.g., Hodges et al., 1996). For fear of driving, many therapists are nervous to ride with driving phobics who may drive poorly. Confidentiality is another problematic issue for in vivo exposure sessions such as treating fear of heights in a hotel elevator where the public can see the patient getting treated. Another advantage of VR is the possibility of

[2]http://www.sensable.com

treating "residual fears" given the fact that VR can go beyond what a real situation would allow, making "overlearning" easier to perform (Botella et al., 1998). VR provides a controlled and protected environment that can make patients who were reluctant to start an exposure program more willing to get involved in treatment (Garcia-Palacios, Hoffman, Kwong See, Tsai, & Botella-Arbona, 2001). VR treatment is presently a relatively expensive treatment due to the additional equipment and software required, but the price of VR systems is dropping quickly and dramatically, largely because conventional desktop PC systems are becoming powerful enough to handle the computational demands of real-time VR (Botella et al., 1999).

Results of this study indicate that VR exposure could offer an attractive alternative for patients unwilling or unable to complete in vivo exposure therapy. VR exposure has potential as a new medium for an old, well-established technique (graded exposure therapy). A medium that makes exposure less aversive and more attractive to patients is likely to increase the proportion of phobia sufferers who seek treatment. The high success rate of VR therapy with tactile augmentation found in this study and its appeal to people with fear of spiders suggests that VR is a medium worthy of further exploration for clinical applications.

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