CyberPsychology & Behavior
Volume 12, Number 2, 2009

DOI: 10.1089/cpb.2008.0008

Cognitive Mechanisms Underlying Virtual Reality Exposure

Sophie Côté, Ph.D.[1] and Stéphane Bouchard, Ph.D.[1,2]

Abstract

Many studies have assessed virtual reality exposures efficacy, but very few examined its treatment processes. The addition of objective measures of arousal and information processing mechanisms would be a valuable contribution in order to provide a more complete and detailed picture. The goal of this study was to better document the cognitive mechanisms associated with therapeutic change after an in virtuo exposure treatment. Twenty-eight adults suffering from arachnophobia were assessed and received an exposure-based treatment using virtual reality. General outcome and specific processes measures included a battery of standardized questionnaires, a pictorial emotional Stroop task, a Behavioral Avoidance Test, and a measure of participants' cardiac response while they looked at a live tarantula. The analyses showed that changes in perceived self-efficacy and dysfunctional beliefs were the best predictors of change in general outcome and cardiac response; change in dysfunctional beliefs were the best predictor of change in behavioral avoidance. These innovative results provide a very detailed and organized picture of the complex cognitive mechanisms involved in therapeutic change following *in virtuo* exposure for arachnophobia.

Introduction

Understanding treatment mechanisms is an important endeavor. Many authors have attempted to identify and empirically support such mechanisms in the treatment of specific phobias. Three major explanations can be found in the literature: the information processing model, the perceived self-efficacy (PSE) model, and the cognitive/dysfunctional beliefs model. In the first model, information processing is considered a good predictor of the *fear* triggered by a phobic stimuli. The second model identifies PSE as the best predictor of one's *performance* on a Behavioral Avoidance Test (BAT). In the cognitive model, change in dysfunctional *beliefs* predicts therapeutic change in general. All three models can explain why virtual reality (VR) is effective in treating anxiety disorders, and they are contrasted in this work.

Information processing

Today, one of the most popular information processing models in the field of anxiety disorders, initially proposed by Lang,[1,2] is from Foa and colleagues.[3,4] Foa and Kozak[3] hypothesized that an individual's fearful experiences are stored in his or her memory in an organized fashion. This organized information, or *fear structure*, becomes pathological when its cognitions and associations are erroneous (therefore triggering maladapted emotions and behaviors).

In order to change a pathological fear structure, therapy must induce "emotional processing,"[3] which is a change in the way an individual perceives the feared object and its consequences. Exposure induces emotional processing by activating the fear structure (e.g., show a spider to a person suffering from a specific phobia of spiders) and by providing the person with experiences that disconfirm the erroneous associations (e.g., the spider does not behave aggressively). According to this model, clients who improve show a physiological activation and report fear during exposure, and their fear responses decrease over time. In other words, successful exposure causes information to be processed in a healthier way, which no longer triggers pathological fear.

Importantly, information processing is considered subconscious and very rapid, therefore automatic. When someone recognizes a stimulus and attributes a given significance to it, a response is automatically emitted. The modified Stroop task is a good example of this type of automatism. A variety of studies have demonstrated that cognitive-behavioral therapy can change that information processing bias.[5–7]

Given that it is possible to activate the fear structure with minimal corresponding input,[4] in virtuo exposure, although

[1]Department of Psychology, University of Ottawa, Ottawa, Ontario, Canada.
[2]Department of Psychoeducation and Psychology, University du Québec en Outaouais, Gatineau, Quebec, Canada.

not representing all aspects of feared stimuli, could nevertheless activate a phobic person's fear structures and offer a valid treatment option.

In order to test the predictive validity of the fear structure's indicators of emotional processing on treatment outcome, Kozak, Foa, and Steketee[8] treated 14 people suffering from obsessive-compulsive disorder with *in vivo* and in imago exposure and found that activation of fear (measured by self-report and cardiac and electrodermal responses) predicted successful outcome following treatment. Intersession habituation in heart rate and self-report scores also predicted successful outcome. Similar results were obtained by Schwartz and Kaloupek[9] with cardiac response.

Emotional processing is beginning to be tested with *in virtuo* exposure. Mühlberger et al.[10] reported significant fear activation and decreased physiological measures of fear (heart rate and skin conductance) in 15 flight phobics both within and across sessions. Similarly, Wiederhold et al.[11] reported significant fear activation and a subsequent trend toward nonphobic physiological response across treatment (skin resistance, heart rate, and skin temperature) with flight phobics. Finally, Wilhelm et al.[12] reported significantly more skin conductance levels in high-anxiety clients suffering from acrophobia when they were exposed to a fear-inducing VR environment. However, their heart rate and other physiological measures remained low, suggesting that some elements of the fear structure (the behavioral activation system) might have not been activated.

Perceived self-efficacy

According to Williams's empirical studies,[13] the intensity of fear shares only little correlation with the onset or disappearance of phobias. It is rather a part of the phobia itself, and not one of its cognitive mechanisms. According to the self-efficacy theory, phobic behaviors are largely derived from self-evaluative cognitive processes or low PSE. That concept is defined as a group of beliefs about one's capacity to control some behaviors and skills and one's own cognitive and emotional reactions.[14] For the tenets of this model, a decrease in fear and an increase in coping skills are not directly and causally linked; both result from an increase in PSE, which acts as a mediator. As Bandura[15] stated, change is mediated through cognitive processes, but it is induced and altered by experiences of mastery. According to this model, PSE strongly predicts phobic behaviors.

Many studies support the strong predictive value of PSE measures for phobic patients' behaviors. For example, Williams, Kinney, and Falbo[16] treated 27 people suffering from severe agoraphobia with a treatment based on performance (exposure). Their analyses showed that participants' PSE was a better predictor of behavior when factors such as previous behavior, anticipatory anxiety, perceived danger, and subjective anxiety were maintained constant. However, when these factors were analyzed as predictors of behavior while maintaining the self-efficacy factor constant, they lost most, if not all, of their predictive power. Other studies obtained similar results.[17] Indeed, Williams's review[13] reports 17 studies with diverse phobic conditions and various exposure treatments (vicarious, imaginal, or performance based). They show a strong correspondence between participants' level of PSE and their level of actual functioning (before and after treatment, correlations between self-efficacy and behavior range between 0.90 and 0.50, with a median of 0.75).

Beliefs

One concept in cognitive-behavioral therapy is that change in dysfunctional threat-related beliefs is key for therapeutic success.[18] In the belief model, therapeutic change is predicted by any improvement in beliefs. Here, PSE and beliefs about fear-provoking stimuli are merged into one concept: threat-related beliefs. Thorpe and Salkovskis[6] assigned 25 participants suffering from a fear of spiders to two treatment conditions: a one-session in vivo exposure treatment and a waiting list (those participants were treated after their waiting period). Results showed that the modification of threat-related beliefs (self-report) is strongly related to a change in the response to phobic stimuli. Indeed, a change in outcome measures was correlated with a change in beliefs (correlations ranged from 0.48 to 0.57). Therefore, change in beliefs is conceptualized here as an important component in treatment efficacy.

The above three models suggest three general hypotheses. First, general improvement (as measured by the Fear of Spiders Questionnaire) will be significantly predicted by changes in process variables such as PSE, beliefs, and the emotional Stroop task (first hypothesis). No prediction is made on the relative contribution of all three predicting variables. The second hypothesis is that improvements in behavioral avoidance (as measured with scores on the avoidance test) will be significantly predicted by changes in process variables such as PSE, beliefs, and the emotional Stroop task. Furthermore, based on data by Williams,[13] a subhypothesis stipulates that changes in PSE will better predict changes in avoidance behavior during the behavioral avoidance test than will changes on the emotional Stroop task or changes in beliefs. The third hypothesis is that improvement in the fear response (as measured by interbeat intervals in the cardiac response) will be significantly predicted by changes in process variables such as PSE, beliefs, and the emotional Stroop task. Based on Foa and Kozak's model,[3] a subhypothesis stipulates that changes in information processing (as measured by the emotional Stroop task) will better predict changes in the fear response than will PSE or changes in beliefs.

Methods

Sample

The sample consisted of 28 French-speaking participants diagnosed with arachnophobia (a ratio of almost 10 participants per predictor variable). It consisted mostly of women (27 of 28 participants). Participants were 21 to 53 years old (mean of 34, $SD = 10.3$). They were the same as in a previous study by Côté and Bouchard.[19] They had to be adults (18 years or older) and had to suffer from a principal diagnostic of arachnophobia according to DSM-IV-TR criteria in order to participate. People suffering from a comorbid disorder (e.g., major depression, psychotic disorders, nonphobic anxiety disorders) that required immediate treatment, people suffering from a psychotic disorder or from substance abuse, and people taking anxiolytic medication (e.g., benzo-

diazepines) were excluded and redirected toward more adequate services. Accordingly, two participants were excluded from the study because they suffered from important comorbid disorders that required treatment.

Procedure

Assessment and treatment were done by a graduate student (S.C.) who had a previous training in cognitive-behavioral therapy and in virtual therapy. Before treatment (session 1), participants went through a semistructured evaluation to confirm the presence of arachnophobia and the absence of comorbid disorders. At pretest and posttest (sessions 1 and 7), they were administered outcome measures (questionnaires), they performed a behavioral avoidance test while their cardiac response was monitored, and they did an emotional pictorial Stroop task. During the second session, the rationale for the treatment of specific phobias was explained to participants. They were also familiarized with the VR equipment and could practice the required navigation skills in a neutral virtual environment with no spider-related stimuli. During sessions 3 to 7, participants gradually exposed themselves to spiders in the virtual environments (*in virtuo* exposure). During the last session (7), the therapist discussed relapse prevention and self-directed *in vivo* exposure at home. For a discussion about the advantages and inconveniences of using *in virtuo* exposure compared to *in vivo*, see Bouchard, Côté, and Richard.[20]

Instruments

The first task was to administer the Structured Clinical Interview for DSM-IV[21] to make sure the inclusion and exclusion criteria were respected. In the cyberpsychology lab, the kappa for specific phobias is at 0.90 between two interviewers and, in addition, all diagnoses were based on a clinical consensus between the two authors: the therapist and an independent clinician.

Outcome measures. At pretreatment and posttreatment, participants completed various self-reports. Most of them were translated in French and validated prior to the study. The Fear of Spiders Questionnaire (FSQ)[22] measures the severity of the fear of spiders and of the avoidance behaviors on a Likert scale. Its test–retest reliability (calculated over 1 month) ranged between 0.63 and 0.97.[22] Its internal consistency is 0.92, as calculated with Cronbach's alpha. For the BAT, a live tarantula (*Grammostola rosea*, 14 cm long) was put in a closed transparent box on a motorized platform placed on a table 173 cm away from the participant and completely hidden under a cardboard box. Performance on the BAT was assessed on a 0 to 10 scale by scoring the last step participants could complete when asked to go through as many steps as they could (until their anxiety became too strong). The 10 steps were described in Côté and Bouchard.[19] The instructions describing these steps were given to participants before they began the BAT. The participants' cardiac response was assessed during the pretreatment and posttreatment BATs. Heart rate was measured with three electrodes placed on the participants' forearms (see Côté and Bouchard[19] for a description of the equipment and procedure). Baseline physiological data was recorded before the participant started the BAT, and the fear response was measured when he or she began the BAT (e.g., looking at the live tarantula for 1 minute when it was 173 cm away from the participant). To control for daily and between-participants variations (law of initial values), an autonomic lability score was calculated using Lacey and Lacey's formula,[23] according to which the fear response was adjusted for the baseline data.

Information processing. To document the difference in information processing between pretest and posttest, participants were subjected to a nonlexical emotional Stroop task. Participants were presented a pad with four colored buttons. They were told they would see a series of color-filtered pictures and that their task was to push the button of the corresponding color as quickly as possible (see Côté and Bouchard[19] for equipment and procedure).

Self-efficacy. The Perceived Self-Efficacy towards Spiders Questionnaire[19] was designed for this study. It consists of 14 items rated on a scale of 0 to 100 about participants' PSE in confronting various situations in which a spider could be present (e.g., going in a basement that is not renovated) or their PSE in undertaking certain actions involving a spider and/or staying in control while doing so (e.g., picking up a live spider in a sealed jar with one's hands). The questionnaire has an internal consistency of 0.92, as calculated with Cronbach's alpha. The corrected item-total correlations are between 0.60 and 0.80.The questionnaire has good convergent validity, showing a -0.82 correlation with the FSQ and a -0.77 correlation with the Spider Beliefs Questionnaire (SBQ-B) (both $p < 0.01$).

Beliefs. The SBQ-B[24] is divided in two subscales, but only *Beliefs towards spiders* was used for this study's statistical analyses. It has a Cronbach's alpha of 0.94 for both subscales and a 2-month test–retest reliability of 0.68 ($p < 0.001$) for the *Beliefs towards spiders* subscale.[24]

Treatment

Equipment. The VR environments were displayed using a computer working with Windows 2000 (Pentium III, 4.2 GHz, 1 GB of RAM, with an nVidia GeForce4 Ti 4200, 128 MB), an Intertrax2 motion tracker from Intersense (USB model, 3dof, update rate 256 Hz), an I-Glass SVGA head-mounted display by IO-Display (800×600, 26° FoV diagonal), and a Gyration wireless mouse. The VR environments were created using a 3D game editor (see www.uqo.ca/cyberpsy for demos).

The VR environments were two apartments, each having many rooms, and presented three levels of difficulty. The first level consisted of some framed pictures of spiders on the walls and a few live spiders, which were small and generally stood still. In the second level, spider sizes ranged from 15 virtual centimeters to 2 virtual feet. Spiders made more unexpected moves, but generally away from or around the participant. In the third level, spiders came in all sizes and were numerous, generally moving toward the participant, some in an aggressive manner (e.g., moved quickly toward the participant's feet when the participant entered a room). In levels two and three, participants could pick up a magazine and kill the spiders by hitting them.

Table 1. Means, Standard Deviations, and Repeated Measures ANOVA Results on the Outcome and Treatment Mechanism Measures ($N = 28$)

Outcome measures	*Pretreatment*	*Posttreatment*	*F(1, 27)*
Fear of Spiders Questionnaire ($N = 27$)	99.71 (22.11)	48.86 (15.16)	67.39**
Behavioral Avoidance Test	4.25 (3.25)	8.39 (2.24)	66.4**
Interbeat interval corrected for the law of initial values	−935.96 (2523.51)	1286.87 (1456.41)	16.94*
Treatment mechanism measures	*Pretreatment*	*Posttreatment*	*F(1, 27)*
Spider Beliefs Questionnaire–Beliefs	99.07 (26.07)	62.93 (12.47)	55.54***
Self-Efficacy Questionnaire	34.16 (20.11)	72.13 (16.71)	70.8**
Emotional Stroop task	883.84 (324.77)	760.15 (177.59)	4.76*

Note: For the Fear of Spiders Questionnaire, one participant was removed from the analyses; $F(1, 26)$.
Erratum: The results for the Spider Beliefs Questionnaire–Beliefs differ slightly (at the decimal level) from those reported in Côte and Bouchard.[19] The latter were erroneous due to minor data-entering mistakes.
*$p < 0.05$; **$p < 0.001$; ***$p < 0.0001$.

Exposure. Therapy itself was conducted in French and made up of five standardized, individual, weekly 1-hour sessions. Using a predetermined hierarchy, participants gradually approached virtual spiders until their anxiety decreased. A 5-minute pause was given in the middle of each session to reduce the risks of cybersickness. Participants were asked to act as normally as possible at home in order to prevent intentional in vivo exposure between sessions, which would have tainted the results. However, they were not told to actively avoid spiders at home. During the exposure sessions, a subjective measure was administered verbally by the therapist to measure anxiety. Every 5 minutes, she asked participants to rate their anxiety on a scale of 0 to 100 and recorded their answers in order to monitor fear during exposure. Its sole purpose was to adjust exposure within the preestablished hierarchy.

Statistical analyses

Although it is tempting to study change by creating change scores (e.g., using posttreatment scores minus pretreatment scores), this approach is notoriously flawed. As suggested in basic textbooks on regressions, this study's statistical approach involved residualized change scores (also called regression-adjusted scores or partialling out results from pretreatment to those of posttreatment) in order to document change in the predicted variables. According to Cohen and Cohen,[25(p 427)] residualized change scores, which have the advantage of being uncorrelated with the pretreatment scores, are obtained by including the pretreatment scores among the set of predictors of the posttreatment scores. Age and pretreatment scores from both the predictor and predicted variables were thus entered first as a set in the hierarchical regressions, followed by the posttreatment scores of the predictors entered as a second set, in order to predict posttreatment scores of the predicted variable.

Analyses were performed to confirm that hierarchical regression assumptions were met. A close examination of the raw data revealed that all variables were normally distributed. No problem of multicollinearity was found, as analyses revealed that all tolerance indices were above 0.10 and all variance inflation factor (VIF) indices were below 10. The linearity, normality, and homoscedasticity of the residuals were confirmed with the scatterplots of the residuals. Standardized residuals indices did not exceed 1.96, and both Mahalanobis distance (for leverage) and Cook's distance (for influence) indices were adequate and less than 1.

Unfortunately, technical problems with the CardioPro software made analyses impossible on one participant. Analyses using the cardiac response data were therefore per-

Table 2. Hierarchical Regression Analyses for Predicting Residualized Change Scores on the Fear of Spiders Questionnaire ($N = 27$)

Set 2: pretreatment scores					
	B	*SE B*	*β*	*t*	sr^2
FSQ	0.02	0.20	0.03	0.12	0.02
SBQ-B	−0.17	0.12	−0.32	−1.44	−0.20
PSE	−0.02	0.13	−0.03	−0.17	−0.02
Stroop	−0.00	0.01	−0.03	−0.17	−0.02
Age	−0.27	0.26	−0.21	−1.05	−0.14
Set 2: posttreatment scores (residualized change scores)					
	B	*SE B*	*β*	*t*	sr^2
SBQ-B	0.31	0.19	0.28	1.65	0.23
PSE	−0.51	0.15	−0.59	−3.50*	−0.48
Stroop	0.01	0.01	0.16	0.95	0.13

FSQ, Fear of Spiders Questionnaire; SBQ-B, Spider Beliefs Questionnaire–Beliefs scale; PSE, Perceived Self-Efficacy towards Spiders Questionnaire; Stroop, Emotional Stroop task, threat bias.
*$p < 0.01$.

Table 3. Hierarchical Regression Analyses for Predicting Residualized Change Scores on the Behavioral Avoidance Test ($N = 28$)

Set 2: pretreatment scores					
	B	*SE B*	*β*	*t*	*sr²*
BAT	0.31	0.19	0.44	1.65	0.22
SBQ-B	0.01	0.02	0.12	0.69	0.09
PSE	0.03	0.03	0.29	1.20	0.16
Stroop	0.00	0.00	0.18	1.02	0.13
Age	0.01	0.05	0.04	0.20	0.03
Set 2: posttreatment scores (residualized change scores)					
	B	*SE B*	*β*	*t*	*sr²*
SBQ-B	−0.07	0.03	−0.38	−2.30*	−0.30
PSE	0.04	0.02	0.26	1.52	0.20
Stroop	0.00	0.00	−0.04	−0.22	−0.03

BAT, Behavioral Avoidance Test; SBQ-B, Spider Beliefs Questionnaire–Beliefs scale; PSE, Perceived Self-Efficacy towards Spiders Questionnaire; Stroop, Emotional Stroop task, threat bias.
*$p < 0.05$.

formed on 27 participants. One outlier participant had to be removed from some analyses on the basis of her unexpectedly low score on the FSQ (she answered 0 on all items). Her score was incongruent with her very high scores on all other arachnophobia measures, suggesting that she had misinterpreted the response scale.

Results

Sample description

Internal consistency analyses were made on the self-report outcome measures used in this study. Participants' scores generated Cronbach's alpha of 0.89 on the FSQ, of 95 on the Beliefs scale of the SBQ-B, and of 0.87 on the Perceived Self-Efficacy towards Spiders Questionnaire. All results show that the outcome measures were reliable.

All changes on outcome measures between pretest and posttest on the emotional Stroop task (threat interference) and on the cardiac response (corrected with the law of initial values) were significant, as shown in Table 1. These results are presented and discussed in more detail in a related paper.[19]

First hypothesis: General improvement will be significantly predicted by changes in process variables. This hypothesis was tested with a hierarchical multiple regression with age and pretreatment scores being included in a first block or set of variables and posttreatment scores being included in the second block or set of variables (i.e., the residualized change scores), all predicting posttreatment scores on the FSQ. Predictor (process) variables were PSE, information processing (Stroop), and the Beliefs scale of the SBQ-B.

The inclusion of the second set of variables (posttreatment scores) in the regression analysis produced a significant increase in explained variance, R^2 change = 0.48, $F(3, 18) = 8.52$, $p < 0.001$, leading to a significant final regression model explaining 66% of variance (adjusted $R^2 = 0.52$). Results on the relative contribution of each predictor used in this model are presented in Table 2, which shows that changes in self-efficacy (residualized change score) were the strongest predictor of general improvement; all other predictors were nonsignificant.

Second hypothesis: Improvement in behavioral avoidance will be significantly predicted by changes in process variables. To test this hypothesis, the same procedure was followed for the performance on the BAT. When introducing the second set of variables (posttreatment scores) in the regression analysis, the model explained a significant increase in variance, R^2 change = 0.28, $F(3, 19) = 5.35$, $p < 0.01$, with the final regression model explaining 67% of variance (adjusted $R^2 = 0.53$). As can be seen from Table 3, changes in dysfunctional beliefs (residualized change score) were the only significant predictor of increased performance on the BAT.

Given the lack of predicting power of changes in self-efficacy on improvement on the BAT, further multiple linear regressions were conducted independently on pretreatment and posttreatment scores (see Table 4). Pretreatment scores of PSE were the only significant predictor of pretreatment performance on the BAT, while no significant predictor was found for the posttreatment performance on the BAT.

Third hypothesis: Improvement in the fear response will be significantly predicted by changes in process variables. This hypothesis was tested with the same hierarchical procedure as the other two. The introduction of the posttreatment scores in the regression led to a significant increase in variance, R^2 change = 0.36, $F(3, 18) = 4.16$, $p < 0.02$. The final regression model explained 48% of the variance (adjusted $R^2 = 0.24$). As can be seen from Table 5, change in dysfunctional beliefs (residualized change score), change in PSE (residualized change score), and age were significant predictors of change in cardiac response, as calculated with interbeat intervals. Further hierarchical regressions testing the impact of self-efficacy and beliefs' respective order of entry

Table 4. Two Hierarchical Regression Analyses Predicting Scores on the Behavioral Avoidance Test at Posttreatment from Information Processing, Perceived Self-Efficacy, and Beliefs at Pre- and Posttreatment Separately ($N = 28$)

Variables	*t*	*B*	*sr²*
SBQ-Beliefs (pretreatment)	−1.17	−0.15	−0.13
PSE (pretreatment)	4.39*	0.62	0.49
Stroop (pretreatment)	−0.29	0.04	0.03
Age	−1.51	−0.24	−0.17
SBQ-Beliefs (posttreatment)	−1.57	−0.29	−0.25
PSE (posttreatment)	1.85	0.36	0.30
Stroop (posttreatment)	−0.07	−0.01	−0.01
Age	−1.18	−0.22	−0.19

SBQ-B, Spider Beliefs Questionnaire–Beliefs scale; PSE, Perceived Self-Efficacy towards Spiders Questionnaire; Stroop, Emotional Stroop task, threat bias.
*$p < 0.0001$.

Table 5. Hierarchical Regression Analyses for Predicting Residualized Changes Scores on the Cardiac Response ($N = 27$)

Set 2: pretreatment scores					
	B	*SE B*	β	*t*	sr^2
IBI	−0.16	0.11	−0.27	−1.37	−0.23
SBQ-B	−07.71	12.09	−0.14	−0.64	−0.11
PSE	20.39	16.17	0.27	1.26	0.22
Stroop	−02.10	1.10	−0.47	−1.91	−0.33
Age	89.26	39.27	0.64	2.27*	0.39
Set 2: posttreatment scores (residualized change scores)					
	B	*SE B*	β	*t*	sr^2
SBQ-B	51.85	24.23	0.45	2.14*	0.37
PSE	44.76	19.39	0.52	2.31*	0.39
Stroop	2.83	1.71	0.34	1.66	0.28

IBI, Interbeat intervals (corrected with law of initial values); SBQ-B, Spider Beliefs Questionnaire–Beliefs scale; PSE, Perceived Self-Efficacy towards Spiders Questionnaire; Stroop, Emotional Stroop task, threat bias.
*$p < 0.05$.

in the model were attempted, but each predictor was found to add, independently, a significant amount of variance to the regression model. Therefore, no predictor was found to have a significantly greater predictive power than the others.

Discussion

The aim of this study was to examine the treatment mechanisms involved during *in virtuo* exposure. Since Côté and Bouchard[19] had already confirmed significant pretreatment to posttreatment changes on all outcome and process measures, the analyses in this paper focused exclusively on *predictors* of change. Also, given that the outcome measures in this study did not rely on the clinical interview but on questionnaires and objective measures, controlling for experimenter's bias with an independent blind assessment was deemed unnecessary. Three of the proposed five hypotheses were confirmed; it was possible to predict a significant and large amount of variance in general outcome, behavioral avoidance, and cardiac response. Regression analyses revealed that increase in PSE was a significant predictor of improvement in general outcome. The only significant predictor for a better performance on the BAT was change in dysfunctional beliefs toward spiders. In this regard, our first subhypothesis (changes in PSE will better predict changes in avoidance behavior during the BAT than will changes on the emotional Stroop task or changes in beliefs) was not supported. PSE significantly predicted the performance on the BAT at pretreatment, but change in PSE did not predict change in behavioral performance on the BAT. Finally, change in PSE and change in beliefs were found to be significant predictors for change in the cardiac response, which supports our third hypothesis. However, change in information processing was not found to be the best predictor of improvement on the cardiac response when participants were confronted with a live tarantula. Therefore, our second subhypothesis (changes in information processing will better predict changes in the fear response than will PSE or changes in beliefs) was not supported.

It is very important to note, however, that those results nuance rather than discredit the theoretical models presented in the introduction. They illustrate how these models apply to *different* elements of the cognitive mechanisms of change. Indeed, the need for a multifaceted explanation of therapeutic change for fear reduction was already expressed by Rachman.[26] He proposed that the need for more than one process in the explanation of fear reduction derives from the variations in fear acquisition and the nature of fear itself. The subjective, physiological, and behavioral components of fear are loosely coupled, can change desynchronously, and may be differentially susceptible to different elements of the therapy.[26]

Perceived self-efficacy versus beliefs

This study's results can be explained in many ways, and they illustrate the importance of looking at therapeutic outcome in more detail. Indeed, depending on the outcome variables, the predictive power of PSE and beliefs are different. In this study, changes in beliefs were found to be a better predictor of change in performance on the BAT over the course of therapy. However, initial PSE was found to be a better predictor of the actual performance on the BAT at pretreatment. Therefore, high PSE was associated with a better performance on the BAT at pretreatment, which is congruent with Bandura's model[14] and Williams's model.[13] However, therapeutic change was better explained by change of irrational beliefs about spiders.

Accordingly, an integrated conceptualization would state that PSE is influenced collaterally by a change in beliefs. Whether the latter acts as a mediator or a moderator variable would need to be defined in a study using a much larger sample (e.g., 300 or 400 participants). Nevertheless, that distinction is interesting because it would have an impact on the main goal of treatment. If change in beliefs is required as a first step to foster change in PSE, participants would get better because spiders are less threatening to them; in turn, they would perceive themselves as more able to face them. Consequently, focusing therapy on self-efficacy without challenging beliefs may bypass an important element of the pathology, which in turn may even influence the likelihood of relapse.

The current study clearly showed that PSE and beliefs each played important and distinct roles during in virtuo exposure. Interestingly, Wiederhold, Gervirtz and Spira[27] found that adding physiological feedback during treatment to 30 participants suffering from a fear of flying increased their likelihood to complete the BAT after treatment. Eighty percent of participants in the condition without physiological feedback completed the BAT, but the completion rate reached 100% when feedback was added during exposure. The authors also observed a superior within-session fear decrease, as reported by participants during the first half of exposure with feedback. This group also showed a superior between-sessions habituation. These results are also consistent with those of *in vivo* exposure and claustrophobia[28] and highlight the importance of self-efficacy.

Behavior versus fear

According to the results of this study, relying on behavioral performance as a sole indicator of treatment success might be misleading. Indeed, clients could display a functional behavior in the presence of spiders but still perceive them as a threat.

What should be the therapeutic goals in exposure treatments for arachnophobia? Should they teach functional behaviors and foster feelings of competence and control? Or should treatment also focus on decreasing actual fear and irrational beliefs about spiders (which would directly target diagnostic criterion A and B of specific phobia) even after a higher level of functioning has been achieved? Which goal is sufficient for lasting therapeutic improvement? Which is necessary? These questions remain to be explored in further studies, along with their possible impact on relapse. As previously mentioned, avoidance behavior and fear are two distinct variables that should not be conceptualized as equivalent when evaluating phobia symptoms or therapeutic improvement.

Fear structure

Although there was a significant decrease in behavioral avoidance for participants, and 61% of them completed the last two steps of the BAT, many were unable to go through the whole task after treatment. Since a tarantula was used rather than a more common spider, it might have been too intense and too different from everyday situations to provide a fair estimate of their improvement (even though other studies used a live tarantula as an *in vivo* fear-provoking stimuli).[29,30] It may also be that some elements of the fear reaction remained untreated because of the virtual nature of the treatment. For example, the *in virtuo* treatment did not have a tactile dimension, and only 3-dof tracking devices were used (i.e., moving toward or away from the spider does not involve actual physical motion). It can be hypothesized that many but not all elements of the participants' fear structure were activated during therapy (e.g., touching or killing a spider). Therefore, some pathological elements might have been left untouched by therapy and explain the lack of correlation with the predictors. It might also explain the information processing data's failure to predict change in cardiac response.

It is also possible that the posttest assessment was conducted so early after treatment that emotional processing was not complete or that generalization had not deployed to its full extent. Changes in PSE and in beliefs might happen sooner during treatment compared to changes in the fear structure. Indeed, it was clinically observed that most patients felt more competent during the very first exposure session. They also reported a *faster reduction* in fear when facing a spider, followed later in therapy by a *smaller reaction* when facing the same stimuli.

Interesting nuances on the emotional processing original model were brought forth by Bouton[31] and by Bouton and Swartzentruber.[32] These authors suggest that a decrease in fear does not necessarily imply the weakening of the pathological associations (in the fear structure) but involves instead the apparition of new associations. According to the authors, treatment creates new associations, then inhibits the access to the previous pathological associations and facilitates access to nonpathological fear structures. This transition is not well understood but implies that previous and new fear structures could act in a somewhat rivaling manner for a while. This conceptualization of the emotional processing model may also explain why, when in a stressful or fatigued state, previously phobic people could be the victims of old automatisms. Instead of using the new fear structure, they would rely on the previous pathological fear structures (which might also lead to relapse).

This may also support the observations that were made in this study about the variations of subjective anxiety reports during treatment. Although participants had developed more adaptive fear structures (as confirmed by all outcome and treatment mechanism measures), their previous fear structures might still have been activated when they were confronted with a tarantula early after treatment. This activation was lower at posttreatment (as demonstrated on the emotional Stroop task) but was still present enough, in some cases, to impair the full completion of the avoidance task. In the same way, it could very well illustrate how, due to an asynchrony between the different components of anxiety,[33] changes in some elements in the fear structure were not varying in harmony with each other in the current study. Unfortunately, this model, although representing a strong theoretical interest, is difficult to test clinically. Indeed, no study has yet attempted to compare the two emotional processing theories with clinical cases.

Strengths and limitations

On an interesting note for further outcome studies, it is important to remember that correlations between questionnaires, BAT, heart rate, and information processing indices were low.[19] These results underline the importance of measuring anxiety on a number of levels instead of relying on questionnaires solely. This recommendation highlights the phenomena of asynchrony between different components of anxiety[33–35] and the importance of assessing more than subjective responses. Therefore, the use of objective and subjective measures in this study is a methodological strength; the greater variety of gathered information allowed the study of a more complete array of cognitive mechanisms.

Although cardiac response is a good indicator for anxiety, the use of more than one physiological measure, such as skin conductance, blood pressure, and respiratory rates, would have been interesting and might have painted a more complete picture. Unfortunately, respiratory data recorded during this study could not be analyzed due to software limitations.

Furthermore, the design of this study did not isolate the specific mechanisms of in virtuo exposure from those related to general exposure or to other therapeutic ingredients. To achieve this level of precision, a minimum of three experimental conditions would be required: a waiting list, an *in vivo* group and an *in virtuo* group. Although quite interesting, such a study would require a very large sample size. Finally, it would be interesting to look at other variables that may play a role in treatment mechanisms, such as therapeutic alliance or clients' characteristics at pretreatment. For example, the predictive value of initial cardiac response during the BAT before treatment has been demonstrated on treatment outcome by Lang et al.[36]

Conclusion

Because VR is a new research area, many elements are still missing in our understanding of its treatment mechanisms. There is need for a reference model explaining how in virtuo exposure acts on phobia symptoms. Until now, no such model has been tested about this form of treatment; research has mostly focused on efficacy demonstrations or on VR's side effects. Nevertheless, according to this study's results, when clinicians use in virtuo exposure, they should bear in mind that increasing self-efficacy and challenging dysfunctional beliefs are essential, even if the stimuli are virtual in nature.

Acknowledgments

This study was the doctoral thesis of Sophie Côté, Ph.D. Stéphane Bouchard, Ph.D., second author, acted as her thesis advisor. This study was funded by research grants from the Canada Research Chairs program and the Canada Foundation for Innovation. Support was also provided by the Fondation du Centre Hospitalier Pierre-Janet and the Université du Québec en Outaouais. The study was conducted at the Laboratoire de Cyberpsychologie de l'UQO (www.uqo.ca/cyberpsy) where the first author was completing her Ph.D. Special thanks to Geneviève Robillard, M.Sc., research coordinator at the Laboratoire de Cyberpsychologie de l'UQO, for her invaluable help during all the stages of this study, and to ThoughtTechnology for providing a computer patch to extract IBI data from CardioPro.

Disclosure Statement

The authors have no conflict of interest.

References

1. Lang PJ. Imagery in therapy: an information processing analysis of fear. Behavior Therapy 1977; 8:862–86.
2. Lang PJ. A bio-informational theory of emotional imagery. Psychophysiology 1979; 16:495–512.
3. Foa EB, Kozak MJ. Emotional processing of fear: exposure to corrective information. Psychological Bulletin 1986; 99:20–35.
4. Foa EB, McNally RJ. (1996) Mechanisms of change in exposure therapy. In Rapee RM, ed. *Current controversies in the anxiety disorders*. New York: Guilford Press, pp. 329–43.
5. Lavy E, van den Hout M. Selective attention evidenced by pictorial and linguistic Stroop tasks. Behavior Therapy 1993; 24:645–57.
6. Thorpe SJ, Salkovskis PM. The effect of one-session treatment for spider phobia on attentional bias and beliefs. British Journal of Clinical Psychology 1997; 36:225–41.
7. Watts FN, McKenna FP, Sharrock R, et al. Colour naming of phobia-related words. British Journal of Psychology 1986; 77:97–108.
8. Kozak MJ, Foa EB, Steketee G. Process and outcome of exposure treatment with obsessive-compulsives: psychophysiological indicators of emotional processing. Behavior Therapy 1988; 19:157–69.
9. Schwartz S G, Kaloupek DG. Acute exercise combined with imaginal exposure as a technique for anxiety reduction. Canadian Journal of Behavioural Science 1987; 19:151–66.
10. Mühlberger A, Herrmann MJ, Wiedemann G, et al. Repeated exposure of flight phobics to flights in virtual reality. Behaviour Research & Therapy 2001; 39:1033–50.
11. Wiederhold BK, Jang DP, Kim SI. Physiological monitoring as an objective tool in virtual reality therapy. CyberPsychology & Behavior 2002; 5:77–82.
12. Wilhelm FH, Pfaltz MC, Gross JJ, et al. Mechanisms of virtual reality exposure therapy: the role of the behavioral activation and behavioral inhibition systems. Applied Psychophysiology & Biofeedback 2005; 30:271–84.
13. Williams SL. (1996) Therapeutic changes in phobic behavior are mediated by changes in perceived self-efficacy. In Rapee RM, ed. *Current controversies in the anxiety disorders*. New York: Guilford Press, pp. 344–68.
14. Bandura A. (1997) *Self-efficacy: the exercise of control*. New York: W.H. Freeman.
15. Bandura A. (1977) *Social learning theory*. New York: Prentice Hall.
16. Williams SL, Kinney PJ, Falbo J. Generalization of therapeutic changes in agoraphobia: the role of perceived self-efficacy. Journal of Consulting & Clinical Psychology 1989; 57:436–42.
17. Williams SL, Turner SM, Peer DF. Guided mastery and performance desensitization treatments for severe acrophobia. Journal of Consulting & Clinical Psychology 1985; 53:237–47.
18. Beck AT. Cognitive therapy: a sign of retrogression or progress. Behavior Therapist 1986; 9:2–3.
19. Côté S, Bouchard S. Documenting the efficacy of virtual reality exposure with psychophysiological and information processing measures. Applied Psychophysiology & Biofeedback 2005; 30:217–32.
20. Bouchard S, Côté S, Richard DCS. (2007) Virtual reality applications. In Richard DCS, Lauterbach D, Hoodin F, eds. *Comprehensive handbook of the exposure therapies*. New York: Elsevier.
21. First MB, Spitzer R, Gibbon M, et al. (1996) *Structured clinical interview for DSM-IV axis-I disorders—Patient version*. New York: Biometrics Research Department, New York State Psychiatric Institute.
22. Szymanski J, O'Donoghue W. Fear of Spiders Questionnaire. Journal of Behaviour Therapy & Experimental Psychiatry 1995; 26:31–4.
23. Lacey J, Lacey B. The law of initial value and the longitudinal study of autonomic constitution. Annals of the New York Academy of Science 1962; 98:1257–90.
24. Arntz A, Lavy E, van der Berg G, et al. Negative beliefs of spider phobics: a psychometric evaluation of the Spider Phobia Beliefs Questionnaire. Advances in Behaviour Research & Therapy 1993; 15:257–77.
25. Cohen J, Cohen P. (1983) *Applied multiple regression/correlation analysis for the behavioral sciences*, 2nd ed. Hillsdale, NJ: Erlbaum.
26. Rachman SJ. (1990) *Fear and courage*, 2nd ed. New York: W.H. Freeman.
27. Wiederhold BK, Gevirtz R, Spira JL. (2001) Virtual reality exposure therapy vs. imagery desensitization therapy in the treatment of flying phobia. In Riva G, Galimberti C, eds. *Towards cyberpsychology: mind, cognition and society in the Internet age*. Amsterdam: IOS Press, pp. 253–72.
28. Telch MJ, Valentiner DP, Ilai D, et al. The facilitative effect of heart-rate feedback in the emotional processing of claustrophobic fear. Behaviour Research and Therapy 2000; 38:373–87.
29. Garcia-Palacios A, Hoffman H, Carlin A, et al. Virtual reality in the treatment of spider phobia: a controlled study. Behaviour Research & Therapy 2002; 40:983–93.
30. Hoffman HG, Garcia-Palacios A, Carlin A, et al. Interfaces that heal: coupling real and virtual objects to treat spider

phobia. International Journal of Human-Computer Interaction 2003; 16:283–300.
31. Bouton M E. Context and ambiguity in the extinction of emotional learning: implications for exposure therapy. Behaviour Research & Therapy 1988; 26:137–49.
32. Bouton ME, Swartzentruber D. Sources of relapse after extinction in Pavlovian and instrumental learning. Clinical Psychology Review 1991; 11:123–40.
33. Rachman SJ. (1990) *Fear and courage*, 2nd ed. New York: W.H. Freeman.
34. Lang PJ. (1968) Fear reduction and fear behavior: problems in treating a construct. In Shlien JM, ed. *Research in psychotherapy*, vol. 3. Washington DC: American Psychological Association.
35. Marks IM. (1984) *Fears, phobias and rituals*. Oxford: Oxford University Press.
36. Lang PJ, Melamed BG, Hart J. A psychophysiological analysis of fear modification using an automated desensitization procedure. Journal of Abnormal Psychology 1970; 76: 220–34.

Address reprint requests to:
Dr. Stéphane Bouchard
Department of Psychoeducation and Psychology
University du Québec en Outaouais
PO Box 1250
Station Hull, Gatineau, QC, J8X 3X7
Canada

E-mail: stephane.bouchard@uqo.ca