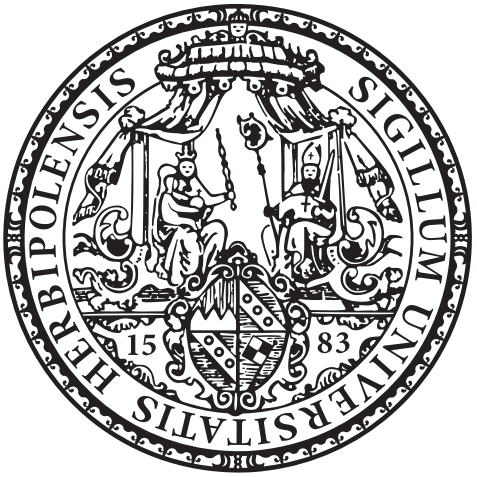

Mechanisms Underlying Virtual Reality Exposure Therapy for Specific Phobias

Wirkmechanismen der Expositionstherapie in virtueller Realität bei spezifischen Phobien

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“Virtual reality seems so real, because reality is so virtual.”

— Richard Gregory

Abstract

Virtual reality exposure therapy (VRET) is an effective cognitive-behavioral treatment for anxiety disorders that comprises systematic confrontations to virtual representations of feared stimuli and situations. However, not all patients respond to VRET, and some patients relapse after successful treatment. One explanation for this limitation of VRET is that its underlying mechanisms are not yet fully understood, leaving room for further improvement. On these grounds, the present thesis aimed to investigate two major research questions: first, it explored how virtual stimuli induce fear responses in height-fearful participants, and second, it tested if VRET outcome could be improved by incorporating techniques derived from two different theories of exposure therapy. To this end, five studies in virtual reality (VR) were conducted.

Study 1 ($N = 99$) established a virtual environment for height exposure using a Computer Automatic Virtual Environment (CAVE) and investigated the effects of tactile wind simulation in VR. Height-fearful and non-fearful participants climbed a virtual outlook, and half of the participants received wind simulation. Results revealed that height-fearful participants showed stronger fear responses, on both a subjective and behavioral level, and that wind simulation increased subjective fear. However, adding tactile wind simulation in VR did not affect presence, the user's sense of 'being there' in the virtual environment. Replicating previous studies, fear and presence in VR were correlated, and the correlation was higher in height-fearful compared to non-fearful participants.

Study 2 ($N = 43$) sought to corroborate the findings of the first study, using a different VR system for exposure (a head-mounted display) and measuring physiological fear responses. In addition, the effects of a visual cognitive distractor on fear in VR were investigated. Participants' fear responses were evident on both a subjective and physiological level—although much more pronounced on skin conductance than on heart rate—but the virtual distractor did not affect the strength of fear responses.

In Study 3 ($N = 50$), the effects of trait height-fearfulness and height level on fear responses were investigated in more detail. Self-rated level of acrophobia and five different height levels in VR (1 m–20 m) were used as linear predictors of subjective and physiological indices of fear. Results showed that subjective fear and skin conductance responses were a function of both trait height-fearfulness and height level, whereas no clear effects were visible for heart rate.

Study 4 ($N = 64 + N = 49$) aimed to advance the understanding of the relationship between presence and fear in VR. Previous research indicates a positive correlation between both measures, but possible causal mechanisms have not yet been identified. The study was the first to experimentally manipulate both presence (via the visual and auditive realism of the virtual environment) and fear (by presenting both height and control situations). Results indicated a causal effect of fear on presence, i.e., experiencing fear in a virtual environment led to a

stronger sense of 'being there' in the virtual environment. However, conversely, presence increased by higher scene realism did not affect fear responses. Nonetheless, presence seemed to have some effects on fear responding via another pathway, as participants whose presence levels were highest in the first safe context were also those who had the strongest fear responses in a later height situation. This finding indicated the importance of immersive user characteristics in the emergence of presence and fear in VR.

The findings of the first four studies were integrated into a model of fear in VR, extending previous models and highlighting factors that lead to the emergence of both fear and presence in VR. Results of the studies showed that fear responses towards virtual heights were affected by trait height-fearfulness, phobic elements in the virtual environment, and, at least to some degree, on presence. Presence, on the other hand, was affected by experiencing fear in VR, immersion—the characteristics of the VR system—and immersive user characteristics. Of note, the manipulations of immersion used in the present thesis, visual and auditory realism of the virtual environment and tactile wind simulation, were not particularly effective in manipulating presence.

Finally, Study 5 ($N = 34$) compared two different implementations of VRET for acrophobia to investigate mechanisms underlying its efficacy. The first implementation followed the Emotional Processing Theory, assuming that fear reduction during exposure is crucial for positive treatment outcome. In this condition, patients were asked to focus on their fear responses and on the decline of fear (habituation) during exposures. The second implementation was based on the inhibitory learning model, assuming that expectancy violation is the primary mechanism underlying exposure therapy efficacy. In this condition, patients were asked to focus on the non-occurrence of feared outcomes (e.g., "I could fall off") during exposure. Based on predictions of the inhibitory learning model, the hypothesis for the study was that expectancy-violation-based exposure would outperform habituation-based exposure. After two treatment sessions in VR, both treatment conditions effectively reduced the patients' fear of heights, but the two conditions did not differ in their efficacy. The study replicated previous studies by showing that VRET is an effective treatment for acrophobia; however, contrary to the assumption, explicitly targeting the violation of threat expectancies did not improve outcome. This finding adds to other studies failing to provide clear evidence for expectancy violation as the primary mechanism underlying exposure therapy. Possible explanations for this finding and clinical implications are discussed, along with suggestions for further research.

Zusammenfassung

Die Expositionstherapie in virtueller Realität (VRET) ist ein wirksames kognitiv-verhaltenstherapeutisches Verfahren zur Behandlung von Angststörungen. Bei einer VRET werden Patienten nach psychoedukativer Vorbereitung mit virtuellen Repräsentationen der von ihnen gefürchteten Objekte oder Situationen konfrontiert. Die VRET zeigt allerdings nicht bei allen Patienten die gewünschte Wirksamkeit, und einige Patienten erleben selbst nach erfolgreicher Therapie eine Rückkehr der Angst. Da die zugrunde liegenden Wirkfaktoren der VRET noch nicht ausreichend aufgeklärt sind, lässt sich ihre Effektivtät möglicherweise noch weiter verbessern. Ziel der vorliegenden Arbeit war es daher zwei Fragen zu untersuchen. Zum einen, wie genau virtuelle Reize Furchtreaktionen bei höhenängstlichen Personen auslösen, und zum anderen, ob sich VRET durch den Einsatz spezifischer Techniken, welche aus Theorien zur Expositionstherapie abgeleitet wurden, verbessern lässt. Um die Fragen zu beantworten, wurden im Rahmen der Dissertation fünf Studien durchgeführt.

In Studie 1 ($N = 99$) wurde eine virtuelle Umgebung für Höhenexposition etabliert und Effekte von taktiler Windsimulation in virtueller Realität (VR) untersucht. In der Studie hatten höhenängstliche und nicht-ängstliche Probanden die Aufgabe einen virtuellen Turm zu besteigen, wobei die Hälfte der Probanden währenddessen eine Windsimulation dargeboten bekam. Die Ergebnisse zeigten, dass höhenängstliche Probanden stärkere Furchtreaktionen zeigten, was sich sowohl im Bericht als auch im Verhalten äußerte. Zusätzlich erhöhte die Windsimulation die subjektiv Furcht der Probanden. Die Windsimulation hatte allerdings keinen Einfluss auf das Präsenzerleben, d. h. wie sehr sich Probanden so gefühlt hatten als seien sie tatsächlich in der virtuellen Umgebung gewesen. In der Studie konnten darüber hinaus zwei Befunde vorheriger Studien zum Präsenzerleben repliziert werden. Furcht und Präsenz korrelierten positiv, und dieser Zusammenhang war bei höhenängstlichen Probanden stärker als bei nicht-ängstlichen Probanden. Die Studie konnte zeigen, dass sich VR eignet um Furcht auf verschiedenen Reaktionsebenen zu untersuchen und es darüber hinaus möglich ist, Furcht in VR experimentell zu manipulieren.

In Studie 2 ($N = 43$) sollten die Ergebnisse der ersten Studie bestätigt werden. Hierfür wurden ein anderes VR-System für die Exposition eingesetzt sowie die Erfassung von Furchtreaktionen um physiologische Maße ergänzt. Zusätzlich wurde der Einfluss einer visuell-kognitiven Distraktionsaufgabe in VR auf Furchtreaktionen untersucht. Die Furchtreaktionen der Probanden zeigten sich sowohl auf subjektiver als auch physiologischer Ebene, wobei Reaktionen der Hautleitfähigkeit stärker ausgeprägt waren als Veränderungen der Herzrate. Ein Einfluss der ablenkenden visuell-kognitiven Aufgabe auf Furchtreaktionen konnte nicht gezeigt werden. Die Studie konnte insgesamt verdeutlichen, dass die Eigenschaft von VR, Furcht zu erzeugen, nicht an einen bestimmten Versuchsaufbau gebunden ist und sich Furcht in VR auf allen Reaktionsebenen zeigt.

Studie 3 ($N = 50$) hatte das Ziel, den Einfluss von Höhenängstlichkeit und Höhe auf Furchreaktionen genauer zu untersuchen. Hierfür wurde per Fragebogen erfasste Höhenängstlichkeit sowie fünf verschiedene Höhen (1 m–20 m) als lineare Prädiktoren für subjektive und physiologische Furchtindizes verwendet. Die Ergebnisse zeigten, dass subjektive Furcht und Hautleitfähigkeitsreaktionen in Abhängigkeit von sowohl Höhenängstlichkeit als auch Höhe zunahmen. Für die Herzrate zeigten sich hingegen keine eindeutigen Effekte. Die Studie konnte zusammenfassend zeigen, dass sich die Furchtreaktionen in VR *spezifisch* auf Höhe zeigten.

In Studie 4 ($N = 64 + N = 49$) sollte der Zusammenhang zwischen Furcht und Präsenzerleben in VR genauer untersucht werden. Vorangegangene Studien zeigten eine positive Korrelation zwischen beiden Maßen, konnten jedoch keine Aussagen über einen möglichen Kausalzusammenhang machen. Die vorliegende Studie war daher die erste, welche sowohl Präsenz als auch Furcht experimentell manipulierte. Präsenz wurde über die Darbietung unterschiedlich realistischer virtueller Umgebungen, Furcht über die Darbietung von Höhen und Kontrollumgebungen manipuliert. Die Ergebnisse der Studie zeigten, dass es einen kausalen Effekt von Furcht auf Präsenzerleben gab, d. h. das Erleben von Furcht in einer Höhensituation in VR führte zu erhöhtem Präsenzerleben. Umgekehrt gab es jedoch keinen Effekt von experimentell manipuliertem Präsenzerleben auf die Stärke der Furchtreaktion. Es zeigte sich allerdings, dass Personen, welche in der ersten sicheren Situation das stärkste Präsenzerleben berichteten, später auch die stärksten Furchtreaktionen zeigten, was darauf schließen lässt, dass es möglicherweise dennoch Effekte von Präsenzerleben auf Furcht gibt. Dieses Ergebnis weist auf die Bedeutung von möglichen Persönlichkeitsunterschieden hin, welche für das Erleben von Präsenz und Furcht in VR von Bedeutung sind. Die Studie verdeutlichte damit zum einen die Komplexität des Zusammenhangs zwischen Furcht und Präsenzerleben und erlaubte zum anderen erstmals Kausalschlüsse zwischen beiden Maßen.

Die Ergebnisse der ersten vier Studien wurden in einem Modell zur Furcht in VR zusammengefasst. Basierend auf bestehenden Modellen zeigt das neue Modell Faktoren auf, welche für die Entstehung von Furcht und Präsenz bedeutsam sind. So konnten die Studien zeigen, dass Furchtreaktionen in Abhängigkeit von habitueller Höhenangst, der furchtbezogenen Relevanz der virtuellen Umgebung (z. B. Höhe), sowie zum Teil vom Präsenzerleben, auftreten. Bezüglich des Präsenzerlebens betont das Modell die Relevanz von aktuellem Furchterleben, Immersion (den Charakteristika des VR-Systems) und immersiven Nutzercharakteristika (z. B. Absorption). Zu erwähnen ist, dass die in der vorliegenden Dissertation untersuchten Manipulationen von Immersion (visueller und auditiver Realismus der virtuellen Umgebung und taktile Windsimulation) jedoch keine sonderlich starken Effekte auf Präsenz hatten.

In Studie 5 ($N = 34$) wurden abschließend im Rahmen einer Therapiestudie zwei verschiedene VRET-Ansätze miteinander verglichen. Die erste Gruppe von Patienten erhielt hierbei eine Therapie auf Basis der Emotional Processing Theory. In dieser Bedingung wurden die Patienten während der Exposition gebeten, sich auf ihr Furchterleben und dessen Rückgang

über die Zeit (Habituation) zu konzentrieren. Die zweite Gruppe von Patienten erhielt eine Therapie auf Basis des Inhibitory Learning Models. In dieser Bedingung wurden die Patienten gebeten, gezielt ihre Befürchtungen (z. B. „Ich könnte herunterfallen“) zu überprüfen und zu widerlegen. Es wurde auf Basis der Vorhersage des Inhibitory Learning Models, dass Erwartungswiderlegung der zentrale Wirkfaktor der Expositionstherapie ist, angenommen, dass eine Therapie auf Basis der Widerlegung von Befürchtungen effektiver ist als eine Therapie auf Basis von Habituation. Nach zwei Therapiesitzungen berichteten die Patienten in beiden Gruppen einen signifikaten Rückgang ihrer Höhenangst, es zeigten sich jedoch keine Wirksamkeitsunterschiede zwischen den Gruppen. Die Studie konnte damit zwar vorherige Befunde replizieren, die zeigten, dass VRET eine effektive Behandlung für Höhenangst ist, die spezifische Fokussierung auf Erwartungswiderlegung zeigte jedoch keinen Vorteil. Dieser Befund reiht sich damit in eine Reihe von Studien ein, die Erwartungswiderlegung als zentralen Wirkfaktor der Expositionstherapie nicht nachweisen konnten. Mögliche Gründe für diesen Befund sowie daraus folgende klinische Implikationen und Vorschläge für weitere Forschung werden diskutiert.

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Abbreviations

ACQ-R	**A**nxiety **C**ontrol **Q**uestionnaire **R**evised
AQ	**A**crophobia **Q**uestionnaire
ATHQ	**A**ttitudes **T**owards **H**eights **Q**uestionnaire
BAT	**B**ehavioral **a**voidance **t**est
BSH	**B**etween-**s**ession **h**abituation
CAVE	**C**omputer **A**utomatic **V**irtual **E**nvironment
CBT	**C**ognitive **b**ehavioral **t**herapy
CR	**C**onditioned **r**esponse
CS	**C**onditioned **s**timulus
DCS	D-**c**yclo**s**erine
DSM	**D**iagnostic and **S**tatistical **M**anual of Mental Disorders
ECG	**E**lectro**c**ardio**g**ram
EDA	**E**lectro**d**ermal **a**ctivity
EPT	**E**motional **P**rocessing **T**heory
HHF	**H**igh **h**eight-**f**earful
HMD	**H**ead-**m**ounted **d**isplay
HR	**H**eart **r**ate
HRR	**H**eart **r**ate **r**eaction
IBI	**I**nter**b**eat **i**nterval
ICD	**I**nternational Statistical **C**lassification of **D**iseases and Related Health Problems
IFA	**I**nitial **f**ear **r**esponse
IPQ	**I**group **P**resence **Q**uestionaire
LHF	**L**ow **h**eight-**f**earful
MEC-SPQ	**MEC S**patial **P**resence **Q**uestionnaire
NMDA	***N***-**m**ethyl-D-**a**spartate
OCD	**O**bsessive-**c**ompulsive **d**isorder

PTSD	**P**ost**t**raumatic **s**tress **d**isorder
SCID-I	**S**tructured **C**linical **I**nterview for **D**SM-IV Axis **I** Disorders
SCL	**S**kin **c**onductance **l**evel
SCR	**S**kin **c**onductance **r**eaction
SSQ	**S**imulator **S**ickness **Q**uestionnaire
SSS	**S**ensation **S**eeking **S**cale
STAI	**S**tate-**T**rait **A**nxiety **I**nventory
SUDS	**S**ubjective **U**nits of **D**iscomfort **S**cale
US	**U**nconditioned **s**timulus
VAR	**Var**iability in fear levels
VR	**V**irtual **r**eality
VRET	**V**irtual **r**eality **e**xposure **t**herapy
WSH	**W**ithin-**s**ession **h**abituation

Chapter 1

Introduction

Climbing a high tower to enjoy incredible panoramic views up to the far horizon is a pleasurable activity for most people. However, for some individuals, it is an intimidating situation that causes a racing heart, sweating, vertigo, and an overwhelming urge to leave the situation instantly. While some people think about their plans for dinner when crossing an autobahn bridge, others endure a nightmare, with thoughts about the bridge falling apart and the own car crashing to the ground. For people with a severe fear of heights, everyday situations like using certain kinds of stairs or staying in multi-story buildings can become insurmountable obstacles. For this reason, people with a pathological fear of heights often try to avoid such situations. Avoidance of heights is an effective strategy to prevent the previously described fear responses. But it is also confining: One patient, for example, told that she had to make detours when going by car to another city because she wanted to avoid bridges by all means. Another patient told that she avoided a metal staircase at her workplace, at the cost of walking an extra fifteen minutes whenever she had to go to a room that was located at the upper level. Besides these costs of avoiding height situations, avoidance strategies offer only temporary relief from fear.

The goal of psychotherapies for pathological fears is to achieve lasting fear reductions and to enable patients to master feared situations. One such therapeutic technique is *exposure therapy*, which comprises systematic confrontations to feared situations (Abramowitz, Deacon, & Whiteside, 2012). Exposure therapy has been proven effective for the treatment of pathological fears (Choy, Fyer, & Lipsitz, 2007; Wolitzky-Taylor, Horowitz, Powers, & Telch, 2008), although the exact mechanisms of change underlying its efficacy are not yet fully understood. However, even though being an effective treatment, there is a lack of dissemination of exposure therapy in routine care, with practicability being the most stated reason by therapists for not conducting exposures (Pittig, Kotter, & Hoyer, 2018). Moreover, also patients express reservations about exposure therapy. Patients with specific phobias stated that they would not undergo an exposure treatment because they were too afraid of confronting the feared situations (Garcia-Palacios, Botella, Hoffman, & Fabregat, 2007).

Fortunately, a new medium to conduct exposure therapy has emerged from technological advances: immersive virtual environments. So-called virtual reality exposure therapy (VRET) utilizes computer-generated virtual environments to expose patients to feared situations from within a therapist's office. Not only does VRET have higher acceptance rates among patients with specific fears (Garcia-Palacios et al., 2007; Garcia-Palacios, Hoffman, Kwong See, Tsai, & Botella, 2001), it is also a proven effective treatment for such fears (Carl et al., 2019). However, like with exposure therapy itself, the mechanisms underlying the process and efficacy of VRET have not been consistently established (Diemer, Lohkamp, Mühlberger, & Zwanzger, 2016).
The present thesis has two aims: First, it investigates how virtual environments induce height-related fear responses and what symptoms of fears of heights are elicited in virtual reality (VR). Second, it explores mechanisms underlying the efficacy of exposure therapy for acrophobia by testing predictions from different theoretical models of exposure therapy.

1.1 Outline of the thesis

The present thesis consists of four parts: Chapter 2 gives an introduction to the pathological fear of heights (2.1), explains the technique of exposure therapy to treat pathological fears (2.2), describes theoretical models underlying exposure therapy efficacy (2.3), introduces VR as a tool for research and treatment of fears (2.4), and presents the research objectives and hypotheses of the present thesis (2.5). Chapter 3 contains four studies investigating various aspects of fear responses in virtual height situations and the viability of those virtual environments for use in VRET. The first study (3.1) established a virtual environment for height exposure, investigated fear responses on both a verbal and behavioral level, and examined the effect of a wind simulation on fear. The second study (3.2) built upon these findings and corroborated the results by moving from a projection-based VR-system to a head-mounted display (HMD). In addition, physiological fear responses were measured, and the effects of a distractor on fear responses were investigated. Physiological fear responses were examined in more detail in the third study (3.3), elaborating on differences between different fear response systems and investigating the specificity of fear responses. Study 4 (3.4) investigated the effects of the design of virtual environments on fear responses and tested whether experiencing fear in VR changes the way virtual environments are perceived. Chapter 4 focuses on the mechanisms underlying exposure therapy and contains a treatment study. This fifth and last study (4.1) compared two implementations of exposure therapy for acrophobia, testing different theoretical models of exposure. Finally, Chapter 5 summarizes and discusses the findings with regards to the research objectives of the thesis and gives an outlook on future research.

Chapter 2

Theoretical Background

2.1 The Fear of Heights: Acrophobia

2.1.1 Concept and Classification

The *fear of heights* or *acrophobia*, from the Greek *ákron* (peak or summit) and *phóbos* (fear; McCabe, 2015), describes an unreasonable or irrational fear towards heights (LeBeau et al., 2010). Situations such as being on a balcony or tower, climbing an external staircase, or crossing a bridge can trigger intense fear responses in individuals with acrophobia. Fear responses include increased heart rate (HR), sweating, and vertigo, which can end up in a full-blown panic attack. Height phobics interpret height situations as unreasonably dangerous and have fears like falling, losing control, or not being able to tolerate their fear responses (Menzies & Clarke, 1995a; Steinman & Teachman, 2011). Height situations are often avoided, or if avoidance is not possible, safety behaviors like holding on to a railing or walking near a wall are frequently used (Öst, 2012). In the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5) and the *International Classification of Diseases* (ICD-10), acrophobia is classified as a specific (isolated) phobia (DSM-5: 300.29, ICD-10: F40.2) of the subtype natural environment (American Psychiatric Association, 2013; World Health Organization, 2016). According to the DSM-5, a specific phobia is diagnosed if the following criteria are fulfilled:

A. Marked fear or anxiety about a specific object or situation (eg, flying, heights, animals, receiving an injection, seeing blood).
   Note: In children, the fear or anxiety may be expressed by crying, tantrums, freezing, or clinging.

B. The phobic object or situation almost always provokes immediate fear or anxiety.

C. The phobic object or situation is actively avoided or endured with intense fear or anxiety.

D. The fear or anxiety is out of proportion to the actual danger posed by the specific object or situation and to the sociocultural context.

E. The fear, anxiety, or avoidance is persistent, typically lasting for six months or more.

F. The fear, anxiety, or avoidance causes clinically significant distress or impairment in social, occupational, or other important areas of functioning.

G. The disturbance is not better explained by the symptoms of another mental disorder, including fear, anxiety, and avoidance of situations associated with panic-like symptoms or other incapacitating symptoms (as in agoraphobia); objects or situations related to obsessions (as in obsessive-compulsive disorder); reminders of traumatic events (as in posttraumatic stress disorder); separation from home or attachment figures (as in separation anxiety disorder); or social situations (as in social anxiety disorder).

Acrophobia as a specific phobia can be differentiated from two other concepts related to the fear of heights. *Physiological height imbalance* is a symptom every person experiences in high places. It describes a decreased sense of postural stability, which is caused by impaired visual control of postural balance (Brandt, Kugler, Schniepp, Wuehr, & Huppert, 2015; Kapfhammer, Huppert, Grill, Fitz, & Brandt, 2015). *Visual height intolerance* is a condition in individuals who are very susceptible to the increased body sway in physiological height imbalance (Kapfhammer et al., 2015). The pathology of visual height intolerance is very similar to acrophobia, with symptoms of fearfulness, vertigo, and palpitations when visually exposed to height situations (Kapfhammer et al., 2015). However, in comparison to visual height intolerance, individuals with acrophobia also show avoidance behavior and psychological or psychosocial impairments due to their fear of heights (Kapfhammer et al., 2015).

2.1.2 Epidemiology

Specific phobias are among the most common mental disorders (Boyd et al., 1990). The German health interview and examination survey for adults (DEGS1) with the mental health module (DEGS1-MH, $N = 5318$) reported a 12-month prevalence rate of 10.3% for specific phobias (Jacobi et al., 2014). In a Dutch sample (NEMESIS study, $N = 7076$), the 12-month prevalence rate for specific phobia was 9.6% (Depla, Have, Balkom, & Graaf, 2008). In a cross-national epidemiology study where the data from 25 WHO World Mental Health Surveys studies were combined ($N = 124{,}902$), the 12-month prevalence rate for specific phobia was 5.5% (with a lifetime prevalence rate of 7.4%; Wardenaar et al., 2017). Only looking at acrophobia in the cases with specific phobia, the lifetime prevalence rates were 4.9% (NEMESIS, Depla et al., 2008) and 2.8% (World Mental Health Surveys, Wardenaar et al., 2017). In another study with a female-only sample (Dresden Mental Health Study, $N = 2064$), the 12-month and lifetime prevalence rates for acrophobia were 1.7% and 1.9% respectively.

Epidemiological studies reported higher prevalence rates of specific phobias in women than in men, with ratios of 3:1 (Jacobi et al., 2014) and 2–2.3:1 (Wardenaar et al., 2017). Also in acrophobia, the prevalence rate was higher in women than in men, with a ratio of 1.9:1 (Wardenaar et al., 2017).

The median age of onset of acrophobia ranges from late childhood (age 8–11, Depla et al., 2008; Jacobi et al., 2014) to early adolescence (LeBeau et al., 2010).

2.1.3 Etiology

What mechanisms underlie the acquisition of pathological fears is still a topic of ongoing debate. During the last century, several different theories and models which try to explain the etiology of fears and phobias in general, as well as acrophobia in particular, have been postulated. These models can roughly be divided into two subgroups: *associative models*, which highlight the importance of learning experiences in the emergence of pathological fears, and the *non-associative model*, which focuses on evolutionary inherited fears (Coelho & Purkis, 2009). The most important and influential models are described in the following paragraphs.

2.1.3.1 Pavlovian conditioning

The Pavlovian or classical conditioning model of fear acquisition describes a learning procedure in which an initially neutral stimulus (conditioned stimulus; CS) is repeatedly paired with a pain-producing or fear-eliciting stimulus (unconditioned stimulus; US; Scheveneels, Boddez, & Hermans, 2019). Once the association between the CS and US is learned, the presentation of the CS alone leads to similar responses (conditioned response; CR) as the presentation of the US. In their seminal case study on fear learning in humans, Watson and Rayner (1920) presented repeated pairings of a CS (a rat) with an US (striking a hammer against a steel bar) to their subject, the 11-month old infant Little Albert. Whereas Little Albert did not show any fear-related emotional responses towards the rat before conditioning, he reacted with fear and avoidance when confronted with the CS and similar stimuli after conditioning (Watson & Rayner, 1920). The idea that fear is learned by associating a stimulus or situation with an aversive event is a central concept in human fear pathology up to this day (Beckers, Krypotos, Boddez, Effting, & Kindt, 2013). However, the initial conceptualization of fear conditioning has been criticized as being too simplistic (Rachman, 1977). For this reason, several extensions to the original theory (Lonsdorf & Merz, 2017; Scheveneels et al., 2019) as well as alternative models have been proposed.

2.1.3.2 Preparedness theory

In his preparedness theory, Seligman (1971) criticizes one of the shortcomings of the classical conditioning theory of fear acquisition. According to Pavlovian conditioning theory, any stimulus can become a CS through conditioning (equipotentiality premise). Seligman (1971), however, argues that phobias are not scattered across all kinds of stimuli, but comprise of only a limited set of stimuli or situations (e.g., spiders, heights, dark places). According to his preparedness theory, human beings are evolutionary prepared to easily learn fear towards a

specific set of stimuli or situations. Furthermore, since these fears are evolutionarily adaptive (i.e., increase survival by protecting individuals from possible threats), they are also difficult to extinguish.

2.1.3.3 Neo-conditioning theory

According to the neo-conditioning theory by Rachman (1977, 1991), two further pathways for the acquisition of fears exist in addition to classical conditioning. *Vicarious learning* describes the phenomenon, that an individual acquires a fear not directly, but indirectly through observation of another individual who either experiences a traumatic event or reacts fearfully to a stimulus or situation. For example, a child who observes its mother reacting fearfully in a height situation may learn that heights are dangerous. *Information transmission* describes a form of learning not through modeling as in vicarious learning, but by verbal transmission of information about the dangerousness of an object or situation. For example, the mother in the previous example could also tell her child to stay away from the railing of a balcony because it might fall off.

2.1.3.4 Non-associative model

The previously described etiological models emphasize prior learning experiences with the feared stimulus or situation. The non-associative, Darwinian account of fear acquisition, as a counterpart, states that fears towards a specific set of stimuli and situations (e.g., water, heights) are not learned, but evolutionary inherited. This view is based on the findings, that many individuals with a fear of heights are not able to recall any conditioning events that led to their phobia (Menzies & Clarke, 1993, 1995b). Furthermore, height-fearful and non-fearful persons do not differ in the amount of direct or indirect traumatic learning events they experienced with heights (Menzies & Clarke, 1993; Menzies & Parker, 2001; Poulton, Davies, Menzies, Langley, & Silva, 1998). What is even more contrary to the associative models is that non-fearfuls report higher levels of experienced fear and pain during such traumatic events (Menzies & Parker, 2001) and that also non-fearfuls (at age 18) reported more severe injuries from falls during ages 5–9 than height-fearfuls (Poulton et al., 1998). As a consequence, the non-associative model assumes that repeated exposure to feared situations leads to habituation and diminishment of fear, and that fearful persons did not have sufficient safe exposure (Clarke & Jackson, 1983, as cited in Menzies & Clarke, 1993).

2.1.4 Maintenance

The last section described several etiological models of specific fears. Another critical aspect of pathological fears is that such fears typically do not remit spontaneously (Becker et al., 2007). Building upon the concept that fear is a learned response, Mowrer (1939) put forward his two-factor theory which includes not only classical conditioning for the acquisition of

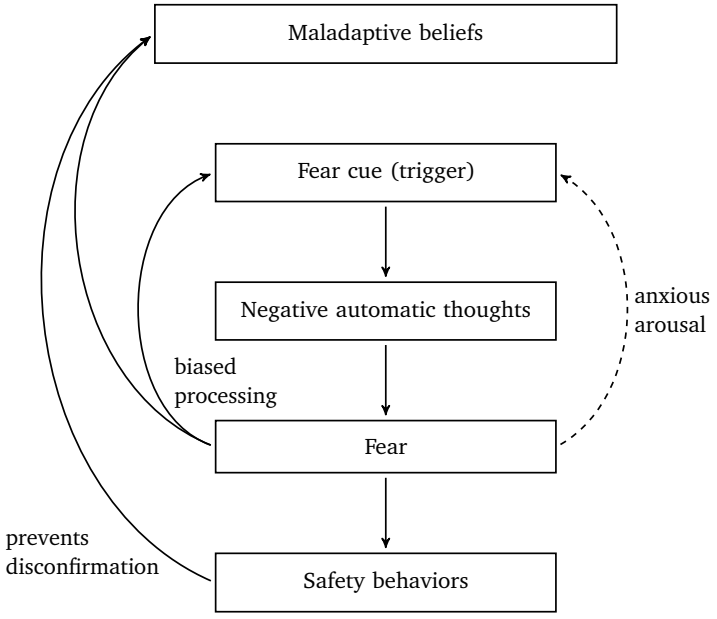


Figure 1: A cognitive-behavioral model for the maintenance of specific phobia. Adapted from Abramowitz et al. (2012).

fear, but also operant conditioning to explain the persistence of pathological fears. According to Mowrer (1939), after the CS–US association is established via Pavlovian conditioning, avoidance of the CS mitigates fear responses and thereby strengthens the CS–US association through operant conditioning. Abramowitz et al. (2012) and Öst (2012) explain the chronicity of pathological fears in their cognitive-behavioral models (see Figure 1). If a person with a fear of heights enters a feared situation (e.g., a rope bridge), negative automatic thoughts are triggered (e.g., "I could fall"). These thoughts lead to the emotional sensation of fear, which in turn strengthens maladaptive beliefs about the dangerousness of height. Safety behaviors like holding on to a railing or leaving the situation are used to avoid the unpleasant emotion and apprehension of imminent threat. However, these safety behaviors prevent the disconfirmation of the maladaptive beliefs about the dangerousness of height, causing persistence of the pathological fear. Furthermore, when the feared situation is left, fear symptoms decline and the feared catastrophe does not occur. This decline in fear and the non-occurrence of feared catastrophes is attributed to the use of safety behaviors (Öst, 2012), further preventing the disconfirmation of maladaptive beliefs. In addition, it negatively reinforces the use of safety behaviors in the future (Mowrer, 1939).

2.2 Exposure Therapy

Once a person develops a fear of heights to the extent of a specific phobia, the disorder is typically persistent and spontaneous remission constitutes more the exception than the rule. This persistence of pathological fears can be explained by operant conditioning. Escaping from or actively avoiding to enter height situations acts as a negative reinforcement by which fear declines in the short term but strengthens in the long term (Mowrer, 1939). Furthermore, since patients with acrophobia avoid height situations, corrective experiences cannot take place, and catastrophic beliefs (e.g., "I will fall") persist (Öst, 2012).
These two maintaining factors of pathological fears—avoidance and catastrophic beliefs—are the starting point for exposure therapy in specific phobia (Öst, 2012). Therapeutical exposures consist of confrontations with the stimulus or situation which is otherwise avoided (e.g., a balcony or an open staircase in height phobics; Hood & Antony, 2012). In the fear-inducing situations, patients are assisted to tolerate distressing symptoms, with the goal to experience the naturally occurring decline in fear symptoms, or are instructed to test their catastrophic beliefs (e.g., falling, fainting, having a heart attack) directly.
This section begins with a description of the exposure technique. Subsequently, it presents a brief historical outline of exposure treatments and discusses early theories on mechanisms underlying exposure therapy efficacy. In the next section, the two prevailing theories on exposure therapy—the Emotional Processing Theory and the inhibitory learning model—will be described and discussed in detail.

2.2.1 Description of the Technique

Exposure therapy is not just a simple confrontation with a fear-eliciting stimulus or situation, but is a cognitive behavioral treatment consisting of different interventions. Beside the therapeutical confrontations, these include diagnostic, psychoeducative, and cognitive interventions, as well as relapse prevention.
Before therapeutical confrontations are conducted, a phase of thorough *behavioral analysis* is inevitable (Teismann & Margraf, 2018). By questioning or behavioral assessment, the therapist and patient identify fear-inducing stimuli and situations, behavioral and cognitive avoidance, safety behaviors, and anticipated consequences of the confrontation with the feared stimulus (Hood & Antony, 2012; Öst, 2012; Teismann & Margraf, 2018).
In the second phase, patients are informed about their pathological fear and its treatment. This *psychoeducation* includes factors that contribute to the development of pathological fear (e.g., fear as learned behavior) and the maintenance of the phobia (through avoidance and safety behaviors). Subsequently, patients are informed about the rationale behind exposure therapy. For example, a patient with catastrophic beliefs about the escalation of his heartbeat and that he could suffer from a heart attack could be informed about the typical course of fear during prolonged exposure, highlighting the naturally occurring decline in fear over time. A

patient with a catastrophic belief about falling from a high place could be informed about how avoidance hinders the critical examination of her belief. Furthermore, she could learn that exposure and the experience of the catastrophe not occurring leads to the development of new non-fear beliefs about heights. Another critical point in the phase of psychoeducation is the discussion of the goals of the exposure treatment. Often, patients hope for a complete elimination of their fear. In order to establish realistic expectations, therapists explain that fear is not *erased* from the brain, but is still needed as a "protection system", and that the goal of exposure is to enable patients to master their feared situations (Hood & Antony, 2012).
Before exposures are conducted, the patient and therapist decide whether the confrontations are designed in a massed or gradual fashion (Teismann & Margraf, 2018). This decision is typically based on patient preferences. *Massed exposure* means that the confrontation begins directly with the most fear-provoking situation. *Gradual exposure*, on the other hand, describes a procedure where the confrontation begins with easier to medium difficult situations and, once these situations are mastered, situations with higher difficulty are tackled. For a gradual approach, the patient and therapist compile a list of possible exposure situations arranged by difficulty (Teismann & Margraf, 2018). For example, a height-phobic would rate standing on a balcony on the second level of a house having a difficulty of 50 (on a scale of 0–100) and staying on a ladder that leans against a wall in 2 m height as a 90. Patient and therapist then decide with which situation of the *fear hierarchy* to begin.
In the actual *exposure sessions*, patient and therapist enter and stay in the feared situation until a previously defined criterion is met. Such a criterion could, for example, be that fear has declined to at least 30 (on a scale of 0–100) or that a feared catastrophe has not occurred within a pre-defined time window. During exposures, the therapist usually instructs the patient to focus on the fear and to refrain from any safety behaviors.
Before ending the treatment, a phase of *relapse prevention* is typically conducted. This phase includes information about a possible return of fear symptoms and how patients should deal with such symptoms (e.g., applying what was learned during the treatment instead of using safety behaviors and avoidance).

2.2.2 A Brief History of Exposure Therapy

That the confrontation with the fear-eliciting situation is a crucial component of treatments for pathological fear has been noted long before the establishment of exposure therapy in its current form (Teismann & Margraf, 2018). For example, German writer Johann Wolfgang von Goethe (1749–1832) describes in his autobiography how he treated his fear of heights by exposing himself for a prolonged time to an open space on a church spire:

> "But I was especially troubled by a giddiness which came over me every time that I looked down from a height. [...] All alone I ascended the highest pinnacle of the minster spire, and sat in what is called the neck, under the nob or crown, for a quarter of an hour, before

> I would venture to step out again into the open air, where, standing upon a platform scarce an ell square, without any particular holding, one sees the boundless prospect before, while the nearest objects and ornaments conceal the church, and everything upon and above which one stands. It is exactly as if one saw oneself carried up into the air in a balloon. Such troublesome and painful sensations I repeated until the impression became quite indifferent to me, and I have since then derived great advantage from this training, in mountain travels and geological studies, and on great buildings, where I have vied with the carpenters in running over the bare beams and the cornices of the edifice, and even in Rome, where one must run similar risks to obtain a nearer view of important works of art."
>
> (translated by Oxenford, 1848)

Further early references to the utility of exposure in the treatment of fears were given by neurologist Oppenheim (1905), who noted the importance of crossing open spaces together with agoraphobic patients, and Freud in his 1918 talk, proposing that the analysts had to encourage their phobic patients to confront their fears (Freud, 1919; Hoffer, 2002).
Perhaps the first description of exposure therapy in the sense of a behavioral treatment was given by Mary Cover Jones (1924a, 1924b). Following up on the fear conditioning study by Watson and Rayner (1920), Jones (1924a) conducted several case studies in fearful children, testing different therapeutical approaches. Jones (1924a) concluded from her studies that two of the approaches were successful: "By the method of *direct conditioning* we associated the fear-object with a craving-object, and replaced the fear by a positive response. By the method of *social imitation* we allowed the subject to share, under controlled conditions, the social activity of a group of children especially chosen with a view to prestige effect." (Jones, 1924a, p. 129, emphasis added). The first method was later described in greater detail (Jones, 1924b), then termed *unconditioning*. Jones and colleagues presented pairings of the fear-inducing stimulus (a rabbit) and appetitive stimuli (food) to their patient Peter. Over several sessions, Peter's fear and avoidance of the rabbit declined, enabling him to pet the rabbit without signs of fear.
Three decades later, South-African psychiatrist Joseph Wolpe established a treatment for phobias which utilized a similar approach as the unconditioning procedure described by Jones (1924a, 1924b). His *Systematic Desensitization* is thought to work through *reciprocal inhibition*, "the complete or partial suppression of the anxiety responses as a consequence of the simultaneous evocation of other responses physiologically antagonistic to anxiety" (Wolpe, 1954, p. 205). In the treatment, patients are first taught progressive muscle relaxation to produce a state of deep relaxation, which, according to Wolpe, is incompatible with the anxiety response. Next, the patient and therapist build a hierarchy of phobic situations, arranged by the anticipated intensity of the fear response. Subsequently, the patient is asked to establish a relaxed state and then the first fear-producing situation is presented in imagination. From then on, relaxation and presentation of anxiety-provoking images are

repeated alternately until the fear response subsides. Once the fear response is no longer there, the therapist and patient proceed to the next element in the hierarchy.

Around the same time as Wolpe developed his Systematic Desensitization, Malleson (1959) described a treatment called *reactive inhibition therapy*, which does not rely on inducing fear-incompatible states but on confronting fearful patients to their feared situations, fully experiencing the unpleasant emotions and bodily sensations until fear declines. Similarly, the technique of *flooding* (or *implosion*) which "involves the subject being exposed without avoidance for prolonged periods to the phobic situation in fantasy and in real life while experiencing his fear at maximum intensity until it extinguishes" (Boulougouris, Marks, & Marset, 1971, p. 7) was proposed as an alternative to the desensitization technique. Stampfl and colleagues proposed their *implosive therapy*, which they called a "learning-theory-based psychodynamic behavioral therapy" (Stampfl & Levis, 1967, p. 496). It builds upon Mowrer's two-factor model and, similar to Wolpe's Systematic Desensitization, uses imaginal exposures to feared and avoided situations. In implosive therapy, the therapist describes feared and avoided situations while the patient imagines these scenes. Instead of using relaxation techniques to oppose fear responses, implosive therapy builds upon spontaneous fear reductions: when such spontaneous fear reductions occur, the therapist describes the scenes in more detail. This procedure is repeated until fear declines. After working through so-called symptom-contingent cues (e.g., an image of a tower in the case of a height-phobic), the therapist and patient proceed to so-called hypothesized sequential cues. These reflect the psychodynamic background of the patient and include aggression, punishment, sexual material, and rejection.

In 1975, Marks introduced the term *exposure* for confrontation-based behavioral treatments and suggested that confrontation alone—as compared to the combination with relaxation—is sufficient for successful treatment (Marks, 1975, as cited in Teismann & Margraf, 2018). This marks the beginning of exposure therapy as it is conducted in its current form.

2.3 Models of Exposure Therapy

As described in the previous section, exposure-based treatments for pathological fears have undergone several modifications in both underlying theory and application. Whereas earlier theories proposed counter-conditioning (pairing the feared stimulus with an appetitive stimulus or with relaxation) to be the fundamental underlying mechanism of exposure therapy efficacy, later theories challenged the necessity of such counter-conditioning, highlighting that exposure-based treatments work well without the use of relaxation techniques. These findings called for new theories explaining the mechanisms of exposure therapy.
This section discusses two contemporary models on the mechanisms of exposure therapy: Foa and Kozak's (1986) Emotional Processing Theory (EPT) and Craske's (2008; 2014) inhibitory learning model. The theories are described in detail to lay the foundations for Study 5 (4.1), which compares the efficacy of two implementations of exposure therapy based on these two theories.

2.3.1 Emotional Processing Theory

For decades, the EPT (Foa, Huppert, & Cahill, 2006; Foa & Kozak, 1986; Foa & McNally, 1996) has been the prevailing model to explain the mechanisms of change underlying exposure therapy. The model integrates Lang's (1977; 1979) bio-informational concept of fear structures, Rachman's (1980) concept of emotional processing, and exposure process research from the 1970s and 1980s (e.g., Borkovec & Sides, 1979; Grayson, Foa, & Steketee, 1982; Watson, Gaind, & Marks, 1972; Watson & Marks, 1971). The theory proposes that pathological fear is represented in memory as a cognitive fear structure that includes information about the fear stimuli, the fear responses (verbal, physiological, and behavioral), and the meaning of both fear stimuli and fear responses (Foa & Kozak, 1986). For acrophobia, a possible fear structure includes representations of height situations (e.g., towers, bridges), physiological and behavioral fear responses (e.g., palpitations, vertigo, standing close to a wall, or leaving a bridge), and threat meanings associated with both height situations (e.g., "I could fall") and the person's responses (e.g., "vertigo means that I don't stand securely"). Explaining the mechanisms underlying exposure therapy efficacy, the EPT further proposes that successful exposure requires two conditions: first, the fear structure has to be activated and must be available for modification, and second, information that is incompatible with the fear structure has to be acquired, which then leads to corrective learning (Foa & Kozak, 1986). In their original formulation, Foa and Kozak (1986) proposed that emotional processing would modify and weaken the existing fear structure, whereas, in their revised version of EPT (Foa & McNally, 1996), the authors stated that emotional processing leads to the formation of a non-fear structure, which competes with the original fear structure. To measure the amount of emotional processing during an exposure treatment, Foa and Kozak (1986) proposed three indicators of successful exposure. First, *initial fear activation* (IFA), i.e., the initial reaction

to a fear stimulus during an exposure session, is thought to be a measure of the extent to which the fear structure has been activated. Second, the decline in fear within an exposure session, called *within-session habituation* (WSH), is regarded as a measure of incompatible information acquired during an exposure session. Third, *between-session habituation* (BSH), the reduction in initial fear responses across sessions, is seen as a measure that indicates changes in threat representations within the fear structure (Foa & Kozak, 1986). Based on inconsistent findings, Foa et al. (2006) deemphasized the importance of WSH as an indicator of positive treatment outcome in their latest revision of EPT. Still, many exposure-based treatment manuals to date include a focus on habituation of fear during exposure sessions (e.g., Teismann & Margraf, 2018).

Previous reviews on the evidence for IFA, WSH, and BSH as indicators of treatment outcome came to different conclusions, with one review in favour of EPT (Crits-Christoph, Gibbons, & Mukherjeed, 2013) and another review stating that there is weak evidence for the assumptions of the EPT (Craske et al., 2008). In a recent meta-analysis, Rupp, Doebler, Ehring, and Vossbeck-Elsebusch (2017) conclude that "the premises of EPT have no sufficient empirical foundation to draw final recommendations" (Rupp et al., 2017, p. 709), highlighting the lack of empirical support for IFA as predictor of treatment outcome and mixed findings for WSH and BSH. The following section reviews research on IFA, WSH, and BSH as predictors of treatment outcome in exposure therapy. Studies were searched in Web of Knowledge and Google Scholar using combinations of the search terms "`exposure therapy`", "`fear activation`", and "`habituation`". Furthermore, reference lists of previous reviews and studies were scanned, and a citation search for Foa and Kozak (1986) on Google Scholar was conducted. Studies were included if they reported results for IFA, WSH, and/or BSH in exposure in different anxiety disorders, as well as posttraumatic stress disorder (PTSD) and obsessive-compulsive disorder (OCD), in both clinical and analogue samples, but not findings from fear-conditioning studies. Figure 2 gives an overview of the results of the literature review and the next paragraphs discuss each EPT indicator in more detail.

The assumption that stronger IFA indicates superior treatment outcome receives support from eight studies (Alpers & Sell, 2008; Beckham, Vrana, May, Gustafson, & Smith, 1990; Borkovec & Sides, 1979; Foa, Riggs, Massie, & Yarczower, 1995; Jaycox, Foa, & Morral, 1998; Kozak, Foa, & Steketee, 1988; Lang, Melamed, & Hart, 1970; Watson & Marks, 1971), whereas seven studies could not find such an effect (Baker et al., 2010; Culver, Stoyanova, & Craske, 2012; Harned, Ruork, Liu, & Tkachuck, 2015; Kircanski & Peris, 2015; Matthews, Naran, & Kirkby, 2015; Peterman, Carper, & Kendall, 2016; Pitman et al., 1996a), and four studies even reported detrimental effects of stronger IFA (Foa et al., 1983; Hayes, Hope, & Heimberg, 2008; Kircanski, Mortazavi, et al., 2012; Telch et al., 2004). Further three studies reported mixed results (Meuret, Seidel, Rosenfield, Hofmann, & Rosenfield, 2012; Norton, Hayes-Skelton, & Klenck, 2011; Pitman et al., 1996b). Taken together, there is no clear evidence that stronger IFA is an adequate indicator of succesful exposure therapy

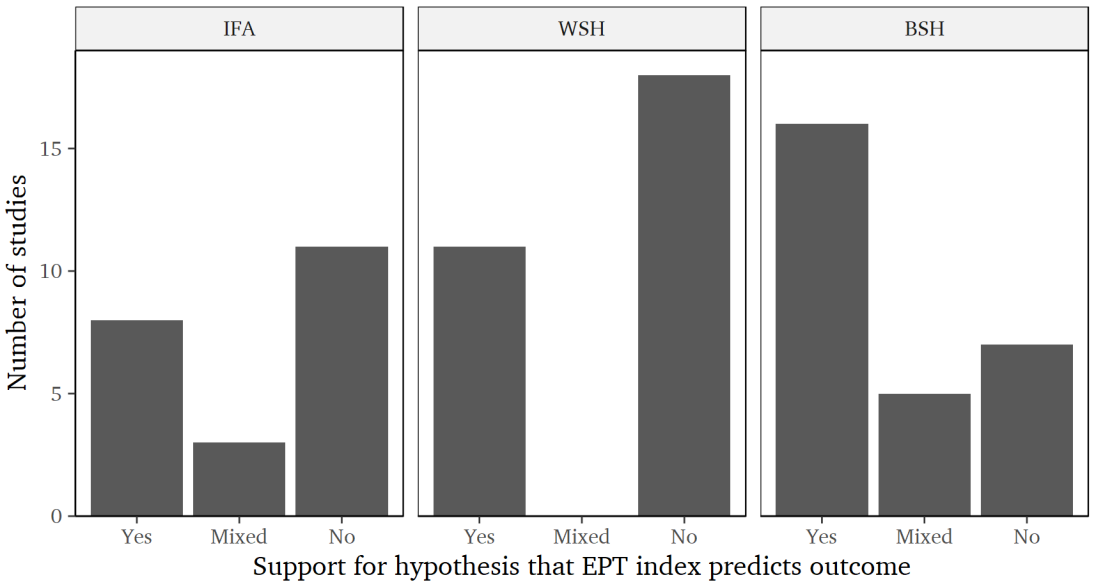


Figure 2: Overview of studies regarding the hypotheses that indicators of the Emotional Processing Theory predict treatment outcome. IFA = initial fear activation, WSH = within-session habituation, BSH = between-session habituation.

outcome. In addition to these ambiguous findings, several methodological issues in studies on IFA should be discussed. First, IFA has been measured by various fear response parameters (e.g., fear ratings, physiological reactivity, facial expressions). It is still unclear how well any of these different parameters represent the activation of the proposed fear network, as studies on the validity of IFA are non-existent. For example, if physiological reactivity at the beginning of an exposure session is used as an index of IFA, then this measure might be confounded by anticipatory anxiety before the exposure (a time frame that is typically used to baseline-correct physiological measures). In line with this, there has not yet been any systematic comparison between different IFA parameters. Second, also the time *when* IFA was measured has not been consistent across studies. For example, some studies used the first fear rating in an exposure trial (e.g., Beckham et al., 1990), whereas other studies used the highest fear rating of an exposure trial (e.g., Foa et al., 1995). Third, IFA may not only be an index for the activation of the fear structure. Most likely, the extent of IFA is confounded with the severity of the fear pathology, i.e., patients with more severe anxiety disorders have stronger IFA, and this, in turn, might influence treatment outcome. For example, several studies showed that fear pathology has an influence on safety learning (Duits et al., 2015; Pittig, Treanor, LeBeau, & Craske, 2018).

The assumption that stronger WSH indicates better treatment outcome receives support from eleven studies (Beck, Shipherd, & Zebb, 1997; Borkovec & Sides, 1979; de Kleine, Hendriks, Becker, Broekman, & van Minnen, 2017; de Kleine, Smits, Hendriks, Becker, & van Minnen, 2015; Foa et al., 1983; Hayes et al., 2008; Kircanski, Mortazavi, et al., 2012; Lang et al., 1970; Minnen & Hagenaars, 2002; Norton et al., 2011; Waters, Potter, Jamesion, Bradley, &

Mogg, 2015), no support from 17 studies (Baker et al., 2010; Harned et al., 2015; Jacoby, Abramowitz, Blakey, & Reuman, 2019; Jaycox et al., 1998; Kircanski & Peris, 2015; Kozak et al., 1988; Kuckertz, Najmi, Baer, & Amir, 2019; Matthews et al., 2015; Meuret et al., 2012; Minnen & Foa, 2006; Nacasch et al., 2015; Peterman et al., 2016; Pitman et al., 1996a, 1996b; Rachman, Craske, Tallman, & Solyom, 1986; Rauch et al., 2018; Sripada & Rauch, 2015), and one study finding even better treatment outcome with less WSH (Culver et al., 2012). One further study showed less treatment dropout in patients with higher WSH (Norton et al., 2011). Taken together, previous studies could not unequivocally show a beneficial effect of WSH on treatment outcome, questioning general statements like "The golden rule is to try never to leave a situation until the fear is going down" (Mathews, Gelder, & Johnston, 1981, p. 182, as cited in Meuret et al., 2012). Furthermore, several methodological problems have to be considered in studies on WSH. First, as in IFA, several different measures (e.g., fear ratings, physiological indices), as well as different operationalizations of WSH, have been used. For example, Jacoby et al. (2019) defined WSH as peak fear minus fear at the end of an exposure session. Baker et al. (2010) defined WSH as the average fear in the 1st quartile minus the average fear in the 4th quartile of the exposure sessions. Kuckertz et al. (2019), in turn, defined WSH as the slope of fear ratings across an exposure session. Second, even the operationalization of WSH that has been used in most studies—peak fear minus end fear—might not be a measure with high validity. Taking the following exposure session for acrophobia as an example: A patient and therapist climb a tower and, once at the top, wait for fear to decline. Next, they approach the railing, bend over, and again wait for fear to decline. A patient who did both exercises in a single session would have had a stronger opportunity to experience a decline in fear, compared to a patient who would have only conducted the first part of the exposure. Still, both patients would score the same on WSH as only peak and end fear are taken into account. For this reason, the total amount of decline in fear might be better operationalized by the variance of fear during an exposure. Indeed, several studies showed that higher variability in fear responding during an exposure session predicted better therapy outcome (Culver et al., 2012; Kircanski, Mortazavi, et al., 2012; Kircanski & Peris, 2015, but see also Jacoby et al. 2019). Another problematic aspect of current operationalizations of WSH is that they do not take the possible effect of fear-reducing behaviors into account. For example, if fear in the previously described exposure exercise declines as a result of holding on to a railing, the patient might learn that fear declines when holding on to the railing. This would however not be reflected in measures of WSH (see also Benito & Walther, 2015).

Regarding BSH, the assumption that stronger BSH indicates superior treatment outcome receives support from sixteen studies (Bluett, Zoellner, & Feeny, 2014; de Kleine et al., 2017, 2015; Foa et al., 1983; Gallagher & Resick, 2012; Harned et al., 2015; Jaycox et al., 1998; Kamphuis & Telch, 2000; Kircanski, Mortazavi, et al., 2012; Kircanski, Wu, & Piacentini, 2014; Kozak et al., 1988; Minnen & Foa, 2006; Minnen & Hagenaars, 2002; Rauch, Foa, Furr, & Filip,

2004; Sripada & Rauch, 2015; Telch et al., 2004). Seven studies could not find a relationship between BSH and treatment outcome (Lang & Craske, 2000; Meuret et al., 2012; Peterman et al., 2016; Pitman et al., 1996a, 1996b; Rowe & Craske, 1998b; Tsao & Craske, 2000), and five studies reported mixed results (Baker et al., 2010; Kircanski & Peris, 2015; Kuckertz et al., 2019; Nacasch et al., 2015; Rothbaum et al., 2014). Taken together, although BSH received the most support of all three EPT indicators, evidence is still mixed. Furthermore, also studies on BSH suffer from methodological issues such as different measures used and inconsistencies in operationalization (e.g., BSH as the differences between peak fear from successive sessions, averaged across sessions, de Kleine et al. 2017; BSH as peak fear of the first session minus peak fear of the last session, Peterman et al. 2016; or BSH as the slope of peak fear across sessions, Kuckertz et al. 2019). Another issue in the interpretation of BSH is that exposure exercises are typically conducted gradually, i.e., with increasing difficulty across sessions. No decrease in peak fear across sessions could be an effect of increasing difficulty of exposures and might therefore not necessarily indicate unsuccessful treatment (Benito & Walther, 2015).

In summary, although there is a large number of studies on the EPT indicators, evidence for their predictive power remains inconsistent. This lack of evidence led to several modifications to the EPT (Foa et al., 2006; Foa & McNally, 1996), but it is still unclear whether these revised versions are an adequate theoretical foundation of exposure therapy. On grounds of the inconsistent results regarding the EPT indiators, Craske et al. (2008) proposed the inhibitory learning model as an alternative to the EPT.

2.3.2 Inhibitory Learning Model

The inhibitory learning model (Craske et al., 2008, 2014) builds upon learning theories and fear extinction research (Craske, Hermans, & Vervliet, 2018). The basic assumption of the theory is that the mechanism underlying exposure therapy is fear extinction (i.e., the presentation of the CS without the US; Craske et al., 2014; Tolin, 2019). During fear extinction, new inhibitory associations (called CS–noUS association) are formed that, once learned, actively inhibit the pathological CS–US association (Craske et al., 2014). The inhibitory learning model predicts exposure to be most effective, if (1) it produces optimal conditions for the formation of CS–noUS associations, and if (2) these associations can later be retrieved readily (Weisman & Rodebaugh, 2018). The theory itself consists of several strategies for enhancing inhibitory learning and its retrieval (Craske et al., 2014). The underlying mechanism by which inhibitory associations are formed is *expectancy violation*. If, for example, a height-fearful patient expects to fall off (US) a balcony (CS), then exposure to a balcony without falling off (no US) violates these expectancies (CS–US association). The inhibitory learning model puts these disconfirming experiences in the center of exposure sessions. Further strategies are thought to enhance expectancy violation and thereby facilitate

inhibitory learning (e.g., deepened extinction, that is combining multiple CSs in a single exposure session, Craske et al., 2018), optimize consolidation of newly learned inhibitory associations (e.g., mental rehearsal, that is debriefing the exposure session by asking the patient what was learned during the session, Craske et al., 2018), and enhance retrieval of inhibitory associations (e.g., conducting exposure sessions in multiple contexts, for example alone vs. accompanied, Craske et al., 2018). Laboratory fear conditioning and fear extinction studies in animals and humans back the recommended strategies (Craske et al., 2018). However, the clinical studies that are available offer mixed evidence for the single strategies (Weisman & Rodebaugh, 2018).

The following section reviews research on the strategies of the inhibitory learning model for improving treatment outcome in exposure therapy. Included are studies on different anxiety disorders, as well as PTSD and OCD, in both clinical and analogue samples, but not findings from fear conditioning studies. Studies were searched in Web of Knowledge and Google Scholar using the search terms "`exposure therapy`" and the respective names of the inhibitory learning strategies (e.g., "`expectancy violation`", "`deepened extinction`"). Furthermore, reference lists of previous reviews and studies were scanned, and a citation search for Craske et al. (2008) on Google Scholar was conducted. If meta-analyses exist for a specific strategy, only newer studies together with the findings from the meta-analyses will be reported.

2.3.2.1 Improving the development of non-threat associations

Expectancy violation

Expectancy violation is the mechanism by which new inhibitory associations are formed (Craske et al., 2008, 2014). This is supported by prediction-error models such as the Rescorla–Wagner model, which proposes new learning to be dependent upon a mismatch between expectancy and outcome (Rescorla & Wagner, 1972). In the original formulation of the EPT, an indicator of successful exposure was WSH (Foa & Kozak, 1986). In the inhibitory learning model, a comparable indicator would be the extent to which expectancies of feared outcomes are violated.

Only few clinical studies assessed whether the extent of expectancy violation or specifically targeting expectancy violation during treatment is predictive of treatment outcome. In the overarching study of the data reported in Baker et al. (2010), two exposure conditions for acrophobia were compared: exposures that were long enough to violate patients' previously measured expectancies regarding the occurrence of their feared outcome and exposures that were of shorter duration (aiming for durations that were too short to violate expectancies). The results showed that multiple shorter exposures were as effective as fewer longer exposures, disagreeing with the assumption that exposures must be long enough to violate expectancies (see also Baker, 2012). In a study with spider phobics, Raes, Koster, Loeys, and De Raedt

(2011) compared a standard exposure with an exposure treatment that was designed to test patients maladaptive cognitions regarding spiders specifically. The results of the study showed that both interventions were equally effective in reducing spider-related fear and maladaptive cognitions as well as in decreasing behavioral avoidance. Another study in participants with elevated anxiety sensitivity compared a standard interoceptive exposure (three trials of 60 s hyperventilation) with an intensive interoceptive exposure (Deacon et al., 2013). In the intensive interoception exposure group, hyperventilation trials were repeated until participants rated the likelihood for the occurrence of their feared outcome less than 5%. Participants in the intensive interoceptive exposure group had better outcomes in both subjective measures and a behavioral test. However, one should be cautious when interpreting expectancy violation as the driving mechanism behind the improved outcome in this study. First, participants in the intensive exposure group had an average of 9.33 exposure trials (vs. 3 trials in the standard exposure condition), making the finding possibly an effect of exposure dose. Second, ratings of fear after each trial declined simultaneously with the ratings of the likelihood of the occurrence of the feared outcome. One could, therefore, also argue that the improved treatment outcome is due to lower end fear. Another study in PTSD patients tested whether expectancy violation during imaginal exposure and changes in threat expectancies between exposure sessions predicted treatment outcome (de Kleine et al., 2017). Expectancy violation during sessions was defined as the difference in ratings for harm expectancy before and harm experience after an exposure session. Change in expectancies was defined as the mean successive difference in harm expectancy scores between sessions. The results showed that neither expectancy violation nor change in harm expectancies predicted treatment outcome. In a study in youth with OCD, Guzick, Reid, Balkhi, Geffken, and McNamara (2018) tested whether affective expectancy violations during exposure were predictive of treatment outcome. Guzick et al. (2018) measured predicted distress before and actual distress after exposure sessions and calculated two indices: average prediction accuracy (the difference between predicted and actual distress) and variability in prediction accuracy across exposure sessions. The latter of both indices was associated with treatment outcome in such a way that higher variability in prediction accuracy was associated with better treatment outcome. Guzick et al. (2018) argue that high variability in prediction accuracy signaled more opportunities for expectancy violation and this, in turn, led to improved outcome. In another study with spider-phobic patients, Blakey et al. (2019) compared two exposure conditions: one group was allowed to use safety behaviors during the first two exposures, and the other was not. Ratings before each exposure session indicated that patients who were not allowed to use safety behaviors had higher harm expectancies. From an inhibitory learning point of view, this group had a higher potential to violate their expectancies. However, treatment outcome at both post-treatment and one-month follow-up did not differ between conditions.

In sum, although the inhibitory learning model regards expectancy violation as the *de facto* mechanism underlying exposure treatments, evidence from clinical studies is scarce.

Deepened extinction

Deepened or *compound extinction* describes a strategy where either multiple CSs are first extinguished separately and subsequently together, or when an already extinguished CS is combined with a non-extinguished CS (Craske et al., 2018). Although both strategies have been found effective in human fear extinction studies (Coelho, Dunsmoor, & Phelps, 2015; Culver, Vervliet, & Craske, 2015), there have not yet been any published clinical studies that investigated deepened extinction in exposure therapy (Craske et al., 2018; Weisman & Rodebaugh, 2018). In one unpublished study in spider-fearful and snake-fearful participants, Lancaster (2017) compared a one-session exposure *in vivo* using deepened extinction vs. control conditions without deepened extinction. In all conditions, participants first received two trials of exposure to two different spiders or snakes. In the deepened extinction condition, the third exposure trial consisted of a confrontation to both spiders or snakes at the same time. In the control conditions, the third exposure trial was conducted with one of the animals from the first two trials. At post-treatment and one-week follow-up, there were no differences in treatment outcome between conditions, neither on behavioral measures nor in questionnaires.
So far, there is not enough evidence from clinical studies to conclude if deepened extinction is improving treatment outcome.

Occasional reinforced extinction

Occasional reinforced extinction describes a treatment strategy where, during exposure, the US is delivered once in a while to the patient (Craske et al., 2014). Examples for this strategy are inducing a panic attack during exposure for panic disorder or a social rejection during exposure for social phobia (Craske, 2015). The strategy is, however, not applicable for every US (e.g., the fear of falling off a bridge). To date, there have not yet been any clinical studies that evaluated effects of adding occasional reinforced extinction in exposure therapy[1].

Attention

The inhibitory learning model proposes that attention to both the CS and non-occurrence of the US are crucial for inhibitory learning (Craske et al., 2018, 2014). Following the theory, the CS must be salient during extinction learning; otherwise, a different stimulus could be associated with the non-occurrence of the US. Several studies tested whether focused attention vs. distraction in exposure therapy affected treatment outcome. In their meta-analysis, Podină,

[1]Notably, two recent fear conditioning studies showed that occasional reinforced extinction reduces return of fear (Culver, Stevens, Fanselow, & Craske, 2018; Thompson, McEvoy, & Lipp, 2018).

Koster, Philippot, Dethier, and David (2013) conclude that distraction during exposure in specific phobia was not detrimental to treatment outcome. Under some conditions (e.g., using an interactive distractor), results were even in favor of distracted exposure. Since this meta-analysis, only a few studies assessed the effects of focused attention vs. distraction on exposure therapy outcome. Dethier, Bruneau, and Philippot (2015) exposed spider phobics to spider images (4 × 5 min) and asked them to form mental images of spider-related concepts (e.g., spider, net) vs. of non-spider concepts (e.g., steel, pen), vs. an exposure-only control condition. At 16-days follow-up, patients who imagined non-spider concepts during exposure had stronger fear responses than patients who imagined spider-related concepts (on two out of six outcome measures). However, there were no significant differences between patients who were distracted by non-spider images vs. exposure-only patients. In a VRET study in patients with fear of flying, Shiban et al. (2017) compared exposure-only vs. a diaphragmatic breathing exercise during exposure. Although patients in the latter group were asked to focus on and continuously maintain a steady breathing cycle (and thereby possibly shifting attention away from the CS and non-occurrence of the US), this exercise was not detrimental to treatment outcome.
In sum, research on the optimal attentional focus during exposure is inconclusive.

Removal of safety signals and behaviors

A *safety signal* is a predictor of the absence of the US (Craske et al., 2008). For example, a person with acrophobia might feel safe in height situations when being accompanied by a friend. *Safety behaviors* are actions which are performed to prevent, escape from, or reduce the outcome of a feared catastrophe (Telch & Lancaster, 2012), e.g., holding on to a railing to prevent falling off from a bridge. Both strategies have been linked to the onset and maintenance of anxiety disorders, and are also thought to negatively influence exposure therapy outcome (see Helbig-Lang & Petermann, 2010, for a review). According to the inhibitory learning model, both safety signals and safety behaviors are thought to reduce threat expectancies (i.e., the likelihood for the occurrence of the US, Craske et al., 2014), and thereby lower the amount of expectancy violation (e.g., “the feared catastrophe did not occur because I used my safety behavior”). A study with spider-phobic patients showed that indeed safety behaviors reduced harm expectancies (Blakey et al., 2019). However, contrary to the assumptions of the inhibitory learning model, this was not detrimental to treatment outcome. Patients who had lower harm expectancies through safety behavior utilization improved just as much from the exposure treatment as patients who were not allowed to use safety behaviors.
In their meta-analysis on the effects of safety behaviors on treatment outcome, Meulders, Van Daele, Volders, and Vlaeyen (2016) could not find that elimination of safety behaviors was beneficial for treatment outcome, although the effect size pointed in this direction

($g = .31$, 95% CI [-.04, .66]). In an unpublished meta-analysis, Lancaster (2017) reported that elimination of safety behaviors in exposure therapy yielded better treatment outcome, $g = .44$, 95% CI [.21, .67].

Taken together, the meta-analyses offer some support to the strategy to eliminate safety behaviors in exposure therapy. However, several questions regarding the use of safety behaviors remain unanswered. Rachman, Radomsky, and Shafran (2008) argue that a judicious use of safety behaviors could be beneficial for exposure treatments, for example by facilitating approach behavior to the feared stimulus. In line with this, Hoffman and Chu (2019) stress the importance of differentiating between dysfunctional safety behavior and functional coping behavior.

2.3.2.2 Improving the consolidation of non-threat associations

Mental rehearsal

Mental rehearsal of CS–noUS associations means discussing with the patient after an exposure session "what is learned regarding the non-occurrence of the feared event, discrepancies between what was predicted and what occurred, and the degree of 'surprise' from the exposure practice" (Craske et al., 2014, p. 12). Furthermore, mental rehearsal can be implemented by asking the patient to mentally rehearse what was learned in an exposure session in the days after the exposure took place.

The effect of mental rehearsal on exposure therapy outcome has, to my knowledge, only been investigated in a single unpublished study (Joos, 2011). Patients with different anxiety disorders who received individual or group-based therapy with exposure *in vivo* received either instructions to mentally rehearse preceding exposure sessions in the week after these had taken place vs. no instructions for the time between exposure sessions. Results showed a tendency towards better outcome in the rehearsal condition.

In summary, no clear conclusion can be drawn towards the effects of mental rehearsal on exposure therapy outcome.

***N*-methyl-D-aspartate agonists**

In the initial formulation of the inhibitory learning model, Craske et al. (2008) discussed the use of a cognitive enhancer, D-cycloserine (DCS), for the facilitation of fear extinction. Earlier research in rats showed that both fear conditioning and fear extinction are dependent on NMDA-type (*N*-methyl-D-aspartate) glutamate receptors in the amygdala (Walker & Davis, 2002). DCS is a partial agonist at the glycine recognition site of the NMDA receptor (Hofmann, 2014), and administration of DCS before fear extinction training showed facilitation of fear extinction in rats (Walker & Davis, 2002). Early clinical studies in humans supported these promising results. For example, in a study with height-phobic patients, Ressler et al. (2004) found that administration of DCS before exposure therapy resulted in improved outcome

compared to placebo. However, later studies showed somewhat mixed findings. In a study by Smits et al. (2013) with acrophobic patients, DCS improved outcome only in patients whose fear was low at the end of an exposure session. For patients whose fear was still high, the DCS group had worse outcomes than the placebo control group. Furthermore, several other studies reported no effect of DCS on exposure therapy outcome or even worse outcomes when compared with placebo (Hofmann, 2014). From a meta-analytic perspective, although earlier meta-analyses found improved outcomes for DCS-augmented exposure therapy (Norberg, Krystal, & Tolin, 2008; Rodrigues et al., 2014), newer meta-analyses question the benefits of DCS (Bürkner, Bittner, Holling, & Buhlmann, 2017; Mataix-Cols et al., 2017). To this regard, Hofmann (2014) concludes that DCS may have a small therapeutic window (e.g., efficacy depending on session process variables like "low fear at the end of the session"), which needs further exploration.

Besides DCS, the influence of several other pharmacological agents on fear extinction and exposure therapy has been investigated (Hofmann, Mundy, & Curtiss, 2015; Singewald, Schmuckermair, Whittle, Holmes, & Ressler, 2015). Although the results for some substances seem promising (e.g., glucocorticoids, de Quervain, Schwabe, & Roozendaal, 2017), others have recently failed in clinical studies (e.g., yohimbine, propranolol, Meyerbröker, Morina, & Emmelkamp, 2018; dexamethasone, Maples-Keller et al., 2019).

Current research on pharmacological agents in exposure therapy is inconclusive and more research is needed before clinical application can be advised.

Sleep

Sleep plays a vital role in several aspects of emotion regulation (Goldstein & Walker, 2014). Because it is also crucial for memory consolidation, sleep as a strategy to improve the consolidation of inhibitory associations has been proposed by Pittig, van den Berg, and Vervliet (2016). In their review on sleep in fear conditioning and extinction, Pace-Schott, Germain, and Milad (2015) summarize that strategically timed sleep may be an option to strengthen and generalize extinction memory in treatments for anxiety disorders.

In a clinical analogue study, Pace-Schott, Verga, Bennett, and Spencer (2012) showed several spider videos to spider-fearful participants, aiming for extinction of fear responses. After extinction learning, participants were divided into two groups: a sleep group that got a full nights sleep before the second session twelve hours later, and a waking group. When being presented again with spider videos (including videos of new spiders), participants in the sleep group showed decreased skin conductance responses (SCRs) to previously seen videos (extinction augmentation) and lower responses to novel spider videos (extinction generalization).

The effects of sleep on treatment outcome of exposure therapy in a clinical setting has been investigated in two studies. In a study by Kleim et al. (2014), two groups of spider phobic

patients received one session of VRET. After the exposure session, patients in one group slept for 90 min, whereas the patients in the other group stayed awake. In the test session a week later, those patients who took a nap directly after the exposure reported less fear and fewer catastrophic spider-related cognitions when confronted with a real spider. In a study in social phobics, naps directly after exposure sessions did neither improve treatment outcome on a subjective nor on a physiological level (Pace-Schott et al., 2018).
Further studies are needed to elaborate on these inconsistencies in order to find out whether sleep after exposure is an adequate augmentation strategy.

2.3.2.3 Retrieval of non-threat associations

Retrieval cues

Research on return of fear phenomena has shown that inhibitory CS–noUS associations are context-dependent, i.e., a context change after fear extinction increases the likelihood of a return of fear, so-called fear renewal (Bouton, 2004). One strategy to attenuate this context effect is the use of *retrieval cues*. For example, wearing the same wristband in both the exposure treatment as well as when later being confronted with the feared stimulus is thought to facilitate retrieval of the CS–noUS association. Retrieval cues can be divided into *external* (e.g., a wristband, a pen) and *internal* cues (mentally retrieving the exposure session; de Jong, Lommen, de Jong, & Nauta, 2018).
External retrieval cues. In an analogue study in participants with a fear of public speaking, Culver, Stoyanova, and Craske (2011) tested the effects of retrieval cues (participants wearing a lab coat and using an unique pen and clipboard) on fear renewal at one-week follow-up after a one-session exposure treatment. In two experiments, the use of retrieval cues did not lead to an attenuation of return of fear when compared to no retrieval cues[2]. In another study with spider-fearful participants, Dibbets, Moor, and Voncken (2013) compared an exposure that was augmented with an external retrieval cue (a colored rubber bracelet with citronella odor) vs. without retrieval cue. At one-week follow-up, participants were confronted with a spider either in the same or in a new context. The retrieval cue did not have any effects on spontaneous recovery of fear (same context) or fear renewal (new context). In a study in participants with a fear of public speaking, Laborda et al. (2016) compared exposure that was augmented with either a physical retrieval cue ("a neon green clipboard and a pen with feathers and a jester on top", Laborda et al., 2016, p. 906) vs. an internal retrieval cue (instruction to carefully re-imagine the exposure and what was learned) vs. a control condition. On a renewal test two days after the exposure session, all three conditions showed a return of fear but there were no differences between conditions. In a study with participants with a fear of public speaking, Shin and Newman (2018) compared exposure with retrieval

[2] An effect of retrieval cues on renewal was visible in one of the two experiments in a single dependent variable, but only after dichotomization of the variable.

cues vs. without retrieval cues. Use of retrieval cues attenuated spontaneous recovery on a behavioral (duration of speech) and physiological level (HR). However, Shin and Newman (2018) note that some participants perceived the retrieval cues as safety cues, and these participants showed worse outcomes than participants for whom the retrieval cues were a reminder for the fear during the exposure.

Internal retrieval cues. In an analogue study in spider-fearful participants, Mystkowski, Craske, Echiverri, and Labus (2006) compared the effects of internal retrieval cues (i.e., mentally retrieving the exposure treatment session) vs. a control condition. Participants received a one-session exposure therapy *in vivo* and were tested at one-week follow-up. Participants who were tested in a novel context (renewal test) and used mental retrieval cues showed less return of fear than participants who did not mentally retrieve the exposure session. For participants who were tested in the same context as the treatment context, no differences between conditions were evident. In a study with dental phobic patients, Elsesser, Wannemüller, Lohrmann, Jöhren, and Sartory (2012) compared effects of internal retrieval cues (i.e., mentally retrieving the exposure treatment session) vs. a control condition (i.e., remembering everyday activities) at a renewal test one week after a one-session exposure treatment. In the renewal test, patients were asked to pick up three different dental instruments and the time until these were picked up, as well as fear ratings and HR were measured. There were no differences in fear ratings and HR between groups. For the latency until the dental instruments were picked up, there was a significant difference between the retrieval conditions for one of the three instruments. Patients in the mental retrieval condition picked up a forceps 1.31 s faster than the control condition. A more recent study already discussed at the external retrieval cues which also included a mental retrieval condition could not find any effects of mental retrieval cues on attenuating renewal (Laborda et al., 2016).

In sum, evidence for the efficacy of retrieval cues is inconclusive as both positive and negative results have been found.

Multiple contexts

As discussed in the previous section, retrieval of CS–noUS associations is context dependent (Bouton, 2004). For this reason, varying the contexts in which exposure therapy is conducted is thought to facilitate the retrieval of CS-noUS associations. In a study with spider phobic patients, Shiban, Pauli, and Mühlberger (2013) compared a single context exposure with a multiple context exposure using differently lid virtual rooms. When tested directly after the 20-minute exposure session, patients in the single context condition showed stronger renewal effects than patients in the multiple context condition. In another study in patients with fear of spiders, Shiban, Schelhorn, Pauli, and Mühlberger (2015) compared VRET in one context with VRET in four different contexts (different virtual rooms). Although patients in the multiple context condition showed lower SCR than patients in the single context condition at

post-test, this was reversed at follow-up, with higher SCR in the multiple context condition. In a behavioral avoidance test (BAT), there was no difference between both conditions. In an analogue study with spider-fearful participants, Bandarian-Balooch, Neumann, and Boschen (2015) compared a one-session exposure *in vivo* in one context with exposure in three different contexts. At one-week and four-week follow-up, the multiple context condition performed better on a renewal test, indexed by fear ratings, HR, and avoidance. In an analogue study with snake-fearful participants, Olatunji, Tomarken, Wentworth, and Fritzsche (2017) used videos of snakes (14 × 60 s) that showed either a snake in the same or snakes in three different contexts. Although the group of participants that was confronted with single context snake videos showed lower levels of fear at post-measurement, the fear levels increased at a renewal test. Directly comparing fear levels at the renewal test, however, both groups showed similar fear responses. During a BAT, the multiple context condition performed better.
As results of the studies have been both positive and mixed, conducting exposure in multiple contexts seems to be a potentially benefical treatment augmentation strategy.

Scopolamine

Further building upon the context-dependency of CS–noUS associations, a strategy proposed by the inhibitory learning model is to pharmacologically block the contextual encoding in the hippocampus during extinction training using scopolamine, a muscarinic cholinergic antagonist (Craske, 2015; Craske et al., 2018). Administration of scopolamine before fear extinction led to an attenuation of fear renewal in rats (Zelikowsky et al., 2013).
In a study in patients with a fear of public speaking, Craske, Fanselow, Treanor, and Bystritksy (2019) compared the effects of two doses of scopolamine (0.5 mg and 0.6 mg) vs. placebo on outcomes of seven sessions of VRET. There was little evidence that scopolamine attenuates fear renewal, namely 0.6 mg scopolamine outperforming placebo in one out of four skin conductance measures, but placebo outperforming 0.6 mg scopolamine on distress ratings[3]. So far, there is insufficient evidence to conclude that scopolamine improves exposure therapy outcome.

2.3.2.4 Additional strategies for the development and retrieval of non-threat associations

Variability

In the inhibitory learning model, the term *variability* has been used to describe four different augmentation strategies: Stimulus variability, variability in exposure timing, variability in

[3]Notably, one experimental condition (0.4 mg scopolamine) and several outcome measures that were pre-registered (Clinicaltrials.gov Identifier NCT01900301) were not reported in the paper.

exposure difficulty, and variability in fear levels. These strategies will be discussed separately below.

First, *stimulus variability* refers to the presentation of different fear stimuli in an exposure treatment (Craske et al., 2018). For example, in acrophobia, an exposure treatment could be conducted on either a single site, or on a balcony, a bridge, a tower, and a ladder. In a study with spider-fearful participants, Rowe and Craske (1998b) compared exposure to one spider vs. exposure to four different spiders. Although the treatment was effective in both conditions, the group using only one exposure stimulus showed a stronger return of fear at follow-up than the group with multiple stimuli. However, when participants were confronted with a novel spider, both groups performed equally well. In a study with height-fearful participants, Lang and Craske (2000) compared twelve exposure trials in a single height location vs. two times six exposure trials in two different height locations. At follow-up, both conditions performed equally well. In a study with patients with fear of spiders, Shiban, Schelhorn, et al. (2015) compared VRET to one spider with VRET to four different spiders. When confronted with real spiders at post-treatment and two-week follow-up, those patients who had conducted the single spider exposure showed stronger fear responses towards a domestic house spider, but not towards a tarantula. In a study with contamination-fearful participants, Kircanski, Mortazavi, et al. (2012) compared a three-session exposure *in vivo* that included either confrontation to one feared stimulus per exposure session or confrontation to all three stimuli in each session. At post-measurement and two-weeks follow-up, both groups performed equally well on all outcome measures.

Second, the *variability in exposure timing* strategy suggests that exposure trials should be conducted with expanding time between trials (vs. massed exposure or constant time between exposure trials) (Craske et al., 2008). The rationale is based on the *new theory of disuse* (Bjork & Bjork, 1992; Rowe & Craske, 1998a) which proposes that successful retrieval of memories increases their storage strength. Increasing the time between exposure sessions (and thereby increasing the difficulty of retrieving learned CS–noUS associations) should increase the strength of CS–noUS associations. In a study with spider-fearful participants, Rowe and Craske (1998a) compared a massed exposure (four exposure trials on a single day) vs. an expanding-spaced exposure (one exposure trial on days 1, 2, 4, and 8 respectively). Compared with the performance at post-treatment, the massed exposure condition showed a return of fear at 1-month follow-up, whereas the expanding-spaced condition did not. However, directly comparing fear levels at follow-up, there was no difference between conditions. Furthermore, at a generalization measure, the massed group showed some return of fear towards a novel spider at post-measurement, whereas the expanding-spaced condition did not. However, again directly comparing the performance of both conditions at follow-up, there were no differences in treatment outcome. In a study with height-fearful participants, Lang and Craske (2000) compared a massed exposure (four exposure trials on a single day) vs. an expanding-spaced exposure (one exposure trial on days 1, 2, 4, and 8 respectively).

At post-treatment and one-month follow-up, there were no differences between groups on questionnaires as well as self-reported fear during a BAT. Contrary to the assumption, heart-rate during the BAT indicated lower fear levels for the massed exposure group. In a study in participants with a fear of public speaking, Tsao and Craske (2000) compared a massed exposure (four exposure trials on a single day) vs. an uniform-spaced exposure (one exposure trial every five days) vs. an expanding-spaced exposure (one exposure trial on days 1, 2, 6, and 16 respectively). The results showed that, at 1-month follow-up, the massed exposure condition showed a return of fear, i.e., subjective fear levels were back at baseline. Both spaced exposure conditions performed equally well; however, the uniform-spaced exposure had a higher attrition rate than the expanding-spaced exposure.

Third, *variability in exposure difficulty* refers to a strategy that, instead of conducting exposures hierarchically—that is progressing from the least to the most difficult fear stimulus or situation—to confront patients variably (e.g., by randomly picking a situation from the fear hierarchy). In the study with contamination-fearful participants by Kircanski, Mortazavi, et al. (2012) that was described at stimulus variability, the two exposure conditions also differed in how items from the fear hierarchy were picked. In the first group, items across sessions and exposure tasks within sessions were progressed from least difficult to most difficult. In the second group, items and exposure tasks were randomly picked from the fear hierarchy. As described before, both groups did not differ in outcome measures at post-measurement and two-weeks follow-up. In an analogue study in participants with obsessional thoughts, Jacoby et al. (2019) compared a gradual hierarchical exposure procedure vs. a variable procedure (i.e., picking items randomly from the fear hierarchy). Both groups received three exposure sessions, and the outcome was measured after treatment and at one- and three-month follow-up. Both, questionnaires and a BAT, showed an improvement in both conditions, but hierarchical and variable exposure did not differ in their efficacy. However, although not statistically significant at group comparison, the variable group continued to improve from post to three-month follow-up in questionnaire measures, whereas the hierarchical group did not.

Fourth, several studies found evidence that *variability in fear levels* during exposure sessions predicts treatment outcome. In a study with contamination-fearful participants, Kircanski, Mortazavi, et al. (2012) found that higher variability in subjective fear during exposure predicted lower anticipatory and actual subjective fear during a follow-up BAT (but it did not predict outcome on questionnaires, self-efficacy ratings, and anticipatory HR and HR during BAT). In a study with participants with a fear of public speaking, Culver et al. (2012) found that increased variability in subjective fear during an exposure session predicted lower subjective fear in a BAT one week after the treatment (but it did not predict questionnaire outcome, and behavioral and physiological measures on a BAT). In a study in youth with OCD, Kircanski and Peris (2015) tested whether different process measures of exposure and response prevention predicted treatment outcome. Outcome at three-month follow-up

on the Children's Yale-Brown Obsessive Compulsive Scale (CY-BOCS) and Clinical Global Impression–Severity Scale (CGI-S) were predicted by variability in distress during exposure sessions. In a study in youth with different anxiety disorders, Waters et al. (2015) found that variability in subjective fear responses during exposure sessions predicted treatment outcome two weeks after treatment. In an analogue study in participants with obsessional thoughts, Jacoby et al. (2019) found that neither variability in subjective fear nor in skin conductance or HR predicted exposure outcome at three-month follow-up.

Taken together, results from clinical and clinical analogue studies do not strongly support the four variability strategies. Evidence for variability in fear levels predicting treatment outcome seems most promising, but its interpretation must remain very cautious. As the studies on variability in fear levels have been cross-sectional, no conclusion should be drawn with regards to intraindividual effects of high vs. low variability in fear levels (Fisher, Medaglia, & Jeronimus, 2018). In other words, there is yet no evidence to support the hypothesis that increasing variability in fear levels for a given patient improves her treatment outcome.

Positive affect

Fear extinction changes threat expectancies; however, negative valence towards fear stimuli may still be present after successful exposure (Zbozinek, Hermans, Prenoveau, Liao, & Craske, 2015). A conditioning study showed that negative valence of CS+ after fear extinction predicted stronger reinstatement[4] (but not spontaneous recovery; Zbozinek, Hermans, et al., 2015). Building upon this finding, the inhibitory learning model proposes two ways in which *positive affect* may be used to enhance exposure therapy outcome.

First, a *positive affect induction* prior to extinction training in a fear conditioning study led to less reinstatement (Zbozinek, Holmes, & Craske, 2015) and more positive affect before and after extinction predicted less reacquisition (Zbozinek & Craske, 2016). There have, however, not yet been any clinical studies investigating the effects of positive affect induction on exposure therapy outcome (Zbozinek & Craske, 2017).

Second, *positive valence to feared stimuli* describes a strategy to modify negative valence towards feared simuli directly. In a study with spider-fearful participants, Dour, Brown, and Craske (2016) compared the effect of a positive valence training after exposure (watching a video designed to induce positive valence towards spiders) vs. a control condition. At post-test, participants in the positive valence condition reported less subjective fear towards spiders and had lower behavioral avoidance in a BAT after reinstatement.

In sum, negative valence towards feared stimuli and situations after successful exposure as well as negative affect in general might be factors that contribute to a return of fear (Zbozinek & Craske, 2017). However, clinical studies that evaluate the effiacy of positive affect strategies are lacking.

[4]Reinstatement describes a procedure where, after successful fear extinction, the US is applied without being signaled by the CS (Zbozinek, Hermans, et al., 2015).

2.3.2.5 Optimizing inhibitory regulation

Affect labeling

Affect labeling is an emotion regulation strategy that can be described as 'putting feeling into words' (Lieberman et al., 2007; Lieberman, Inagaki, Tabibnia, & Crockett, 2011). Applied to exposure therapy, affect labeling encourages patients to verbalize their emotional responses (Craske et al., 2018). It is not directly related to inhibitory learning per se, but seen as a complement or augmentation strategy for inhibitory learning (Craske et al., 2018).
In an analogue study in spider-fearful participants, Kircanski, Lieberman, and Craske (2012) compared two sessions of exposure *in vivo* augmented with either affect labeling (e.g., "I feel anxious the disgusting tarantula will jump on me"), reappraisal (e.g., "Looking at the little spider is not dangerous for me"), distraction (e.g., "There is a television in front of my couch in the den"), or exposure alone. Participants in the affect labeling condition showed the strongest attenuation of SCR in a BAT from post-test to one-week follow-up (attenuation from pre-test to post-test did not differ between conditions, attenuation from pre-test to follow-up was not calculated). For approach behavior and fear ratings during the BAT, there were no differences between conditions. In an analogue study in participants with a fear of public speaking, Niles, Craske, Lieberman, and Hur (2015) compared two sessions of exposure *in vivo* either augmented with affect labeling (e.g., "I feel nervous. The audience will be disinterested.") or exposure-only (control condition). Participants gave a BAT speech before and directly after treatment and at five-days follow-up. From post-test to follow-up, there was an increase in HR in the control condition but not in the affect labeling condition (but no significant difference between conditions at either time point). Furthermore, non-specific SCRs after the BAT speech was given decreased (at trend level) from post to follow-up in the affect labeling group but not in the control group (but again with no differences between conditions at either time point). For HR and non-specific SCRs in anticipation of the speech, SUDS, and fear of public speaking measured via questionnaire, there were also no differences between conditions at either time point. In an analogue study in participants with fear caused by traumatic events, Brown et al. (2018) compared three computer-delivered imaginal exposure conditions: exposure augmented with affect labeling vs. exposure augmented with distraction vs. exposure-only (control). Contrary to the study's hypotheses, affect labeling, compared with the other conditions, did not improve treatment outcome on self-reported PTSD symptoms. On a physiological outcome measure, both linguistic processing conditions outperformed the exposure-only condition, but affect labeling was not more effective than distraction (describing an object or piece of furniture from one's home).
Although there is initial evidence that affect labeling is beneficial for exposure-based treatments, studies are needed to evaluate the effects in clinical samples.

2.3.2.6 Other strategies

Reconsolidation

Inhibitory learning builds on the assumption that the original CS–US association is not altered during exposure therapy, but instead a new CS–noUS association is formed, which competes actively with the CS–US association. Interestingly, some studies indicate that there may be an approach to actually modify CS–US associations (Walsh, Das, Saladin, & Kamboj, 2018). Memory research has shown that retrieving a memory from long-term storage causes this memory to enter a temporary labile state (Telch, York, Lancaster, & Monfils, 2017). In a process called *reconsolidation*, the memory is later put back into long-term storage. Studies in rats indicate that chemical blockade of this protein synthesis-dependent process—so-called *disruption of reconsolidation*—makes it possible to modify memories (Nader, Schafe, & Le Doux, 2000). Two seminal fear-conditioning studies showed that reactivation of fear memory prior to extinction (so-called *retrieval extinction*) eliminated return of fear in rats (Monfils, Cowansage, Klann, & LeDoux, 2009) and humans (Schiller et al., 2010)[5].
In a study in patients with a fear of spiders, Shiban, Brütting, Pauli, and Mühlberger (2015) compared two conditions of one-session VRET: one group that underwent a 5 s retrieval phase 10 min before exposure (using a virtual spider) vs. one control group that viewed a virtual plant. One day after the exposure session and at six-month follow-up, both groups showed an equal decline in fear of spiders, i.e., no effect of fear reactivation on treatment outcome. In a study with spider-fearful and snake-fearful participants, Telch et al. (2017) compared a one-session exposure *in vivo* with 10 s fear reactivation 30 min prior to exposure vs. a control condition. Although there were no differences between conditions at post-treatment (one day after exposure), the fear reactivation group reported lower fear at one out of two one-month follow-up BATs. Fear of spiders or snakes measured via questionnaire did not differ between conditions. In an unpublished study with spider-fearful and snake-fearful participants conducted in the same lab, Lancaster (2017) compared a one-session exposure *in vivo* with two times 10 s fear reactivation 25 min before treatment vs. conditions without fear reactivation. At post-treatment and one-week follow-up, there were no differences in treatment outcome between conditions. In a study in patients with a fear of flying, Maples-Keller et al. (2017) compared four sessions of VRET with 15 s fear reactivation 10 min before exposure vs. a control group without fear reactivation. At post-treatment and 12-month follow-up, both groups showed a similar decline in symptoms of fear of flying. Differences between treatment conditions were found on a physiological level, but these were mixed. At 3-month follow-up, the reactivation group showed higher HR in response to a flying clip in VR. Conversely, at post-treatment and 3-month follow-up, the control group showed higher

[5]Notably, both studies have recently been criticized. A direct replication of the Monfils et al. (2009) study was not successful (Luyten & Beckers, 2017). The study by Schiller et al. (2010) used a highly selected sample: in the two experiments, 48% and 72% of the participants were excluded respectively after inspection of skin conductance responses on a trial-by-trial basis (Schiller et al., 2018).

skin conductance in response to the VR clip. In a study with spider-fearful participants, Björkstrand et al. (2016) analyzed the effects of fear reactivation 10 min prior to exposure to spider pictures vs. a fear reactivation 6 h prior to exposure. On a return of fear test 24 h later, the group with 10 min fear reactivation showed less return of fear as indexed by amygdala reactivity and less avoidance behavior as indexed by a task where participants could choose to either view a spider image and receive a small amount of money or view a mushroom image and receive no money. Interestingly, this effect was still evident after 6 months (Björkstrand et al., 2017).
In sum, exposure therapy studies showed mixed results for retrieval extinction procedures.

2.3.2.7 Summary

The inhibitory learning model suggests numerous strategies to enhance the efficacy of exposure therapy. The strategies are derived from findings in fear extinction research in both rodents and humans and are therefore thought to be well-grounded (Craske et al., 2018). However, clinical and clinical analogue exposure studies on the proposed strategies have revealed mixed findings (see Figure 3 and Appendix A for a tabular representation) that do not allow a general conclusion about the benefits of inhibitory learning strategies.
Assumptions from both theories, the EPT and the inhibitory learning model, have insufficient evidence from clinical studies. Furthermore, there have been no clinical studies that aimed to compare the assumptions of both theories directly. In the present dissertation project, a study that compares two cornerstones of the theories—fear habituation vs. expectancy violation—was conducted (see 4.1).

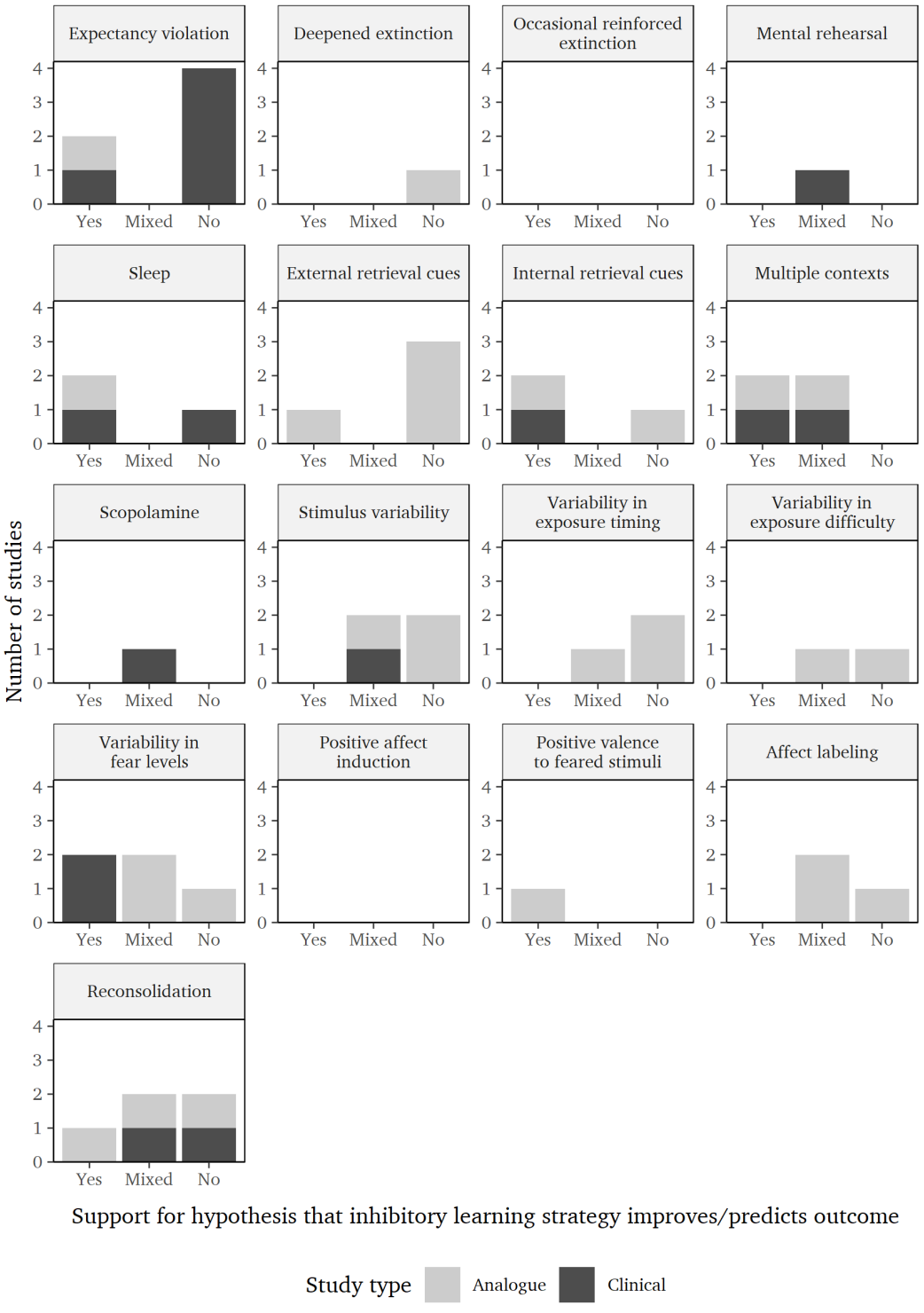


Figure 3: Overview of clinical and clinical analogue studies regarding the exposure therapy augmentation strategies proposed by the inhibitory learning model. The strategies "Attention", "Removal of safety signals and behaviors", and "*N*-methyl-D-aspartate agonists" are omitted from the figure as meta-analyses exist for these strategies, which are described in the respective sections. Graphs are empty if no clinical or clinical analogue studies exist for the respective strategies.

2.4 Virtual Reality

Although VR is a commonly used term, it has been defined quite differently by researchers over time. Whereas some definitions concentrate on the technological aspects of VR applications—such as the use of HMDs and tracked input devices—other definitions focus on what VR allows to experience, that is the illusion of actually being in a simulated environment (Steuer, 1992). Such a simulated or *virtual environment* might, for example, be a computer-generated representation of a tower or bridge for use in height exposure. In a more recent definition, Rizzo and Koenig (2017) differentiate between non-immersive and immersive VR. The former describes a setup where virtual environments are delivered on a standard computer display (e.g., computer monitor, TV). Immersive VR, on the other hand, is characterized by occlusion of the outside world using either HMDs or large projection-based systems (Computer Automatic Virtual Environments, CAVE, or Powerwalls) in combination with body-tracking sensors and specialized input devices. Data from these tracking and input devices (e.g., the user's head position and rotation) are used to update the sensory stimulation in real-time, allowing the user to interact with the virtual environment in a natural way and "creat[ing] the illusion of being immersed 'in' a virtual space" (Rizzo & Koenig, 2017, p. 4).

2.4.1 Virtual Reality Exposure Therapy

Since VR allows to create and present any kind of virtual environment to a user, it has been thought of as an ideal tool to study and treat pathological fears (Freeman et al., 2017). In VRET, virtual environments that represent phobic situations or contain phobic stimuli are used to conduct confrontations. As an example, a computer-generated basement containing spiders or a virtual dog may be used to treat fears of animals. VRET has been applied to various kinds of pathological fears, including fear of heights (Herrmann et al., 2017; Hodges et al., 1995; Krijn et al., 2004), fear of flying (Mühlberger, Weik, Pauli, & Wiedemann, 2006; Mühlberger, Wiedemann, & Pauli, 2003), spider phobia (Shiban, Schelhorn, et al., 2015), and claustrophobia (Botella et al., 1998), among others (see Freeman et al., 2017, for a review). The exposure itself is conducted similar to exposure *in vivo* (see 2.2) and efficacy of VRET has been shown in several studies (see Carl et al., 2019; Fodor et al., 2018, for the latest meta-analyses).

VRET is thought to have several advantages over exposure *in vivo* (Bouchard, Robillard, Larouche, & Loranger, 2012). First, VR allows creating any kind of situation at any time that otherwise might be difficult to obtain (e.g., a thunderstorm). Second, VR offers complete control over stimuli and situations. For example, in an exposure for fear of elevators, one can easily control the duration of a ride, how crowded the elevator is, or how small the elevator is. Third, for some phobic situations, VRET can be cheaper and require less time or effort for preparation as it can be conducted from within the therapist's office (e.g., buying plane tickets and traveling to the airport in fear of flying; keeping spiders or insects). Fourth,

patients may be more willing to conduct exposures in VR before being confronted with the real stimuli or situations (Garcia-Palacios et al., 2007).

2.4.2 Concepts

As discussed in the previous section, VR has a great potential for application in psychological treatments and research. Beside these applications of VR, research has focused on the characteristics of VR itself. The following section describes and discusses two VR-related concepts: *immersion*, the characteristics of the VR-system, and *presence*, the user's sense of 'being there' in a virtual environment. After the discussion of different definitions of these concepts, I will give a brief overview of how presence relates to fear and its treatment in VR.

2.4.2.1 Immersion

Slater defines *immersion* as the objective description of the VR system used to present a virtual environment (Slater, 1999; Slater & Wilbur, 1997) and distinguishes several aspects of immersion (Slater & Wilbur, 1997). A first aspect is to what extent the reality is occluded from the user. For example, viewing a virtual environment on a standard computer monitor still allows surrounding visual stimuli to be perceived. An HMD that blocks all incoming light, allowing the user only to see the display screen, is thought to be more immersive to this extent. A second aspect is the number of sensory modalities that are addressed by the VR system (e.g., visual, auditory, tactile, and olfactory stimuli). A third aspect is to which extent the VR surrounds the user. A system with a greater field of view, e.g., a five-sided CAVE system vs. a single-screen projection system, is thought to be more immersive to this regard. A fourth aspect regards the vividness of the display, e.g., display resolution, frame rate, quality of textures, and the lighting of the virtual environment. A fifth aspect describes to what extent behavior of the user is tracked and translated to the virtual environment. For example, a system that tracks both the user's head position and rotation is thought to be more immersive than a system that only tracks head rotation.

Contrary to the definition by Slater, which focusses on objective characteristics of the VR system, Witmer and Singer (1998) define immersion as "a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences" (Witmer & Singer, 1998, p. 227). According to this definition, immersion is not an objective description of the system but a subjective experience of the user ("I feel immersed").

In 2009, Slater put forth a new definition of immersion that is based on the concept of simulation: A system A is thought to be more immersive than a system B, if system B can be simulated in system A. For example, a VR system with a HMD that tracks both head position and head rotation can simulate what it is like to use a HMD that tracks only head rotation (Slater, 2009; Slater, Spanlang, & Corominas, 2010).

In the present dissertation, I will follow others (e.g., Cummings & Bailenson, 2016; Diemer, Alpers, Peperkorn, Shiban, & Mühlberger, 2015; Rizzo & Koenig, 2017; Schubert, 2003) and use Slater's first definition of immersion as the objective description of the VR system.

2.4.2.2 Presence

Over the last three decades, several authors defined the term *presence* in various ways to describe a user's response towards a virtual environment. Being a subjective response, it as been seen as the "experiential counterpart of immersion" (Wirth et al., 2007, p. 496). Given the variety of definitions of presence, I will in the following provide a selection of influential definitions. Slater and Usoh (1993) define the *sense of presence* as "the (suspension of dis-) belief that they [the users] are in a world other than where their real bodies are located" (Slater & Usoh, 1993, p. 222). Later, Slater, Usoh, and Steed (1994) use the term presence to describe "the participant's sense of 'being there' in the virtual environment" (Slater et al., 1994, p. 131). Lombard and Ditton (1997) define presence as the "perceptiual illusion of nonmediation". Lee (2004) defines presence as "a psychological state in which virtual objects are experienced as actual objects in either sensory or nonsensory ways" (Lee, 2004, p. 27). In the structural model of the Igroup Presence Questionnaire, Schubert (2003) differentiates three components of presence: *spatial presence*, the sense of 'being there' in the virtual environment, *involvement*, a measure of the attentional focus on the virtual vs. the real world, and *realness*, a judgment about how real the experience in the virtual world seems. In their process model on the formation of spatial presence, Wirth et al. (2007) use the description of a "conviction of being located in a mediated environment" (Wirth et al., 2007, p. 495). To avoid confusion caused by the many different definitions of presence, Slater (2009) proposes the term *place illusion (PI)* to describe "the strong illusion of being in a place in spite of the sure knowledge that you are not there" (Slater, 2009, p. 3551). Furthermore, Slater (2009) proposes the term *plausibility illusion (Psi)* to describe "the illusion that what is apparently happening is really happening" (Slater, 2009, p. 3553). In the current dissertation, I will use the term presence to describe the user's sense of 'being there' in the virtual environment.
The variety of definitions for presence is further evident in the number of different instruments that aim to measure presence, e.g., the Presence Questionnaire (PQ; Witmer & Singer, 1998), the Slater-Usoh-Steed Presence Questionnaire (SUS; Usoh, Catena, Arman, & Slater, 2000), the Igroup Presence Questionnaire (IPQ; Schubert, 2003), the MEC Spatial Presence Questionnaire (MEC-SPQ; Wirth et al., 2007), online ratings (Bouchard et al., 2004), physiological measures (e.g., skin conductance, HR; Meehan, Razzaque, Insko, Whitton, & Brooks, 2005), brain activity (Baumgartner et al., 2008), or breaks in presence (Slater & Steed, 2000).
The main factor that leads to the experience of presence in VR is thought to be immersion (Diemer et al., 2015). As an example, having an HMD with a 110° instead of a 45° field of view better matches the human visual field of view. This, in turn, is thought to increase the

likelihood that a person focuses on the virtual instead of the real world, leading to more presence. In their meta-analysis on the effects of different characteristics of VR systems on presence, Cummings and Bailenson (2016) showed that frame rate, tracking quality, field of view, and use of stereoscopy had the most substantial effects on presence. It is, however, important to note that these effects have not been shown unequivocally. For example, although Peperkorn, Diemer, and Mühlberger (2015) could show that the use of stereoscopy led to higher online presence ratings and less awareness for acoustic breaks in presence, no difference between stereoscopic and monoscopic conditions was evident on the IPQ.

2.4.2.3 The relevance of presence for VRET

Several researchers suggested that presence is crucial for successful VRET. For example, Wiederhold and Wiederhold (2000) state that "[...] high levels of presence seem to be correlated with increased responsiveness to therapy, more dramatic treatment success, and more prolonged positive effects of the therapy" (Wiederhold & Wiederhold, 2000, p. 393). Likewise, Freeman et al. (2017) suggest that "VR has extraordinary potential to help people overcome mental health problems if high levels of presence are achieved [...]" (Freeman et al., 2017, p. 2394). Although these statements seem valid prima facie, scientific evidence is rather mixed. In a pilot study on VRET for fear of heights with six participants, Schuemie et al. (2000) could not find a correlation between presence and treatment outcome. In another study in fear of heights, Krijn et al. (2004) manipulated presence experimentally by using either an HMD or CAVE for conducting VRET. Although patients in the CAVE-condition reported higher presence, there was no effect on treatment outcome. Quero et al. (2008) analyzed outcome data from 107 VRET cases in specific phobias, panic disorder with agoraphobia, and eating disorders. Positive correlations between treatment outcome and presence were found for two subscales of the PRJQ (Presence and Reality Judgement Questionnaire; Baños et al., 2000): *emotional involvement* and *influence of the quality of software in presence and reality judgement*. In a study in social phobia, Price, Mehta, Tone, and Anderson (2011) found that the *involvement* subscale of the IPQ predicted treatment outcome. Fodor et al. (2018) conclude in their meta-analysis that there is not enough evidence to support the assumption that more presence leads to improved treatment outcome in VRET. Being not directly related to treatment outcome, presence may still be a necessary requirement for successful VRET (Price & Anderson, 2007). According to Hodges et al. (1995), presence is essential for successful VRET, because it facilitates the activation of the phobic fear structure, which is a prerequisite for successful exposure therapy according to the EPT (Foa & Kozak, 1986). Similarly, Price et al. (2011) propose that "[...] presence is the mechanism by which a virtual stimulus can elicit fear [...]" (Price et al., 2011, p. 768). This implicated causal relationship between presence and fear has however not yet been established empirically (Diemer et al., 2015; Peperkorn et al., 2015; Riva et al., 2015). So far, most studies on the

relationship between presence and fear have only been correlational. In their meta-analysis, Ling, Nefs, Morina, Heynderickx, and Brinkman (2014) report a positive, medium-sized effect for the association between presence and fear in VR. Moderator analyses showed differences between anxiety disorders, with larger effects for specific fears and no effect for social phobia. Only a few studies report on the causal relationship between presence and fear. Bouchard, St-Jacques, Robillard, and Renaud (2008) compared an anxiety-inducing virtual environment (where participants were informed that snakes could be present) vs. a neutral virtual environment. In the fear-relevant situation, participants reported a higher sense of presence, leading to the author's conclusion that fear increases presence. Robillard, Bouchard, Fournier, and Renaud (2003) found higher presence ratings in phobic vs. non-phobic participants, arguing that anxiety led to increased presence. Furthermore, using linear regression analyses, the best predictor for both presence and anxiety was the respective other measure, leading to the conclusion of the authors that presence and anxiety have a synergistic relationship. Peperkorn et al. (2015) analyzed cross-lagged correlations of multiple trials of spider exposure. On the one hand, presence ratings in the first trial predicted fear ratings in the second trial, but on the other hand, fear ratings did not predict presence ratings. In the third trial, both presence and fear were predicted by the respective other measure from the second trial. Peperkorn et al. (2015) conclude that presence predicts fear in earlier phases of exposure, whereas the relationship becomes bidirectional in later phases. So far, there has not yet been a study that manipulated both presence and fear experimentally. Possibly further related is the *presence-as-a-gateway* hypothesis (Bouchard et al., 2012; Felnhofer et al., 2014). This hypothesis states that the effect of presence on fear is not linear, but that a specific amount of presence is needed for VR to elicit emotions. Once this presence threshold is reached, further increases in presence should not affect fear responses. However, there have also not yet been any studies reporting on this hypothesis.
In summary, there is a lack of empirical evidence to support both the assumptions that presence increases treatment outcome and that presence in VR is critical for VR to elicit fear. The current dissertation project will elaborate on presence as a process variable of VR exposure, more specifically, how presence relates to the experience of fear in VR.

2.4.3 A Model of Fear in VR

Since VRET uses a mediated representation instead of the real fear stimulus during confrontation, it must be ensured that the virtual stimulus is suitable for exposure. A possible measure for the applicability of a virtual fear stimulus is the extent to which it elicits fear responses or the expectancy of a threatening event in fearful individuals. As a framework for the studies of the next part of the dissertation, I suggest a model of fear in VR (see Figure 4). The model assumes that fear—on a subjective, physiological, and behavioral level—depends on both the level of trait-fearfulness and presence. The link between trait height-fearfulness

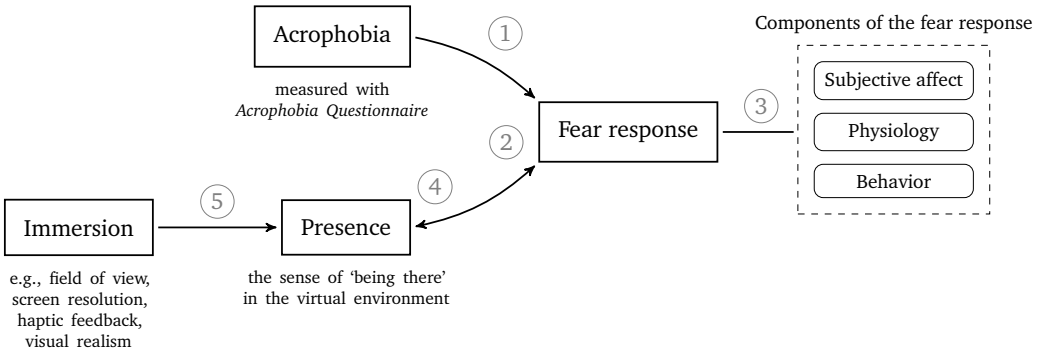


Figure 4: A model for the study of fear in virtual height situations. The fear response towards a virtual height is hypothesized to be dependent on the trait height-fearfulness and on the sense of presence in the virtual environment. Furthermore, presence is thought to be dependent upon both immersion and fear.

and fear (1) is drawn from the diagnostic criteria of specific phobia (American Psychiatric Association, 2013), assuming that trait height-fearfulness is the primary factor influencing fear responses. The presence → fear link (2) has been implicated by several authors (Hodges et al., 1995; Peperkorn et al., 2015; Price et al., 2011, see also 2.4.2.3), but so far lacks empirical evidence. The assumed three components of the fear response (3) are based on the tripartite model of fear (Lang, 1979). The model further assumes that presence in fear situations depends on fear and immersion. The fear → presence (4) link has been implicated in previous studies (Bouchard et al., 2008; Robillard et al., 2003) and the effects of immersion on presence (5) have been demonstrated in several studies (see Cummings & Bailenson, 2016, for a meta-analysis). The first four studies of the present thesis will test hypotheses derived from this model (see 2.5).

2.5 Research Objectives and Hypotheses

The goal of the present thesis is to elaborate on the mechanisms underlying VRET for acrophobia. The first four studies focus on the mechanisms how height-related virtual environments elicit fear responses. The fifth and last study compares two implementations of exposure treatment—following the EPT and inhibitory learning model respectively.
Based on the model of fear in VR (see 2.4.3), I hypothesize the following for Studies 1–4:

(1) Virtual height environments elicit fear responses in height-fearful individuals. These fear responses can be measured on different levels, i.e., on a subjective, physiological, and behavioral level (Studies 1–4).

(2) The strength of fear responses in virtual height environments is dependent upon the trait level of height-fearfulness (Studies 1 + 3).

(3) Besides trait height-fearfulness, the strength of fear responses in virtual height environments is also dependent upon presence, the sense of 'being there' in the virtual environment. Vice versa, fear responses also influence the level of experienced presence (Study 4).

(4) Presence can further be manipulated via immersion, i.e., the objective characteristics of the VR system (Studies 1 + 4).

Based on assumption of the inhibitory learning model that expectancy violation is the mechanism underlying lasting fear reduction in exposure therapy (Craske et al., 2008), I hypothesized the following for Study 5:

(5) Exposure treatment following the expectancy violation approach of the inhibitory learning model outperforms exposure treatment following a habituation-based approach (Study 5).

Chapter 3

Validating Virtual Height Environments for Exposure

3.1 Study 1: Establishing an Environment for Virtual Height Exposure

Parts of the following section have already been published as

> Gromer, D., Madeira, O., Gast, P., Nehfischer, M., Jost, M., Müller, M., Mühlberger, A., & Pauli, P. (2018). Height Simulation in a Virtual Reality CAVE System: Validity of Fear Responses and Effects of an Immersion Manipulation. *Frontiers in Human Neuroscience*, *12*.
> doi: 10.3389/fnhum.2018.00372

3.1.1 Introduction

VRET is a type of exposure treatment for anxiety disorders (Bouchard et al., 2012, see also 2.4.1). In VRET, virtual environments are used to expose a patient to a stimulus or situation he/she fears, such as a virtual spider or a height situation. VRET has been found to be an effective treatment, especially for specific fears (Carl et al., 2019; Fodor et al., 2018; Morina, Ijntema, Meyerbröker, & Emmelkamp, 2015; Opriş et al., 2012; Parsons & Rizzo, 2008; Powers & Emmelkamp, 2008; Turner & Casey, 2014). Giving the promising results of the effectivity of VRET, underlying mechanisms are, however, still unclear (Diemer et al., 2016).

Several constructs related to VR have been implicated to affect VRET outcome and VR's capabilities to trigger fear responses. The most prominent psychological construct that has been studied in the context of VRET is *presence* in virtual environments. Experienced presence is the *sense of 'being there'* in the virtual environment (Slater et al., 1994; Witmer & Singer, 1998, see also 2.4.2.2). Schubert and colleagues characterized presence by three factors: *spatial presence*, a feeling of being inside the virtual environment and interacting directly

with it; *involvement*, how much a person focuses on the virtual environment instead of the real world; and *realness*, the degree to which experiences within the virtual environment seem consistent with real world experiences (Schubert, 2003, 2009). A second construct related to presence is *immersion*, the objective characteristics of the equipment used to create and display the VR experience, such as display size and resolution, frame rate, and whether stereoscopic presentation is used (Slater, 1999; Slater et al., 1994, see also 2.4.2.1). The assumed association between immersion and presence is: the higher the immersion of the VR system, the higher the experienced presence of users (Cummings & Bailenson, 2016; Diemer et al., 2015). For example, in VR exposure to phobic stimuli, immersion augmentation of VRET for spider phobia with tactile cues (a toy spider) led to an increase in presence (Hoffman, Garcia-Palacios, Carlin, Furness III, & Botella-Arbona, 2003; Peperkorn & Mühlberger, 2013). Given these first results, Price and Anderson (2007) call for further studies to explore presence-increasing methods in virtual environments for exposure treatments.
The level of presence in a virtual environment has been theorized to be a factor influencing the effectivity of VRET (Wiederhold & Wiederhold, 2000, see also 2.4.2.3). According to Hodges et al. (1995), presence is essential for successful VRET, because it facilitates the activation of the phobic fear structure, which is a prerequisite for successful exposure therapy according to the EPT (Foa & Kozak, 1986). However, there is only a small number of studies experimentally assessing the influence of presence on treatment outcome in VRET for anxiety disorders, and these studies show mixed findings (Krijn et al., 2004; Price & Anderson, 2007; Price et al., 2011; Quero et al., 2008; Schuemie et al., 2000). To combine these empirical findings on the relationship of presence and treatment outcome in VRET, Price and Anderson (2007) discuss presence as a necessary but insufficient requirement for successful VRET.
Besides the relationship between presence and treatment outcome, a further line of research focused on the relationship between presence and the extent to which fear is elicited by virtual environments. First studies on the relationship between presence and experienced fear in virtual environments date back to the late 1990s. Regenbrecht, Schubert, and Friedmann (1998) found a positive correlation between presence and fear in a virtual height situation. In 2014, Ling and colleagues conducted a meta-analysis on 33 studies and reported a medium effect size of $r = .28$ (95% CI: .18–.38) for the relationship between presence and fear in virtual environments, with differences between anxiety disorders: a high correlation for specific phobia animal subtype and no correlation for social phobia; and differences between clinical and non-clinical populations: the correlation was higher in samples with clinical anxious persons (Ling et al., 2014). However, since most previous studies conducted only correlational analyses, the direction of the relationship between presence and fear is still subject to debate (Diemer et al., 2015, see also 2.4.2.3). While some authors argue that fear leads to higher presence (Bouchard et al., 2008), and others assume that higher levels of presence have an effect on the fear felt in virtual environments (Peperkorn et al., 2015), still

others discuss the relationship between presence and fear as synergistic (Robillard et al., 2003).

The goals of the current study were (1) to test the validity of a virtual environment for inducing height related-fear on a subjective and behavioral level, (2) to test whether these fear responses were dependent upon the trait level of height-fearfulness, and (3) to test the influence of a tactile cue (i.e., wind simulation) on presence and fear.

3.1.2 Methods

3.1.2.1 Sample

One hundred and four participants took part in the study. Five participants had to be excluded from data analysis due to technical reasons, therefore the final sample consisted of ninety-nine participants (age: $M = 22.68$, $SD = 3.84$; 65 female participants). Participants were divided in two groups (low height-fearful vs. high height-fearful) based on scores in the Acrophobia Questionnaire (AQ; Cohen, 1977, subscale Anxiety, cut-off: 20). The low height-fearful (LHF) group consisted of 44 and the high height-fearful (HHF) group of 55 participants. Participants received either 6 EUR or course credit for compensation.

3.1.2.2 Apparatus

The study was conducted in the 3D multisensory laboratory of the Department of Psychology I of the University of Würzburg, Germany. A modification (VrSessionmod 0.5) based on the Source Engine SDK 2007 (Valve, Bellevue, Washington, USA) was used for rendering the virtual environment in combination with the CS-Research 5.6 software (VTplus, Würzburg, Germany; see `www.cybersession.info` for detailed information) for experiment control. The virtual environment was presented in a 5-sided CAVE (I Space by BARCO, Kuurne, Belgium; see Figure 5) at a size of 4 × 3 × 3 m. Six projectors were used for displaying the virtual environment. The projectors had a resolution of 1920 × 1200 pixels (one wall had a slightly higher resolution of 2016 × 1486 pixels as two overlapping projections were used). For each projector, two computers rendered the images for the left and right eye respectively in order to produce stereoscopic images. Passive interference-filtering glasses (Infitec Premium, Infitec, Ulm, Germany) were used for stereoscopic vision. A 7.1 surround sound system was used for audio presentation. Wind simulation was operationalized with four fans mounted to the top of the CAVE. An active infrared LED system with four cameras (PhaseSpace Impulse, PhaseSpace Inc., San Leandro, CA, USA) recorded positional and orientational tracking data. Movement in the virtual environment was possible by both a gamepad (Xbox 360 Wireless Controller, Microsoft, Redmond, Washington, USA) and walking inside the CAVE.

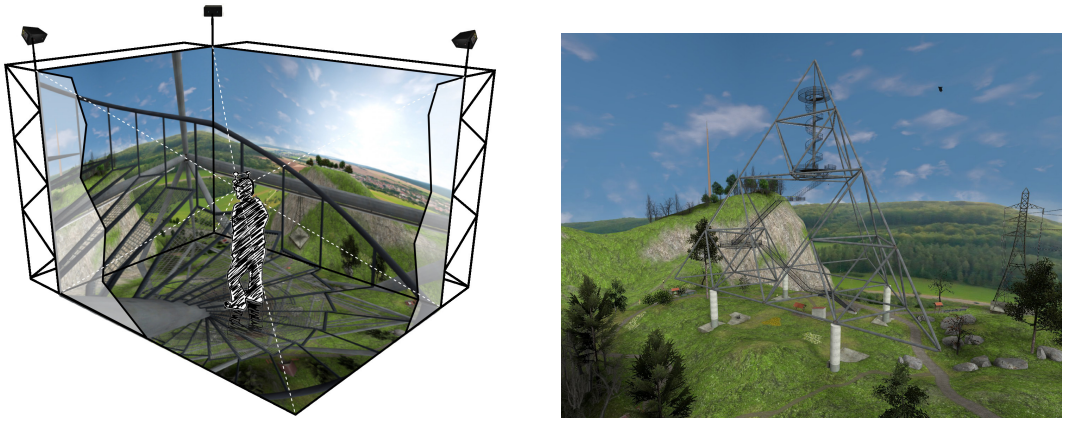


Figure 5: Schematic representation of a participant in the 5-sided Cave Automatic Virtual Environment (CAVE) climbing the stairs of the lookout (left). Screenshot of the virtual environment showing the complete lookout (right). Virtual environment developed by VTplus®. Figure from Gromer et al. (2018) (CC BY 4.0).

3.1.2.3 Virtual environment

The virtual environment comprised a lookout tower with four platforms (at 18 m, 29 m, 35 m, and 50 m) surrounded by a mountainous landscape (see Figure 5). The lookout tower was based on the Tetrahedron in Bottrop (Germany), a tetrahedron-shaped steel structure (see `https://en.wikipedia.org/wiki/Tetrahedron_in_Bottrop`). The platforms were either made of solid steel or a steel mesh, and the stairs connecting the individual platforms with each other were made of the metal mesh.

3.1.2.4 Experimental design and procedure

A 2 × 2 between-subject design was used for the study. The factors were *height-fearfulness* (low vs. high) and *wind simulation* (off vs. on).

Upon arrival at the laboratory, participants read an information letter (see Appendix B) and gave their informed consent (see Appendix C). Next, participants filled in questionnaires (demographics, AQ, STAI, and SSS, see 3.1.2.5). After being equipped with interference glasses and the gamepad, the participants entered the CAVE and completed a training environment to familiarize themselves with the VR. Afterwards, participants were placed in a hilly environment with the lookout tower in the middle of the scene (see Figure 5) and were asked to go to the stairs of the lookout tower to complete several tasks. First, participants climbed the lookout tower as high as they wanted to, indicating by pressing a gamepad button if they did not want to go any higher. Then followed a series of trials in which participants were teleported to each platform of the lookout tower to give their ratings of fear, dangerousness, and dizziness. The final task was to approach the railing at the top platform of the tower. Here, too, participants could decide how close they wanted to get to

the railing. After leaving the CAVE, participants filled in another set of questionnaires (STAI State, SSQ, and IPQ, see 3.1.2.5).

3.1.2.5 Measures

Questionnaires

Acrophobia Questionnaire (AQ; Cohen, 1977). The AQ is a self-report questionnaire that measures height-fearfulness on the subscales *Anxiety* and *Avoidance*. The Anxiety subscale consists of 20 items describing different situations, e.g., "looking down a circular stairway from several flights up." Each item is rated on a seven-point Likert scale ranging from 0 ("not at all anxious") to 6 ("extremely anxious"), resulting in a sum score of 0–120. The Avoidance subscale comprises the same 20 situational items and each item is rated on a three-point Likert scale ("would not avoid doing it", "would try to avoid doing it", and "would not do it under any circumstances"), which are summed to a score of 0–40.

State-Trait Anxiety Inventory (STAI; Laux, Glanzmann, Schaffner, & Spielberger, 1981). The STAI is a self-report questionnaire which measures anxiety as a state and as a trait. For the state anxiety subscale, participants are asked to rate 20 items (e.g., "I feel frightened") according to their present feelings on a four-point Likert scale ranging from "not at all" to "very much so." For the trait anxiety subscale, participants are asked to rate 20 items (e.g., "I feel nervous and restless") according to how they feel in general, on a four-point Likert scale ranging from "almost never" to "almost always." A sum score with a range of 20–80 is calculated for each subscale.

Sensation Seeking Scale (SSS; Zuckerman, Kolin, Price, & Zoob, 1964). The SSS is a self-report questionnaire that measures sensation seeking and consists of the four subscales *thrill and adventure seeking*, *disinhibition*, *experience seeking*, and *boredom susceptibility*. The questionnaire comprises a total of 40 items with two answer options each, resulting in a sum score of 0–10 for each subscale. Example items are "I would like to take up the sport of water-skiing" vs. "I would not like to take up water-skiing" (thrill and adventure seeking), "Heavy drinking usually ruins a party because some people get loud and boisterous" vs. "Keeping the drinks full is the key to a good party" (disinhibition), "I would like to take off on a trip with no pre-planned or definite routes, or timetable" vs. "When I go on a trip I like to plan my route and timetable fairly carefully" (experience seeking) and "I get bored seeing the same old faces" vs. "I like the comfortable familiarity of everyday friends" (boredom susceptibility). Participants are asked to choose the answer option that better describes their preferences or feelings.

Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, Berbaum, & Lilienthal, 1993). The SSQ is a self-report questionnaire that measures simulator sickness, i.e., symptoms such as nausea, dizziness, headache, or eyestrain, caused by immersion into virtual environments. The questionnaire consists of 16 items which are rated on a four-point Likert scale ranging from "none" to "severe." The resulting weighted sum scores represent the three factors *nausea* (e.g., stomach awareness), *oculomotor problems* (e.g., eyestrain), and *disorientation* (e.g., vertigo), and a total score.

Igroup Presence Questionnaire (IPQ; Schubert, 2003). The IPQ is a self-report questionnaire that measures presence, the sense of 'being there' in virtual environments. The questionnaire consists of 14 items which are rated on seven-point Likert scales. The IPQ measures three subscales representing different dimensions of presence. The *spatial presence* subscale measures a feeling of being inside the virtual environment (e.g., "Somehow I felt that the virtual world surrounded me"). The *involvement* subscale consists of items measuring an attentional focus towards the virtual environment (e.g., "I was not aware of my real environment"). The *experienced realism* subscale measures how real the virtual environment seems to the participant (e.g., "How real did the virtual world seem to you?"). One additional item measures a general sense of being in the virtual environment ("In the computer generated world I had a sense of 'being there' "). The resulting scores on each subscale have a range of 0–6.

Online ratings

Throughout the experiment, ratings of fear, dangerousness of the situation, and dizziness were measured with Subjective Units of Discomfort Scales (SUDS) on a range of 0–100. Furthermore participants rated the perceived height (in meters) at each level of the lookout tower. In addition to the IPQ, spatial presence was also measured with an online rating using the item "To which extent did you feel present in the virtual environment, as if you were really there?" (Bouchard et al., 2004) on a range of 0–100.

Behavioral measures

Two behavioral avoidance measures were derived from the movement data of participants. First, how high participant climbed the lookout tower (first task of the experiment), and second how near they approached the railing at the tower's top platform (last task of the experiment).

Table 1
Questionnaire data

	LHF		HHF			
	M	***SD***	***M***	***SD***	***t***	***p***
Age	23.25	4.59	21.95	2.48	1.80	.076
AQ Anxiety	10.57	5.80	33.85	12.31	-12.41	< .001
AQ Avoidance	2.30	2.12	6.22	3.42	-6.99	< .001
STAI State t_1	34.71	8.52	39.13	7.37	-2.68	.009
STAI State t_2	33.29	7.99	40.72	7.86	-4.53	< .001
STAI Trait	33.77	7.55	38.69	7.06	-3.30	.001
SSS Thrill & Adventure Seeking	7.45	2.11	5.83	2.36	3.59	< .001
SSS Disinhibition	4.39	2.32	4.17	2.04	0.49	.625
SSS Experience Seeking	6.25	2.13	5.81	2.03	1.03	.306
SSS Boredom Susceptibility	3.57	1.74	2.80	1.66	2.22	.029
SSQ Total	25.93	22.60	44.61	27.06	-3.74	< .001
SSQ Nausea	39.37	31.54	18.00	18.08	4.23	< .001
SSQ Oculomotor Problems	31.70	19.41	22.74	20.74	2.20	.031
SSQ Disorientation	50.37	37.17	28.47	31.34	3.18	.002
IPQ Spatial Presence	4.50	0.66	4.47	0.85	0.22	.826
IPQ Involvement	3.69	1.32	3.61	1.23	0.32	.751
IPQ Experienced Realism	3.20	0.98	3.17	1.18	0.14	.893
IPQ General	4.25	1.21	4.43	1.04	-0.78	.435

Note: LHF = low height-fearful, HHF = high height-fearful. AQ = Acrophobia Questionnaire; STAI = State-Trait Anxiety Inventory (t_1 = at the beginning and t_2 = in the end of the experiment); SSS = Sensation Seeking Scale; SSQ = Simulator Sickness Questionnaire; IPQ = Igroup Presence Questionnaire. Table adapted from Gromer et al. (2018) (CC BY 4.0).

3.1.2.6 Data analysis

Statistical analyses were conducted in R 3.2.3 (R Core Team, 2016) using the `afex` package (Singmann, Bolker, Westfall, & Aust, 2016) for ANOVA with type 3 sum of squares (with Greenhouse-Geisser correction if sphericity was violated).

3.1.3 Results

Group characteristics

Participants in the two experimental conditions did not differ in sex, $\chi^2(1) = 2.08$, $p = .149$, and age. Both groups did differ in height-fearfulness, in trait anxiety, in state anxiety before and after the experiment, in thrill and adventure seeking and boredom susceptibility, and in symptoms of simulator sickness after the experiment (see Table 1).

Validation of the virtual environment

To test the suitability of the virtual height environment in terms of provoking acrophobia-related fear responses, the relationship between trait height-fearfulness and reported fear

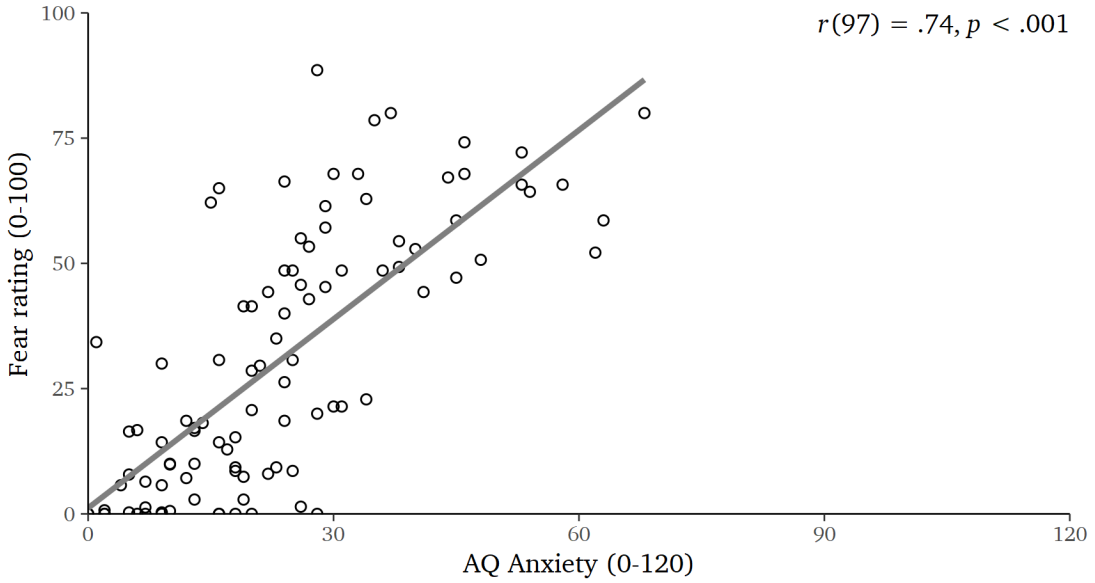


Figure 6: Scatter plot of scores on the Acrophobia Questionnaire (AQ) Anxiety subscale (x-axis) and fear ratings at the top level platform of the lookout (y-axis). The gray line indicates a linear model fitted to the values and the associated correlation is displayed in the top right corner. Figure adapted from Gromer et al. (2018) (CC BY 4.0).

was analyzed. The correlation between the AQ Anxiety subscale and the mean fear ratings was $r(97) = .74$, $p < .001$ (see Figure 6). To control for possible effects of trait anxiety, the partial correlation of the AQ Anxiety and mean fear ratings controlling for STAI Trait was also calculated, $r(96) = .73$, $p < .001$.

Influence of height-fearfulness and wind simulation on fear, dangerousness, and dizziness

The effect of height-fearfulness and wind simulation on experienced fear, dangerousness, and dizziness was analyzed with three two-way ANOVAs with height-fearfulness and wind simulation as between factors (see Figure 7).

For the fear ratings, the ANOVA revealed a significant main effect of height-fearfulness, $F(1, 95) = 66.06$, $p < .001$, $\eta_p^2 = .41$, a marginal significant main effect of wind simulation, $F(1, 95) = 3.20$, $p = .077$, $\eta_p^2 = .03$, and a significant height-fearfulness × wind simulation interaction, $F(1, 95) = 4.74$, $p = .032$, $\eta_p^2 = .05$. The interaction was further analyzed *post hoc* using Tukey's HSD, which revealed a significant difference for wind vs. no wind in HHF, $p = .022$ (higher fear ratings in HHF with wind simulation compared to HHF without wind simulation), but no significant difference for wind vs. no wind in LHF, $p = .993$ (see Figure 7 A).

For the dangerousness ratings, there was also a significant main effect of height-fearfulness, $F(1, 95) = 49.41$, $p < .001$, $\eta_p^2 = .34$, a marginal significant main effect of wind simulation,

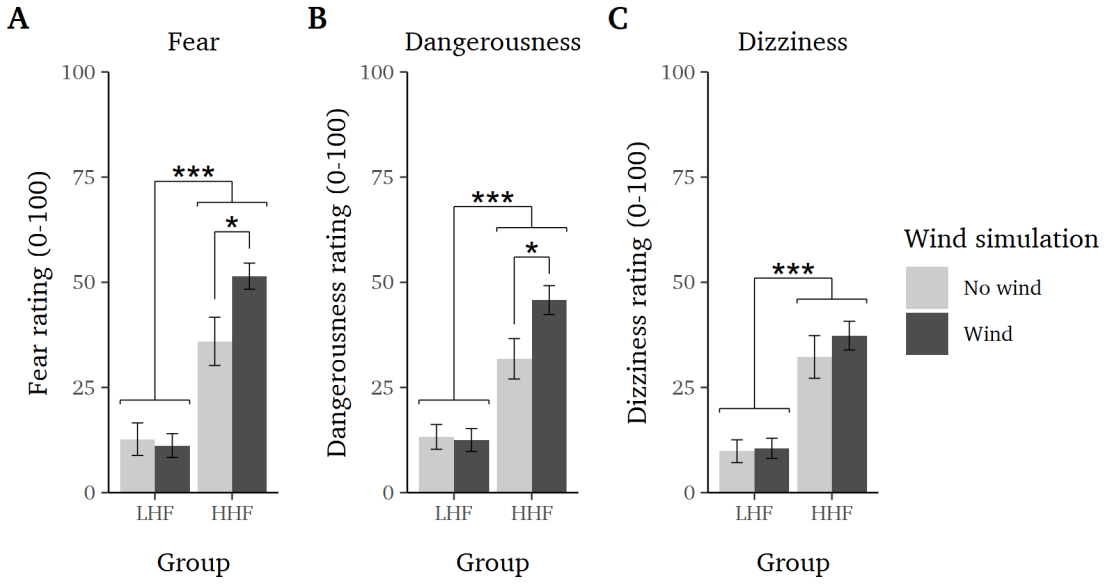


Figure 7: Mean ratings (± standard error) of fear (A), dangerousness (B), and dizziness (C). LHF = low height-fearful, HHF = high height-fearful. $^*p < .05$, $^{***}p < .001$. Figure adapted from Gromer et al. (2018) (CC BY 4.0).

$F(1, 95) = 3.21$, $p = .076$, $\eta_p^2 = .03$, and a significant height-fearfulness × wind simulation interaction, $F(1, 95) = 3.98$, $p = .049$, $\eta_p^2 = .04$. Again, Tukey's HSD revealed a significant difference for wind vs. no wind in HHF, $p = .031$ (higher dangerousness ratings in HHF with wind simulation compared to HHF without wind simulation), but no significant difference for wind vs. no wind in LHF, $p = .999$ (see Figure 7 B).

Lastly, for the dizziness ratings there was a significant main effect of height-fearfulness, $F(1, 95) = 45.43$, $p < .001$, $\eta_p^2 = .32$, but no significant main effect of wind simulation, $F(1, 95) = 0.62$, $p = .432$, $\eta_p^2 < .01$, and no significant interaction, $F(1, 95) = 0.36$, $p = .551$, $\eta_p^2 < .01$ (see Figure 7 C).

Influence of height-fearfulness and wind simulation on presence

To test the influence of height-fearfulness and the wind simulation on feelings of presence in the virtual environment, both the online rating of presence and the IPQ scores were analyzed. For the online rating, a two-way ANOVA with height-fearfulness and wind simulation as between factors was calculated. There was no main effect of height-fearfulness, $F(1, 95) = 0.46$, $p = .500$, $\eta_p^2 < .01$, no main effect of wind simulation, $F(1, 95) = 2.52$, $p = .116$, $\eta_p^2 = .03$, and no interaction, $F(1, 95) = 0.90$, $p = .345$, $\eta_p^2 < .01$. On a descriptive level, presence ratings were higher with wind simulation compared to without wind simulation in both LHF, $M = 64.80$ ($SD = 14.82$) vs. $M = 62.32$ ($SD = 18.63$), and HHF, $M = 65.86$ ($SD = 21.37$) vs. $M = 56.00$ ($SD = 18.47$). However, the effect size for this effect was very small ($\eta_p^2 = .03$) and thus the differences were statistically not significant.

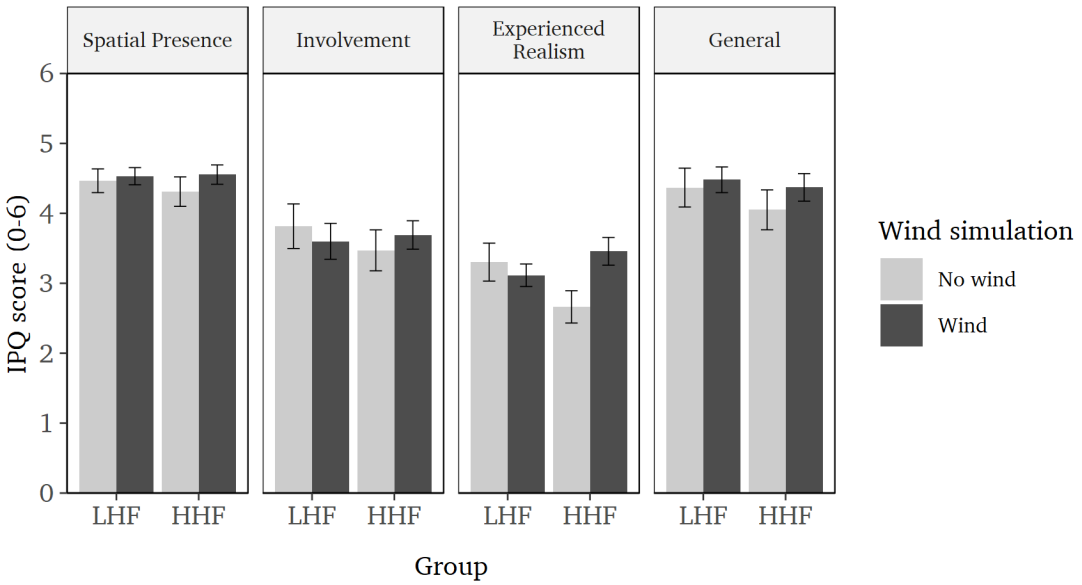


Figure 8: Mean scores (± standard error) on the Igroup Presence Questionnaire (IPQ) subscales Spatial Presence, Involvement, Experienced Realism and General presence. LHF = low height-fearful, HHF = high height-fearful.

For the IPQ scores (see Figure 8), a two-way MANOVA with the subscales of the IPQ as dependent variables and height-fearfulness and wind simulation as between factors was calculated. There was no main effect of height-fearfulness, Wilks' $\lambda = .94$, $F(4, 90) = 1.50$, $p = .209$, no main effect of wind simulation, Wilks' $\lambda = .92$, $F(4, 90) = 0.42$, $p = .795$, and no interaction, Wilks' $\lambda = .98$, $F(4, 90) = 2.01$, $p = .100$.
Contrary to the fear and dangerousness ratings, wind simulation had thus no effect on presence measures, i.e., how much participants had a sense of 'being there' in the virtual environment.

Predicting fear in virtual reality

The correlation between presence (as measured by the online rating) and the mean fear rating was $r(97) = .31$, $p = .002$ for the whole sample. Separated by height-fearfulness, the correlation was non-significant for the LHF group, $r(42) = .19$, $p = .224$, but highly significant for the HHF group, $r(53) = .55$, $p < .001$. For the IPQ, the correlations with the mean fear rating were: IPQ Spatial Presence, $r(95) = .28$, $p = .006$; IPQ Involvement, $r(97) = .12$, $p = .234$; IPQ Experienced Realism, $r(96) = .26$, $p = .009$; and IPQ General, $r(97) = .15$, $p = .134$. Separated by group, the correlations for the LHF group were: IPQ Spatial Presence, $r(41) = .32$, $p = .034$; IPQ Involvement, $r(42) = .16$, $p = .289$; IPQ Experienced Realism, $r(41) = -.03$, $p = .837$; and IPQ General: $r(42) = .10$, $p = .510$. The correlations for the HHF group were: IPQ Spatial Presence, $r(52) = .41$, $p = .002$; IPQ Involvement, $r(53) = .21$,

Table 2
Results of the hierarchical regression of trait height-fearfulness and presence on subjective fear

	R^2	*AIC*	*B*	*SE B*	β	*p*
Step 1	.54	849.48				< .001
Intercept			1.16	3.20		.717
AQ Anxiety			1.26	0.11	0.74	< .001
Step 2	.61	832.76				< .001
Intercept			-22.26	6.00		< .001
AQ Anxiety			1.24	0.10	0.73	< .001
Presence			0.38	0.08	0.28	< .001

Note: AQ = Acrophobia Questionnaire. Table from Gromer et al. (2018) (CC BY 4.0)

$p = .123$; IPQ Experienced Realism, $r(53) = .54$, $p < .001$; and IPQ General, $r(53) = .35$, $p = .008$.

To test whether presence explained variance in fear ratings that was not already explained by the level of height-fearfulness, a hierarchical regression on the mean fear ratings (dependent variable) was conducted (see Table 2). In the first step, trait height-fearfulness (measured by the AQ Anxiety) was added as a predictor to the model. In the second step, the presence rating was added as a predictor and both models were compared. The model with both predictors, trait height-fearfulness and presence, explained significantly more variance than the model with trait height-fearfulness only, $F(1, 96) = 19.99$, $p < .001$.

Avoidance behavior

Two behavioral avoidance measures were evaluated: how high participants climbed the tower and how near they approached the railing at the tower's top platform.

Since most participants climbed to the tower's top platform, I could not conduct a parametric test due to non-normality of the dependent variable. Therefore a χ^2-test was conducted to test for a relationship between height-fearfulness and whether the top platform was reached or not. In the HHF group, 19 out of 55 participants did not climb to the top platform (34.5 %), in the LHF group 1 out of 44 participants (2.3 %) did not reach the top, $\chi^2(1) = 13.85$, $p < .001$.

Approach behavior to the railing of the tower's top platform was analyzed by comparing the covered distance from the starting position to the railing. The two-way ANOVA with height-fearfulness and wind simulation as between factors showed a significant main effect of height-fearfulness, $F(1, 95) = 8.01$, $p = .006$, $\eta_p^2 = .08$, indicating the LHF group ($M = 2.47$, $SD = 0.53$) covered more distance to the railing than the HHF group ($M = 2.01$, $SD = 0.81$). There was no main effect of wind simulation, $F(1, 95) = 0.29$, $p = .589$, $\eta_p^2 < .01$, and no

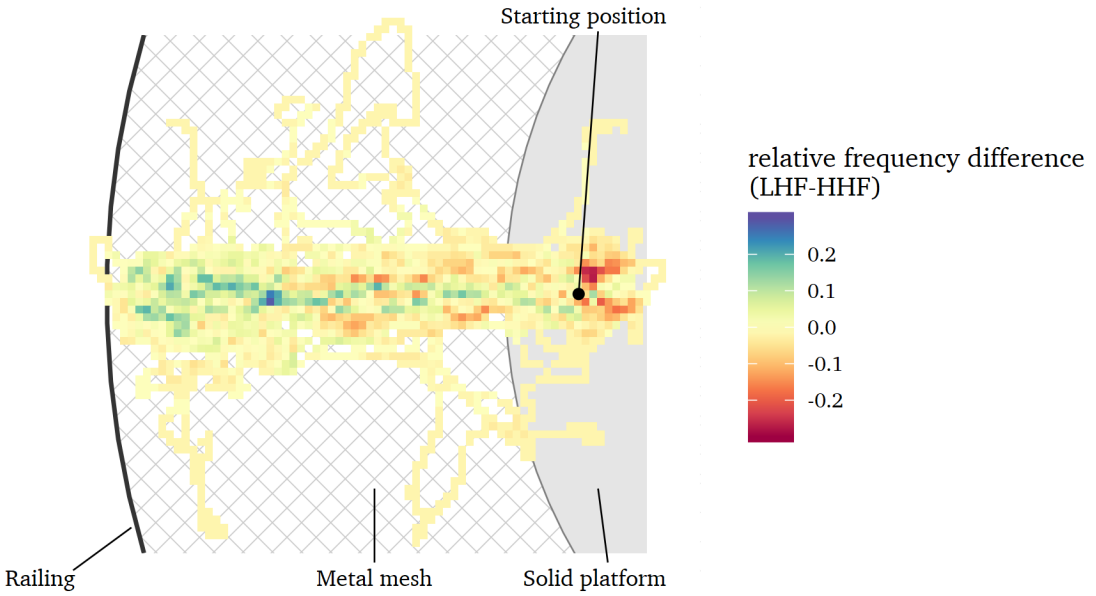


Figure 9: Bird's eye view on the tower's top platform (50 m). The heatmap shows differences in group movement behavior comparing low height-fearful (LHF, blue) and high height-fearful (HHF, red) participants. Participants started on a solid platform and had the task to walk over a metal mesh as close to the railing as they wanted to. Blue areas indicate that more participants of the LHF group walked there, whereas red areas indicate that more participants HHF group were there. The more intense a color is, the greater the relative difference between both groups. Figure adapted from Gromer et al. (2018) (CC BY 4.0).

interaction, $F(1, 95) = 1.93$, $p = .168$, $\eta_p^2 = .02$. The main effect of group is illustrated in Figure 9, which contrasts moving patterns of HHF and LHF participants.

Estimated height

To test for differences in height estimation between HHF and LHF participants (see Figure 10), the ratings of estimated height at 28 m, 35 m, and 50 m were compared between groups using a mixed-design ANOVA with height-fearuflness as between factor and height as within factor. The assumption of sphericity for the within factor was violated, Mauchly's $W = 0.45$, $p < .001$, so Greenhouse-Geisser adjustment was used for degrees of freedom. There was no main effect of height-fearfulness, $F(1, 86) = 0.44$, $p = .511$, $\eta_p^2 < .01$, a significant main effect of height, $F(1.29, 111.26) = 47.98$, $p < .001$, $\eta_p^2 = .36$, and no height-fearfulness × height interaction, $F(1.29, 111.26) = 1.43$, $p = .240$, $\eta_p^2 = .02$. On a descriptive level, the difference in estimated heights between LHF and HHF increased with actual height—with HHF giving higher ratings than LHF—however, the effect size for this interaction effect ($\eta_p^2 = .02$) was very small.

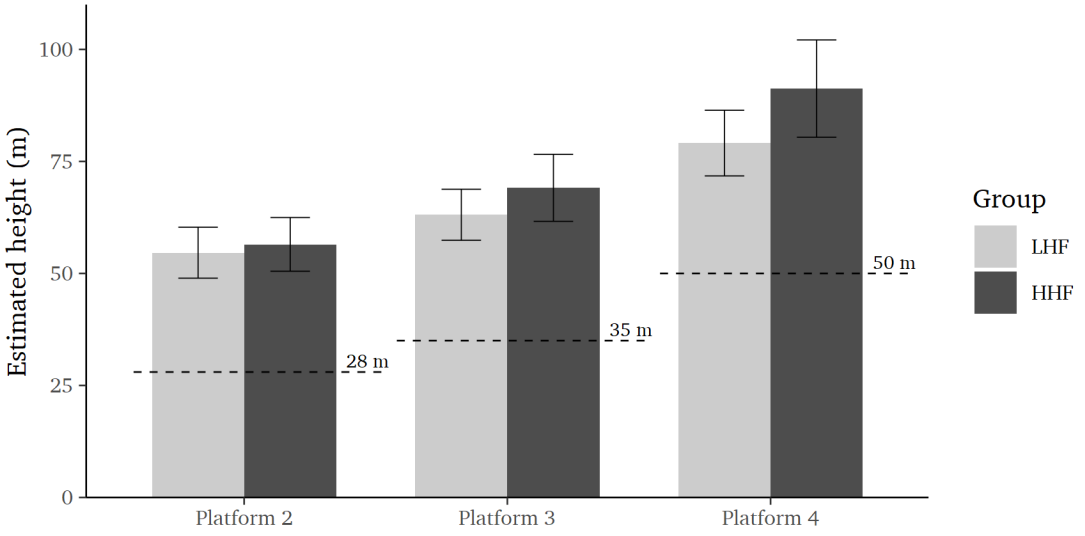


Figure 10: Mean ratings (± standard error) of perceived height at three different positions on the lookout (28 m, 35 m and 50 m). Dashed lines indicate the actual height. LHF = low height-fearful, HHF = high height-fearful.

3.1.4 Discussion

In this study, participants with low vs. high height-fearfulness were immersed into a virtual height environment consisting of a hilly landscape with a 50 m lookout tower. Immersion was manipulated by providing tactile cues (i.e., wind simulation). Ratings of fear, dangerousness, dizziness, presence, and perceived height were assessed, as well as the participants movement behavior in the virtual environment.

The subjective and behavioral measures indicate a high external validity for the used virtual environment in terms of triggering height-related fear responses. Compared to LHF participants, the HHF participants reported more fear and dizziness, and rated the height situation as more dangerous. Furthermore, participants in the HHF group showed more acrophobia-related avoidance behavior. That is, HHF participants did not walk as near to the railing of the tower's top platform as did LHF participants, and in the climbing task, HHF participants stopped earlier than LHF participants. From a clinical viewpoint, the present virtual environment is therefore suitable for application in VRET, as it is thought to activate the fear structure (according to the EPT, Foa & Kozak, 1986) and can act as a CS for fear extinction (Craske, Liao, Brown, & Vervliet, 2012).

3.1.4.1 Presence and fear

The correlation between fear ratings and presence ($r = .31$) is in line with previous research (Ling et al., 2014), i.e., increased fear ratings go along with increased presence ratings. More importantly, as shown in the hierarchical regression models, presence explained variance in

fear ratings even when controlling for trait height-fearfulness. This highlights the importance of the concept of presence when investigating experienced fear in virtual environments (Diemer et al., 2015). However, the current study does not explore a potential causal link between presence and fear, i.e., if an increased sense of presence leads to more fear or if fear in virtual environments causes participants to experience themselves to be more present in the virtual environment. Only a small number of studies investigated a causal relationship in more detail (Bouchard et al., 2008; Peperkorn et al., 2015) and results are inconclusive. Both potential causal pathways seem plausible: a higher sense of presence (i.e., feeling to be more present in the virtual environment) might lead to more fear because an exposure to a phobic stimulus or situation is then experienced more similar to the real life experience. On the other hand, fear might lead to an increase in the sense of presence, because feeling one's emotional reaction in a virtual environment makes the experience more realistic. In the future, more studies with experimental manipulations are needed to untangle the relationship between presence and fear (or emotions in general) in VR.

3.1.4.2 Immersion

The effect of the tactile cues (i.e., wind simulation) on subjective fear is in line with previous research showing increased fear ratings in virtual exposure combined with tactile cues (Hoffman et al., 2003; Peperkorn & Mühlberger, 2013). Tactile cues may therefore be used as a tool to build up fear hierarchies for graduated exposure protocols or in persons that only experience low levels of fear in virtual environments. Taken together, immersion manipulations may help to improve treatment outcomes in VRET by providing stronger initial fear responses (Foa & Kozak, 1986) and higher dangerousness perception, resulting in greater expectancy violation if these threat expectancies are violated (Craske et al., 2012). However, compared to studies using spider toys as tactile cues in spider phobia (Hoffman et al., 2003; Peperkorn & Mühlberger, 2013), wind simulation in the present study did not have an effect on experienced presence. A possible explanation for this finding is that, compared to a spider toy, the wind simulation was too subtle and may therefore have only been experienced subconsiously for the majority of participants. A way to test this hypothesis might be comparing the current results with more noticeable tactile cues in acrophobia, e.g., railings and edges which can be felt with the hands and feet (Schuemie et al., 2000) or stronger wind gusts.

3.1.4.3 Limitations

The present study has some limitations that should be noted: The scores on the AQ Anxiety subscale of the sample of HHF participants ($M = 33.9$, $SD = 12.3$) were lower than in samples in VRET studies for acrophobia, e.g., $M = 47.7$, $SD = 9.3$ (Coelho, Santos, Silvério, & Silva, 2006), $M = 59.7$, $SD = 14.1$ (Krijn et al., 2004), and $M = 57.1$, $SD = 12.2$ (Emmelkamp

et al., 2002). For this reason, the present results might not thoroughly translate to clinical populations.
Furthermore, only subjective and behavioral fear responses to the virtual height situation were assessed. Effects of immersion on fear could be found for subjective fear and dangerousness ratings, but not for behavioral avoidance patterns. Investigating further components of the fear response, i.e., physiology (Lang, 1979), cognition (Davis & Ollendick, 2005) and perception (Teachman, Stefanucci, Clerkin, Cody, & Proffitt, 2008) and using multiple immersion manipulations would allow to draw more comprehensive conclusions about the relationship between immersion and fear in virtual environments.

3.1.4.4 Conclusions

The present study shows that VR is a suitable tool for studying fear in naturalistic settings combined with high experimental control. VR can be used to better describe the different components of the fear response (cognition, physiology, behavior, perception; e.g., Teachman et al., 2008) in anxiety disorders due to its high internal validity, especially behavioral responses like avoidance and freezing can be captured reliably.
As a medium for exposure therapy, VRET has been shown to be an effective technique, however underlying mechanisms need to be better understood, especially the roles of immersion and presence for both the process and outcome of VRET.

3.2 Study 2: Virtual Height Exposure Using a Head-Mounted Display

3.2.1 Introduction

The tripartite model of fear (Lang, 1979) describes three components of the fear response: subjective affect, physiological arousal, and avoidance behavior. Study 1 showed increased fear ratings and behavioral avoidance in height-fearful compared to non-fearful participants during an exposure to a virtual height scene. The present study builds upon these results and expands the paradigm of virtual height exposure in two ways: First, it incorporates physiological measures of fear, and second, it validates the same virtual height environment on a different VR system (using a HMD instead of a CAVE).

As an adjunct, a proof of concept for applying a modification of the attentional focus of participants during the VR height exposure will be investigated. In the context of exposure therapy, *attentional focus* means whether patients focus on the feared stimulus or sensations of fear during exposure or whether they shift their attention away (Podină et al., 2013). There has been an ongoing debate about what the optimal attentional focus during exposure treatment is, and study findings on this topic have been inconclusive (Senn & Radomsky, 2018). On a theoretical level, both the EPT and the inhibitory learning model assume that distraction away from the fear stimulus is detrimental to therapy efficacy. According to the EPT, a distraction away from the fear stimulus interferes with the activation of the fear structure, and this, in turn, is thought to allow for less emotional processing (Foa & Kozak, 1986). According to the inhibitory learning model, exposure is most effective when the attention of the patient is directed towards both the CS and the non-occurrence of the US (Craske et al., 2008). A shift of attention towards other stimuli would result in less expectancy violation and thus less inhibitory learning. In concordance, manuals for exposure therapy for specific phobias encourage therapists to prevent the use of distraction and safety behaviors in patients (e.g., Abramowitz et al., 2012).

Previous studies comparing focused with distracted exposure revealed mixed findings. Grayson et al. (1982) compared a distracted exposure (playing video games with the therapist) with a focused exposure (having a conversation about the feared stimulus and the symptoms of discomfort with the therapist) in patients with OCD. The results showed that, although both treatment conditions led to similar fear reduction during the first exposure session, the return of fear on the second day was higher in the distraction condition (Grayson et al., 1982). In a study in spider phobics, Johnstone and Page (2004) compared a distracted exposure (having a stimulus-irrelevant conversation with the therapist) with a focused exposure (having a stimulus-relevant conversation with the therapist). This time, results were in favor of the distraction condition, with higher within- and between-session fear reduction, higher self-efficacy ratings, higher ratings of perceived control, and better performance at a

BAT after treatment (Johnstone & Page, 2004). In their meta-analysis on studies in specific phobias, Podină et al. (2013) conclude that distraction was not detrimental to treatment efficacy. Distracted, focused, and uninstructed exposure yielded similar treatment outcomes on subjective and physiological measures. On a behavioral level, distracted exposure even outperformed focused exposure, but uninstructed exposure yielded the best treatment outcomes. Furthermore, distraction was especially advantageous, if the distraction was interactive or the exposure was spread across multiple sessions. So far, no study used VR for both the presentation of the fear stimuli as well as the distraction. To this end, the present study implements a visual-cognitive distractor in the form of a task where participants have to count the number of birds in flying-by flocks of birds.

3.2.1.1 Aim of the study

The aim of the study was threefold: first, to validate the virtual height environment in terms of eliciting fear responses in a simpler VR-system (HMD) compared to the previous study (CAVE); second, to verify these fear responses on a physiological level by measuring both the skin conductance level (SCL) and HR; and third, to investigate the effect of an attentional distractor within the virtual environment on fear responses.
The hypotheses are:

1. Fear ratings increase with ascending height. The higher participants are located on the virtual lookout, the stronger fear they report.
2. This effect is also visible on both the measures of SCL and HR.
3. Distraction during virtual height exposure attenuates fear responses.

3.2.2 Methods

3.2.2.1 Sample

Fifty-one participants took part in the study. Five participants dropped out due to simulator sickness, further two participants had to be excluded from data analysis due to technical reasons, therefore the final sample consisted of 43 participants (age: $M = 24.09$, $SD = 5.96$; 32 female participants).

3.2.2.2 Apparatus

Rendering of the virtual environment was done with a modification (VrSessionMod 0.6) based on the Source SDK 2013 (Valve, Bellevue, Washington, USA) in combination with the CS-Research 5.6 software (VTplus, Würzburg, Germany; see `www.cybersession.info` for detailed information) for simulation control. The experiment ran on a Windows 7 32-bit machine with an Intel Core i7-2600k, 8 GB RAM and a Nvidia GTX 560 Ti. An Oculus Rift DK2 (Oculus VR, Menlo Park, CA, USA) with a resolution of 960 × 1080 pixels per eye and

a 100° field of view was used for image presentation. A Sennheiser HD 439 (Sennheiser, Wedemark-Wennebostel, Germany) was used for audio presentation. Psychophysiological data (electrodermal activity, EDA, and electrocardiogram, ECG) was recorded with a Brainproducts V-AMP 16 and the Vision Recorder 1.2 software (Brain Products, München, Germany).

3.2.2.3 Experimental design and procedure

A 2 × 5 mixed design was used for the study. Participants were randomly assigned to the between-subject factor *attention* (focus vs. distraction) and visited five different *height* locations (within-subject factor) on a virtual lookout in ascending order. The experimental conditions differed by the task given via audio instruction while being in the height situations: The focus group was asked to concentrate on physiological symptoms (e.g., "Notice what feelings the height triggers in you") and the height itself (e.g., "Look down and perceive the depth," see Appendix E), the distraction group was asked to watch flocks of crows flying by, count the number of birds in each swarm, and give the number to the experimenter.
At the beginning of the session, participants read the participant information (see Appendix D), gave their informed consent (see Appendix C), and filled in questionnaires (demographics, AQ, ATHQ, STAI, and SSS, see 3.2.2.4). After being equipped with electrodes for physiological measures, the HMD, and the gamepad, participants were placed in front of the tracking camera. To get accustomed to the VR, participants completed a training environment. Participants were then placed in the same mountainous environment with a lookout at the center of the scene as in the previous study (see 3.1.2.4) and were asked to walk to the stairs of the lookout. Before climbing to the first level, participants were asked to give a baseline fear rating. Then, participants walked to a marked position on the first level of the lookout. On each level, participants completed a trial of (1) focus or distraction for two minutes, (2) fear rating, and (3) walking to the next level. After the fear rating on the topmost level, participants gave a presence rating and then took the HMD off. Finally, participants filled in another set of questionnaires (STAI State, SSQ, and IPQ).

3.2.2.4 Measures

Questionnaires

For descriptions of the questionnaires Acrophobia Questionnaire (AQ), State-Trait Anxiety Inventory (STAI), Sensation Seeking Scale (SSS), Igroup Presence Questionnaire (IPQ), and Simulator Sickness Questionnaire (SSQ) see the methods section of the previous study (see 3.1.2.5).

Attitutes Towards Heights Questionnaire (ATHQ; Abelson & Curtis, 1989). A self-report questionnaire that measures how individuals generally feel about height situations. The

questionnaire comprises 6 items consisting of 11-point semantic differential scales (e.g., pleasant–unpleasant, safe–dangerous), resulting in a sum score of 0–60.

Online ratings

Verbal ratings of fear (SUDS) and presence were assessed analogously to the previous study (see 3.1.2.5).

Physiological measures

Skin conductance level (SCL). The EDA was derived using two 13/7 mm Ag/AgCl electrodes filled with 0.5% NaCl gel. The electrodes were placed on the thenar and hypothenar of the right hand and the signal was recorded at a samplerate of 500 Hz. The EDA signal was segmented into a baseline phase (walking towards the lookout) and one phase per height level respectively. The SCL (in μS) for each phase was calculated by (1) computing the mean over the EDA signal per phase and (2) applying a baseline correction to each phase, i.e., substracting the SCL value of the baseline phase. To control for skewness, SCL values were adjusted using the $\log(\text{SCL} + 1)$ transformation.

Heart rate (HR). The ECG was derived using three Ag/AgCl electrodes placed under the right collarbone, on the lower left costal arch (reference electrode), and on the lower left back (ground electrode), recorded at a samplerate of 500 Hz. The ECG was filtered offline with a 50 Hz fourth-order Butterworth notch filter and a 2.5 Hz second-order Butterworth highpass filter. Detection of R waves and correction of interbeat interval (IBI) artifacts was done in PeakMan 0.3.0 (see `https://github.com/dgromer/PeakMan`). The sequence of IBIs was processed with the R package `phyr6` (see `https://github.com/dgromer/phyr6`). Segmentation of the sequence of IBIs was done analogous to the EDA signal. The HR (in bpm) for each phase was calculated by (1) computing the mean over the sequence of IBIs per phase, (2) transforming the mean IBI to HR ($\text{HR} = 60000/\text{IBI}$), and (3) applying a baseline correction analogously to the SCL.

3.2.2.5 Data analysis

All statistical analyses were conducted with R 3.3.1 (R Core Team, 2016). The `afex` package (Singmann et al., 2016) was used for ANOVA with type 3 sum of squares (with Greenhouse-Geisser correction if sphericity was violated) and the `lsmeans` package (Lenth, 2016) was used for post-hoc tests (using the `mvt` method for adjusting for multiple comparisons).

Table 3
Questionnaire data

	Distraction		Focus			
	M	***SD***	***M***	***SD***	***t***	***p***
Age	24.09	4.52	24.10	7.41	-0.01	.995
AQ Anxiety	29.13	9.36	30.10	11.61	-0.30	.767
AQ Avoidance	6.43	3.51	5.95	3.58	0.45	.657
ATHQ	25.17	12.78	24.35	9.03	0.25	.807
STAI State t_1	36.87	6.09	33.75	6.85	1.57	.125
STAI State t_2	40.70	7.93	39.95	7.98	0.31	.761
STAI Trait	39.43	8.56	39.60	8.68	-0.06	.950
SSS Thrill & Adventure Seeking	4.91	3.03	5.75	2.27	-1.03	.308
SSS Disinhibition	3.87	1.60	4.60	2.30	-1.19	.243
SSS Experience Seeking	6.39	1.90	6.05	2.21	0.54	.593
SSS Boredom Susceptibility	3.48	1.93	3.70	1.89	-0.38	.706
SSQ Total	66.83	43.47	69.19	46.85	-0.17	.866
SSQ Nausea	54.34	37.11	64.87	45.02	-0.83	.412
SSQ Oculomotor Problems	47.13	34.73	42.07	29.15	0.52	.606
SSQ Disorientation	82.91	58.53	85.61	67.03	-0.14	.890
IPQ Spatial Presence	4.05	1.24	4.09	1.06	-0.11	.915
IPQ Involvement	3.41	1.32	3.61	1.10	-0.54	.592
IPQ Experienced Realism	2.59	1.11	3.00	0.96	-1.31	.198
IPQ General	3.83	1.47	4.20	1.11	-0.95	.347

Note: AQ = Acrophobia Questionnaire; ATHQ = Attitudes Towards Heights Questionnaire; STAI = State-Trait Anxiety Inventory (t_1 = at the beginning and t_2 = in the end of the experiment); SSS = Sensation Seeking Scale; SSQ = Simulator Sickness Questionnaire; IPQ = Igroup Presence Questionnaire.

3.2.3 Results

Group characteristics

Participants in the two experimental conditions did not differ in sex, $\chi^2(1) < 0.01$, $p > .999$, and age. Furthermore, participants did not differ with regards to height-fearfulness, trait and state anxiety, sensation seeking, and presence in the virtual environment (see Table 3).

Validation of the virtual environment

The validation of the virtual environment in terms of eliciting height related fear was tested analogous to the previous study, by calculating the correlation between the AQ Anxiety subscale scores and the mean fear ratings. Both measures were positively correlated, $r(41) = .45$, $p = .003$, indicating higher subjective fear in participants with higher trait height-fearfulness. Again, this relationship was also significant when controlling for STAI Trait scores, $r(41) = .46$, $p = .002$.

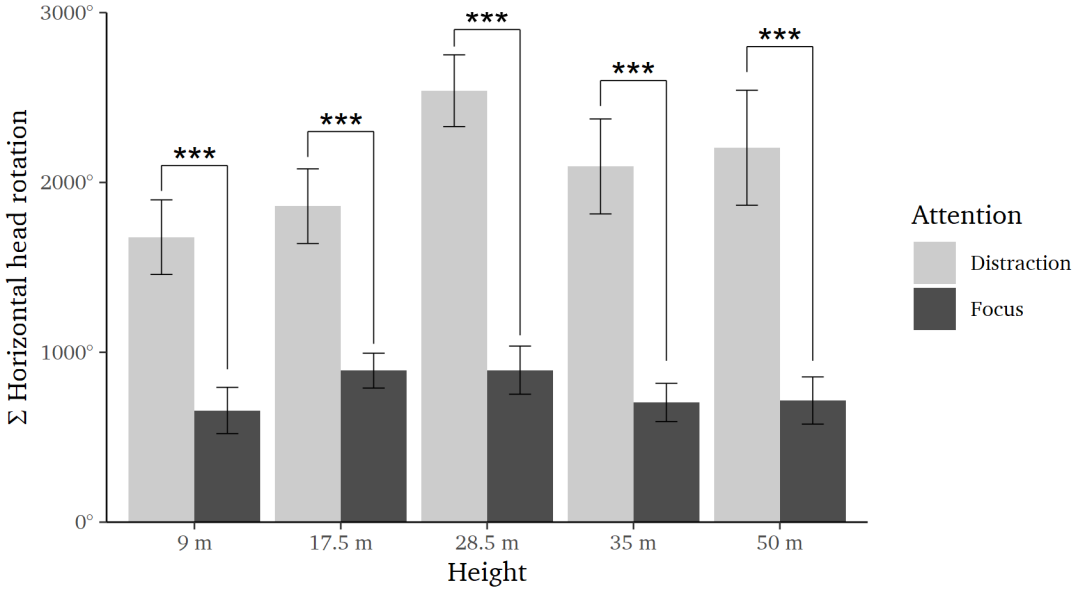


Figure 11: Mean values (± standard error) of summarized head rotations for each trial.

Manipulation check

To check whether participants in the distraction condition focused on the flying-by crows (i.e., looked out for the flocks of birds), the total amount of horizontal head rotation of participants was compared between both experimental conditions. Participants in the distraction group showed significantly more horizontal head rotation on each level of the lookout, level 1: $t(34.32) = 3.95$, $p < .001$, $d = 1.19$; level 2: $t(29.53) = 3.99$, $p < .001$, $d = 1.19$; level 3: $t(35.72) = 6.47$, $p < .001$, $d = 1.96$; level 4: $t(27.51) = 4.61$, $p < .001$, $d = 1.36$; and level 5: $t(27.76) = 4.07$, $p < .001$, $d = 1.20$ (see Figure 11).

Effects of focus and distraction on fear responses

The effects of attention and height level on fear ratings, SCL, and HR were analyzed with three two-way ANOVAs with attention as between-subject factor and height level as within-subject factor.

Fear ratings. For the fear ratings, there was no main effect of attention, $F(1, 41) = 1.19$, $p = .282$, $\eta_p^2 = .03$, a significant main effect of height, $F(1.67, 68.32) = 88.07$, $p < .001$, $\eta_p^2 = .68$, and no attention × height interaction, $F(1.67, 68.32) = 0.78$, $p = .441$, $\eta_p^2 = .02$. Following the main effect of situation, post-hoc consecutive contrasts revealed (marginal) significant differences between each two consecutive height levels: level 1 vs. level 2: $t(164) = 2.35$, $p = .072$; level 2 vs. level 3: $t(164) = 5.02$, $p < .001$; level 3 vs. level 4: $t(164) = 2.60$, $p = .037$; level 4 vs. level 5: $t(164) = 6.89$, $p < .001$ (see Figure 12 A).

Table 4
Correlations between components of the fear response

	Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Fear ratings & SCL	.05	.10	.15	.18	.23
Fear ratings & HR	.14	.09	-.15	-.06	.11
SCL & HR	.48 **	.57 ***	.62 ***	.49 ***	.53 ***

Note: SCL = skin conductance level, HR = heart rate, $^{**}p < .01$, $^{***}p < .001$.

SCL. For the SCL, there was no main effect of attention, $F(1, 38) = 0.07$, $p = .795$, $\eta_p^2 < .01$, a significant main effect of height, $F(2.34, 88.88) = 44.25$, $p < .001$, $\eta_p^2 = .54$, and no attention × height interaction, $F(2.34, 88.88) = 1.24$, $p = .298$, $\eta_p^2 = .03$. Following the main effect of situation, post-hoc consecutive contrasts revealed (marginal) significant differences between each two consecutive height levels: level 1 vs. level 2: $t(152) = 2.91$, $p = .015$; level 2 vs. level 3: $t(152) = 2.90$, $p < .016$; level 3 vs. level 4: $t(152) = 2.40$, $p = .062$; level 4 vs. level 5: $t(152) = 3.97$, $p < .001$ (see Figure 12 B).

HR. For the HR, there was no main effect of attention, $F(1, 39) = 1.12$, $p = .296$, $\eta_p^2 = .03$, a significant main effect of height, $F(2.52, 98.32) = 2.90$, $p = .048$, $\eta_p^2 = .07$, and no attention × height interaction, $F(2.52, 98.32) = 1.36$, $p = .262$, $\eta_p^2 = .03$. Following the main effect of situation, post-hoc consecutive contrasts revealed no significant differences between two consecutive height levels: all $ps > .206$ (see Figure 12 C).

Correlations between components of the fear response

In order to test whether the different measures of the fear response (fear ratings, SCL, and HR) were associated with each other, correlations between these measures were calculated for each height level separately (see Table 4). For fear ratings and SCL there was no significant correlation on any height level. Correlation coefficients were however all positive and increased with height level. For fear ratings and HR there were also no significant correlations. The correlations between SCL and HR were significant on all height levels.

Correlations between presence and fear

The correlation between the online presence rating and the fear rating at the tower's top-level platform was significant, $r(41) = .52$, $p < .001$. For the IPQ, the correlations with the fear rating were: IPQ Spatial Presence, $r(41) = .32$, $p = .040$; IPQ Involvement, $r(41) = .24$, $p = .119$; IPQ Experienced Realism, $r(41) = .46$, $p = .002$; and IPQ General, $r(41) = .22$, $p = .155$.

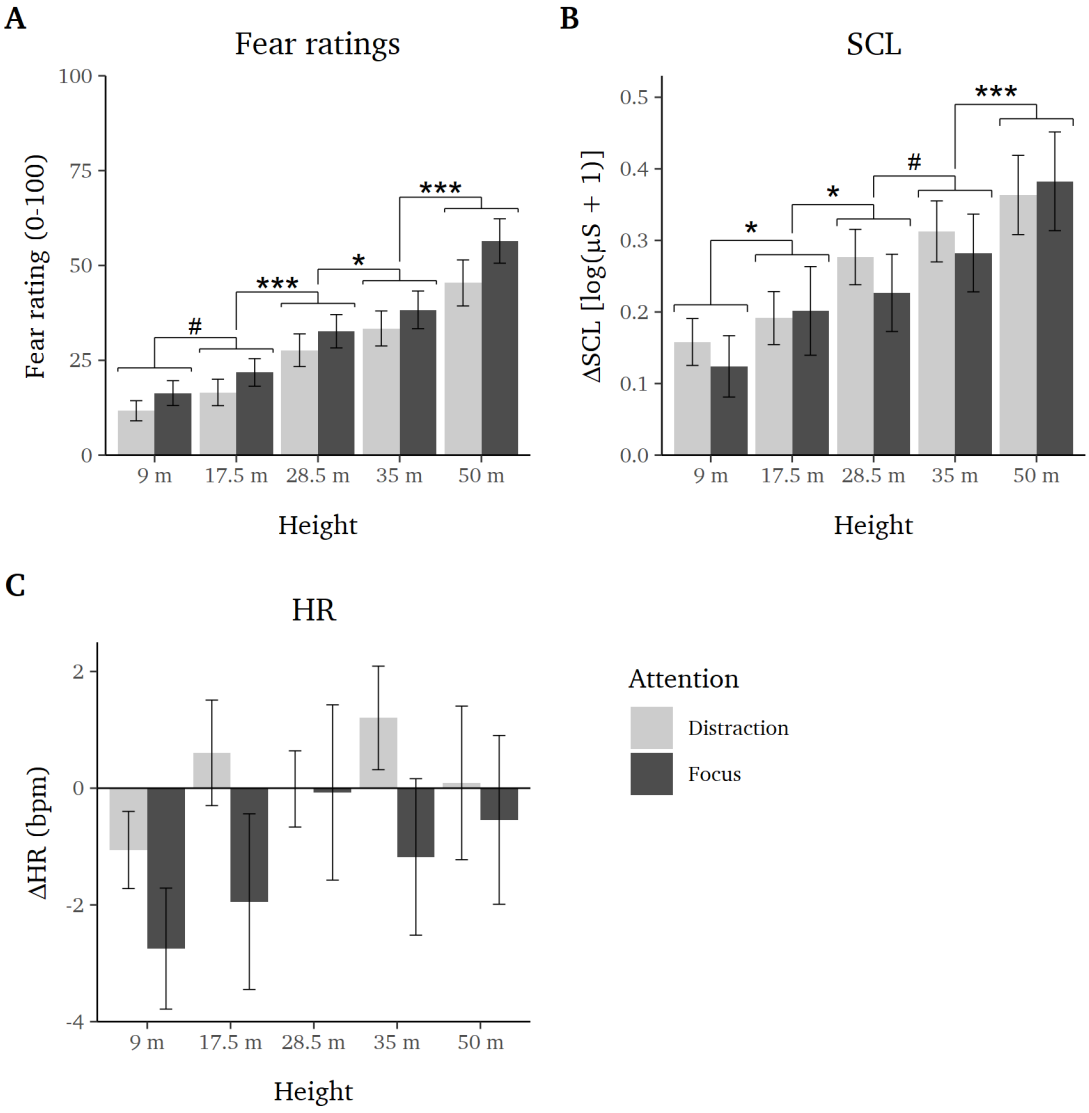


Figure 12: Mean values (± standard error) of fear ratings (A), SCL (B), and HR (C). $\#p < .10$, $*p < .05$, $***p < .001$.

3.2.4 Discussion

In this study, height-fearful participants were immersed into the same virtual height environment as in the previous study, but using a different VR system (HMD instead of CAVE). Fear responses were measured on a subjective verbal and physiological level. In addition, the attentional focus of participants was manipulated via either a visual distractor or instructions to focus on the height and on fear symptoms, and the influence of this manipulation on fear responses was analyzed.

As in the previous study, fear ratings on the virtual lookout correlated positively with a trait measure of height fearfulness. Furthermore, fear ratings increased with ascending height. These findings further validate the virtual environment for use in exposure, as the ability

of the virtual environment to provoke height-related fear responses is not restricted to a particular VR system.

3.2.4.1 Physiological fear responses

Apart from the subjective and behavioral fear responses measured in the first study, the present study shows that the virtual height environment also triggers physiological reactions. This finding was however more prominent in a measure of EDA, where ascending height led to significant increases in SCL. For HR, the effect of height was rather small ($\eta_p^2 = .07$), with no significant indication of increased HR with ascending height. This finding is in accordance with a previous study, which also found physiological reactivity towards a VR height exposure in height-fearful participants only in SCL, but not in HR (Wilhelm et al., 2005). Examining HR responses more closely, Diemer et al. (2016) found increased HR only when gazing down during a virtual height exposure. In their review on physiological reactivity towards fear stimuli and situations in VR, Diemer, Mühlberger, Pauli, and Zwanzger (2014) conclude that the fear responses on measures of EDA were strongest. Regarding HR, Diemer et al. (2014) summarize, that results are inconclusive, possibly due to a more complex mechanism behind HR activation and deactivation in fear situations compared to the responses in EDA (see also Bradley, Codispoti, Cuthbert, & Lang, 2001).

3.2.4.2 Distraction vs. attentional focus

The manipulation of the focus of attention resulted in more horizontal head rotation in the group that was asked to count the number of crows in flying-by flocks of birds. However, compared with the group of participants who were specifically asked to focus on the height itself and on symptoms of fear, the distracted group did not show any differences in subjective and physiological fear responses.

A possible reason for this finding is that, although participants in the distraction group led their focus of attention towards non-fear-relevant stimuli, the birds flying by might have served as motion parallax cues, and thus increased height perception (Rogers & Graham, 1979). This, in turn, might have led to a less conscious, but still comparable amount of height perception as in the focus group. Another explanation is that the manipulation of attention via the visual distractor and the simple cognitive task was probably not strong enough. Having intervals where no birds were flying by, participants could have shifted their attention back on the height and their symptoms of fear.

In sum, the present study could not establish a visual and cognitive distraction task within the virtual environment. Further studies following up on this research question need to consider using different (e.g., interactive tasks) or stronger distraction tasks (e.g., more birds, higher frequency of birds flying by) and carefully measure the amount of attentional focus spent towards either the fear stimuli or distractor.

Furthermore, besides finding effective distractors for fear exposure, it is important to unravel why distracted exposure has been found to be effective in some exposure therapy studies in the first place. One hypothesis is based on the assumption that there is an optimal level of fear for exposure therapy (Foa et al., 2006; McNally, 2007), and that distraction might be a way to achieve this optimal level in patients with too high fear levels (Asnaani, McLean, & Foa, 2016). Another possible explanation is that during distracted exposure, patients engage faster with the fear stimuli due to alleviated fear levels and may therefore process through the fear hierarchy more quickly (Rachman et al., 2008).

3.2.4.3 Relationships between components of the fear response

The analysis of the correlations between the different fear measures showed a significant correlation only within the physiological fear component: on each level of the virtual lookout, SCL correlated positively with HR. The correlation between fear ratings and SCL was also positive for each height level, but not significant, although the correlation increased with ascending height. Between fear ratings and HR, there was no significant correlation and correlation coefficients pointed to different directions between height levels. Previous VR exposure studies showed a similar pattern of correlations between the components of the fear response in tunnel-fearful (Mühlberger, Bülthoff, Wiedemann, & Pauli, 2007) and spider-fearful participants (Mühlberger, Sperber, & Wieser, 2008). In sum, the present study could not find a correlation between the subjective verbal and physiological component of the fear response. This pattern is typically refered to as a discordance[1] between response systems (Hodgson & Rachman, 1974). On a theoretical level, this finding is in line with two-system frameworks of fear (Evers et al., 2014; LeDoux & Pine, 2016), which consider subjective verbal and physiological responses to threat to arise from different neural systems (but see also Fanselow & Pennington, 2018, for a criticism of two-system frameworks of fear). However, other previous studies found support for a concordance between components of the fear response (e.g., McCall, Hildebrandt, Bornemann, & Singer, 2015, for a VR study). Accordingly, and also on the basis of the theoretical debate, future studies need to explore the conditions and causes of both concordance and discordance of fear responses.

3.2.4.4 Limitations

Some limitations need to be considered when interpreting the findings of the present study. First, horizontal head rotation is only a distal and indirect measure of the distractive capabilities of the utilized task. For example, further studies could use eye-tracking to directly assess

[1] A similar but distinct concept is the synchrony vs. desynchrony of the components of the fear response (Hodgson & Rachman, 1974). Whereas concordance vs. discordance refer to the correlations between the extent of the activation of different fear response systems (subjective verbal, physiological, and behavioral), synchrony vs. desynchrony refer to the correlations of changes of activation, e.g., a decline in subjective fear and of HR (Hodgson & Rachman, 1974).

whether participants visually focus on the distractors or the height itself. Second, only a single trial per height level was used for the study. This could have been problematic for the measurement of HR, where the signal-to-noise ratio might be lower than in SCL. Third, since participants climbed the virtual lookout, height levels were always presented in ascending order. The findings of increased fear ratings and increasing SCL with ascending height could therefore also be explained by accumulation of fear, i.e., a sequence effect. To control for this issue, further studies should also test different heights in a random order.

3.2.4.5 Conclusion

In summary, the present study further validated the virtual height environment as a suitable medium to trigger height-related fear responses. Findings for the physiological fear responses were in line with previous research (Diemer et al., 2014). However, previous VR studies on physiological fear responses have also shown some methodological issues. For example, increased SCL is not specific for fear reactions, but is rather seen as a broader measure of arousal, which is independent of valence (Diemer et al., 2014). To overcome this issue, Diemer et al. (2014) stress the importance of including both participants with different levels of fearfulness and virtual environments with different levels of aversiveness, which will be the goal for the next study.

3.3 Study 3: Physiological Reactions to Virtual Height Environments

3.3.1 Introduction

The importance of fear activation in exposure treatments is one cornerstone of the EPT (Foa & Kozak, 1986). According to the EPT, successful exposure therapy is only possible if the pathological fear structure in memory has been activated and is ready for modification (see 2.3.1). This activation is typically indexed by fear response parameters. Study 1 and 2 showed fear responses towards a virtual height environment on a subjective verbal, physiological, and behavioral level. However, as outlined in the discussion of the previous study, several open research questions and methodological issues regarding physiological measures in previous VR exposure studies have to be addressed. First, in order to corroborate the findings from the first two studies, the present study aims to demonstrate the specificity of fear responses in VR, i.e., that the fear responses towards the virtual height environment are a function of both height-fearfulness and the height level participants are located at. This verification of specificity has been an issue in earlier studies (Diemer et al., 2014). For example, by presenting non-fear and fear stimuli in a non-random order, i.e., a safe environment followed by a phobic environment (e.g., Diemer et al., 2016; Laforest, Bouchard, Crétu, & Mesly, 2016), it cannot be ruled out that increased physiological responding is merely an effect of time. Furthermore, although the impact of VR exposure on skin conductance has been shown in previous studies (Diemer et al., 2014), there is also evidence that this effect is not specific for phobic participants, but also present in non-phobic participants (Diemer et al., 2016). Second, although HR is often used as an index of fear in exposure studies (e.g., Benoit Allen, Allen, Austin, Waldron, & Ollendick, 2015), findings in VR have been inconclusive (Diemer et al., 2014). On the one hand, some studies found increased HR in fear-related virtual environments. For example, Diemer et al. (2016) exposed patients with acrophobia and healthy controls to a height scene in VR. Compared to a baseline measure on ground level, staying in the height scene led to significant increases in HR. On the other hand are studies that could not find effects of VR exposure on HR. For example, Wilhelm et al. (2005) exposed height-fearful and non-fearful participants to a virtual height environment. Height-fearful participants showed increased SCL towards the height scene, but no effects were evident on HR. Simeonov, Hsiao, Dotson, and Ammons (2005) compared exposure to a real vs. a virtual height situation in non-fearful participants. Whereas SCL increased with ascending height in both the real and virtual situation, HR increases were only present in the real but not in the virtual height environment. Summing up the evidence of previous VR exposure studies on physiological responding, Diemer et al. (2014) state the need for more systematic assessment of VR's potential to provoke physiological reactions.

Table 5
Questionnaire data

	M	*SD*	*Min*	*Median*	*Max*
AQ Anxiety	29.02	12.66	8.00	29.00	59.00
AQ Avoidance	5.94	3.68	0.00	5.50	14.00
STAI State t_1	36.68	7.80	23.00	35.00	59.00
STAI State t_2	35.32	6.74	22.00	35.00	51.00
STAI Trait	38.14	9.26	22.00	36.00	75.00
SSQ Total	32.84	26.29	0.00	26.18	100.98
SSQ Nausea	19.27	20.35	0.00	19.08	76.32
SSQ Disorientation	42.32	43.11	0.00	27.84	139.20
SSQ Oculomotor problems	28.20	20.43	0.00	22.74	75.80
IPQ Spatial Presence	4.52	0.94	0.80	4.70	5.80
IPQ Involvement	3.50	1.14	1.00	3.50	5.75
IPQ Experienced Realism	2.88	1.19	0.25	3.00	5.00
IPQ General	4.16	1.15	1.00	4.00	6.00

Note: AQ = Acrophobia Questionnaire; STAI = State-Trait Anxiety Inventory (t_1 = at the beginning and t_2 = in the end of the experiment); SSQ = Simulator Sickness Questionnaire; IPQ = Igroup Presence Questionnaire.

3.3.1.1 Aim of the study

The aim of the current study was to take a more in-depth look at the fear responses in VR on both a verbal and physiological level. Specifically, I wanted to test whether the fear responses towards a virtual height situation are specific, i.e., dependent upon *both* the height level and the trait height-fearfulness of participants.

3.3.2 Methods

3.3.2.1 Sample

Fifty-one participants took part in the study. One participant had to be excluded from data analysis due to technical problems during data recording, therefore the final sample consisted of fifty participants (age: $M = 23.60$, $SD = 6.49$; 34 female participants).

3.3.2.2 Apparatus

The hardware and software for presentation of the virtual environment and recording of physiological signals were the same as in the previous study (see 3.2.2.2), with the exception that the graphics card of the computer used to render the virtual environment was changed from a Nvidia GTX 560 Ti to a Nvidia GTX 970.

3.3.2.3 Virtual environment

Two virtual environments were used in the present study: a training environment and a height environment. The training environment was a simple square room. Participants were located in the center of the room and were asked to look out for floating blue balls (which could be either left, right, directly in the front, on the floor, or below the ceiling) and to give their direction to the experimenter. This task was implemented to give participants the opportunity to learn that that it was possible to look around in the virtual environment by moving the head. The height environment was a wide grasslands and forest scene (see Figure 13 C and D), where participants were placed on artificial pillars of different height.

3.3.2.4 Experimental design and procedure

A within-subject design was used for the study. The factor *height* in the virtual environment was manipulated at levels of 1 m, 2 m, 5 m, 10 m, and 20 m.
Participants read the participant information (see Appendix F), gave their informed consent (see Appendix C), and filled in questionnaires (demographics, AQ, and STAI, see 3.3.2.5). After being equipped with EDA and ECG electrodes, as well as the HMD, participants were placed in front of the VR tracking camera. To get accustomed to the VR, participants completed the training environment. After the training was completed, the height situations were presented for measurement of physiological responses. Each one of the five different height situations was presented ten times for 11 s per trial (including 0.5 s fade-in at the beginning and fade-out in the end of each trial respectively). Trials were presented in a semi-randomized order (ten blocks of randomized five trials; with a unique randomization for each participant). Each trial was preceeded by a fixation cross for 4 s and succeeded by an intertrial interval of 2–4 s (see Figure 13 A). The fixation cross was placed in such a way, that participants had to look down in a roughly 45° angle (see Figure 13 B). After the 50 trials, each height situation was presented again for 11 s and participants were asked to give an online rating of fear (fixed sequence of 2 m, 10 m, 1 m, 20 m, and 5 m for all participants). After taking the HMD off, participants filled in another set of questionnaires (STAI State, SSQ, and IPQ, see Section 3.3.2.5).

3.3.2.5 Measures

Questionnaires and ratings

For descriptions of the questionnaires Acrophobia Questionnaire (AQ), State-Trait Anxiety Inventory (STAI), Simulator Sickness Questionnaire (SSQ), and Igroup Presence Questionnaire (IPQ) see 3.1.2.5, for description of the Attitudes Towards Height Questionnaire (ATHQ) see 3.2.2.4. Ratings of fear were assessed using SUDS on a scale from 0–100 analogously to the previous studies (see 3.1.2.5).

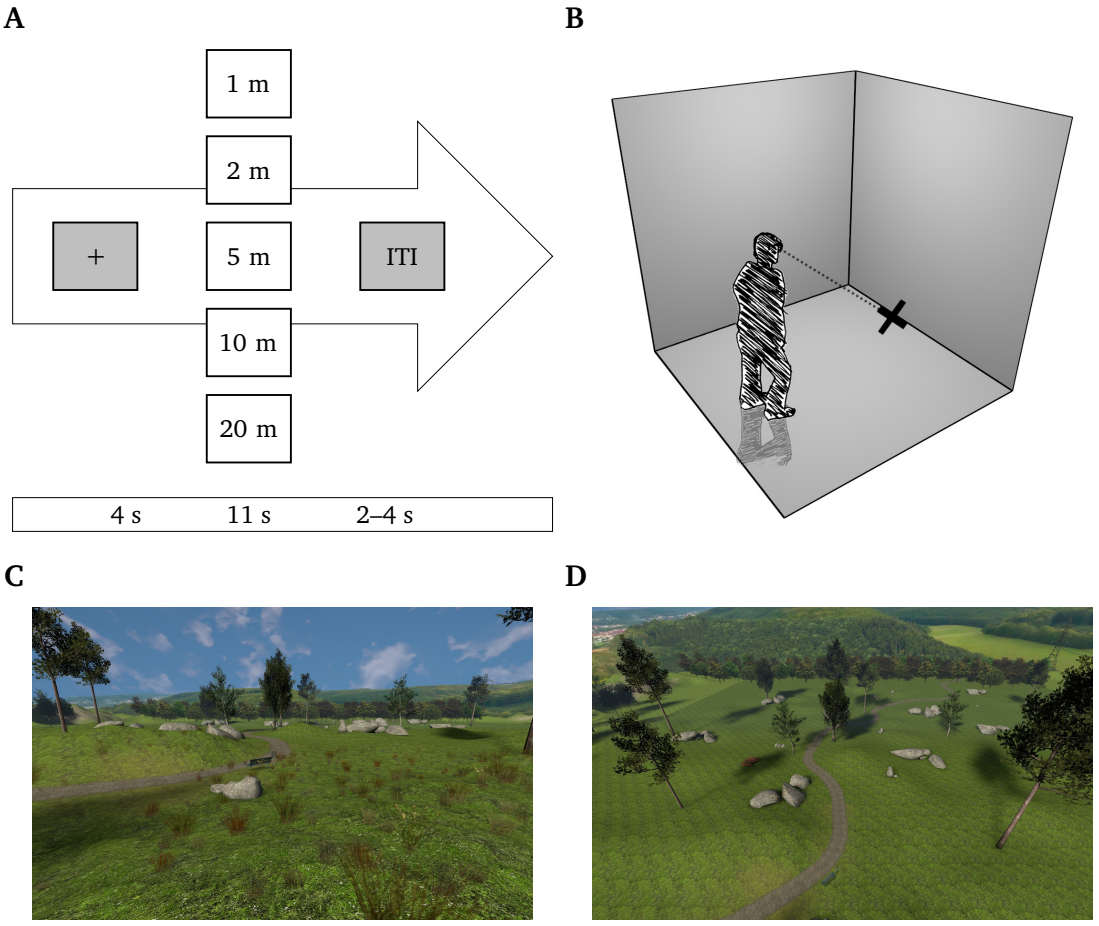


Figure 13: (A) Design of a single trial in the *Physiological Reactions to Virtual Height Environments* study. Each trial begins with a fixation cross (4 s), followed by 11 s in one of the five height levels, and ends with a blank intertrial interval (ITI) screen (2–4 s). (B) Schematic visualization of the postition of the fixation cross in 3-dimensional space (borders and illumination were not visible during the experiment). (C) Screenshot of the virtual environment at 1 m and (D) at 20 m height.

Physiological measures

Skin conductance response (SCR). For description of recording of the EDA signal, see the methods section in the previous study (3.2.2.4). The EDA signal was segmented trial-wise (i.e., extracting the 11 s per trial). The SCR was then calculated for each trial as the largest change in EDA between 1 and 5 s after stimulus onset, relative to the smallest value < 1 s after stimulus onset. To control for skewness, SCR amplitudes were adjusted using the $\log(\text{SCR}+1)$ transformation.

Heart rate (HR) and HR reaction (HRR). The ECG was recorded, filtered, and processed analogously to the previous study (see 3.2.2.4). Then, both the mean HR per trial and the HRR were calculated. First, the sequence of IBIs was segmented trial-wise and subsequently baseline corrected using the mean HR one second before stimulus onset as baseline for each

trial. Second, the HR parameter was calculated by computing the mean HR for each segment (ΔHR in bpm). Third, the HRR parameter was calculated as the largest increase in HR between 2 and 6 s after stimulus onset, relative to the smalles value < 2 s after stimulus onset.

3.3.2.6 Data analysis

All statistical analyses were conducted with R 3.3.1 (R Core Team, 2016). The `lme4` package (Bates, Mächler, Bolker, & Walker, 2015) was used for fitting linear mixed models, `afex` (Singmann et al., 2016) was used for calculating p-values of fixed effects of these models, and `MuMIn` (Barton, 2016) was used for calculating indices of explained variance.

3.3.3 Results

3.3.3.1 Components of the fear response

To the test the specificity of fear responses, i.e., if fear responses were a function of both height-fearfulness and height level, fear ratings, SCR, HR, and HR reaction were fit in separate linear mixed models using forward model selection based on AIC, BIC, and the likelihood-ratio test for model comparison to find the model which best described the data. A random intercept-only model was used as the null model and the following predictors were added one after another: (1) the fixed effect for height level, (2) the random slope for height level, (3) the fixed effect for AQ Anxiety, and (4) the interaction between height level and AQ Anxiety. See Figure 14 for visualization of the data, Table 6 for all models, and Appendix G for the commands used to calculate the models.

Fear ratings. For fear ratings (see Figure 14 A), the best model included the fixed effect for height level, $\beta = 2.07$, $F(1, 61.78) = 124.06$, $p < .001$, the random slope for height level, the fixed effect for AQ Anxiety, $\beta = 1.00$, $F(1, 52.59) = 58.79$, $p < .001$, and the interaction between height level and AQ Anxiety, $\beta = 0.08$, $F(1, 61.78) = 28.05$, $p < .001$. The fixed effects in this model explained 59.2% of the variance in fear ratings, $R^2_{GLMM(m)} = .592$; the entire model (including random effects) explained 83.9% of the variance in fear ratings, $R^2_{GLMM(c)} = .839$.

SCR. For the SCR (see Figure 14 B), the best model included the fixed effect for height level, $\beta = 0.019$, $F(1, 76.12) = 73.50$, $p < .001$, the random slope for height level, and the fixed effect for AQ Anxiety, $\beta = 0.004$, $F(1, 75.44) = 6.29$, $p = .010$. The fixed effects in this model explained 24% of the variance in the SCR, $R^2_{GLMM(m)} = .24$; the entire model (including random effects) explained 85.5% of the variance in the SCR, $R^2_{GLMM(c)} = .855$.

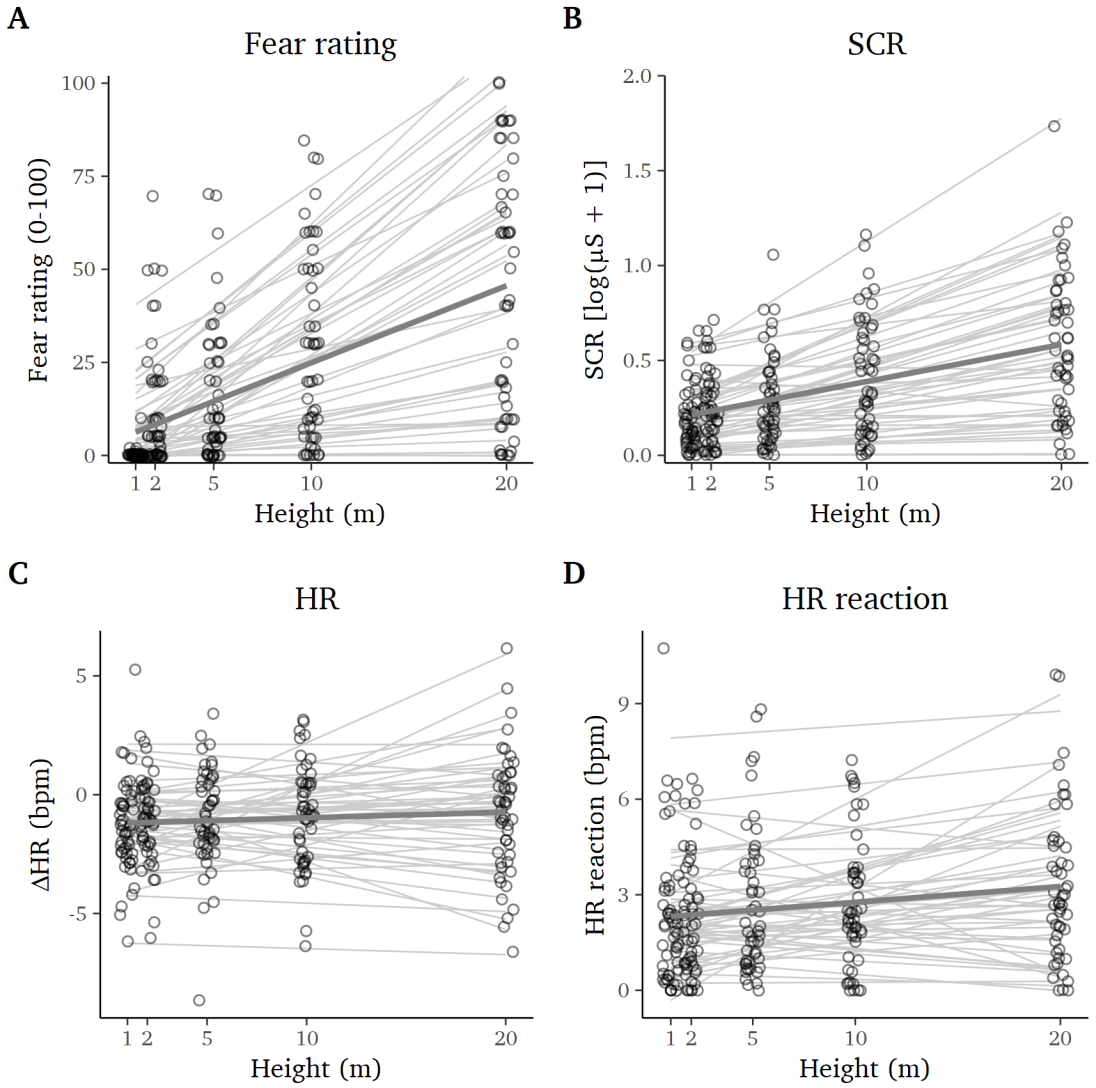


Figure 14: Scatter plots of the dependent variables (A) fear ratings, (B) skin conductance response (SCR), (C) heart rate (HR), and (D) HR reaction. The gray lines show linear models, fitted participant-wise (light gray lines) and to all data points (dark gray line) respectively.

HR. For HR (see Figure 14 C), the best model included the fixed effect for height level, $\beta = 0.023$, $F(1, 55.46) = 1.63$, $p = .210$, and the random slope for height level. The fixed effects in this model explained 0.6% of the variance in the HR, $R^2_{GLMM(m)} = .006$; the entire model (including random effects) explained 55.6% of the variance in the HR, $R^2_{GLMM(c)} = .556$.

HRR. For HRR (see Figure 14 D), the best model included only the fixed effect for height level, $\beta = 0.049$, $F(1, 199) = 10.76$, $p = .001$. The fixed effects in this model explained 2.5% of the variance in the HRR, $R^2_{GLMM(m)} = .025$; the entire model (including random effects) explained 41.3% of the variance in HRR, $R^2_{GLMM(c)} = .413$.

Table 6
Linear mixed models for fear responses

Model		*df*	*AIC*	*BIC*	Likelihood-ratio test				
					log L	*deviance*	χ^2	*df*	*p*
Fear ratings									
(0)	$Y_{si} = \beta_0 + S_{0s} + e_{si}$	2	2363.41	2370.46	-1179.71	2359.41			
(1)	$Y_{si} = \beta_0 + S_{0s} + \beta_1 H_i + e_{si}$	4	2178.67	2192.76	-1085.34	2170.67	188.74	2	< .001
(2)	$Y_{si} = \beta_0 + S_{0s} + (\beta_1 + S_{1s})H_i + e_{si}$	6	2044.63	2065.76	-1016.31	2032.63	138.04	2	< .001
(3)	$Y_{si} = \beta_0 + S_{0s} + (\beta_1 + S_{1s})H_i + \beta_2 AQ_s + e_{si}$	7	2029.06	2053.71	-1007.53	2015.06	17.57	1	< .001
(4)	$Y_{si} = \beta_0 + S_{0s} + (\beta_1 + S_{1s})H_i + \beta_2 AQ_s + \beta_3(H_i \times AQ_s) + e_{si}$	8	2008.06	2036.23	-996.03	1992.06	23.00	1	< .001
SCR									
(0)	$Y_{si} = \beta_0 + S_{0s} + e_{si}$	2	95.42	102.46	-45.71	91.42			
(1)	$Y_{si} = \beta_0 + S_{0s} + \beta_1 H_i + e_{si}$	4	-92.67	-78.58	50.34	-100.67	192.09	2	< .001
(2)	$Y_{si} = \beta_0 + S_{0s} + (\beta_1 + S_{1s})H_i + e_{si}$	6	-184.81	-163.68	98.40	-196.81	96.14	2	< .001
(3)	$Y_{si} = \beta_0 + S_{0s} + (\beta_1 + S_{1s})H_i + \beta_2 AQ_s + e_{si}$	7	-189.04	-164.39	101.52	-203.04	6.23	1	.013
(4)	$Y_{si} = \beta_0 + S_{0s} + (\beta_1 + S_{1s})H_i + \beta_2 AQ_s + \beta_3(H_i \times AQ_s) + e_{si}$	8	-188.24	-160.07	102.12	-204.24	1.20	1	.273
HR									
(0)	$Y_{si} = \beta_0 + S_{0s} + e_{si}$	2	1041.17	1048.22	-518.59	1037.17			
(1)	$Y_{si} = \beta_0 + S_{0s} + \beta_1 H_i + e_{si}$	4	1023.63	1037.71	-507.81	1015.63	21.55	2	< .001
(2)	$Y_{si} = \beta_0 + S_{0s} + (\beta_1 + S_{1s})H_i + e_{si}$	6	1012.33	1033.46	-500.17	1000.33	15.29	2	< .001
(3)	$Y_{si} = \beta_0 + S_{0s} + (\beta_1 + S_{1s})H_i + \beta_2 AQ_s + e_{si}$	7	1011.50	1036.15	-498.75	997.50	2.83	1	.092
HR reaction									
(0)	$Y_{si} = \beta_0 + S_{0s} + e_{si}$	2	1116.55	1123.59	-556.27	1112.55			
(1)	$Y_{si} = \beta_0 + S_{0s} + \beta_1 H_i + e_{si}$	4	1040.39	1054.48	-516.20	1032.39	80.16	2	< .001
(2)	$Y_{si} = \beta_0 + S_{0s} + (\beta_1 + S_{1s})H_i + e_{si}$	6	1042.23	1063.36	-515.11	1030.23	2.16	2	.339

Note: S_{0s} = random intercept, S_{1s} = random slope, H_i = height level, AQ_s = Acrophobia Questionnaire anxiety subscale score. s = subject index, i = height level index, SCR = skin conductance response, HR = heart rate.

Table 7
Correlations between components of the fear response

	Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Fear ratings & SCR	-.16	.14	.33 *	.37 **	.36 *
Fear ratings & HR	.07	.26	< .01	.10	-.02
Fear ratings & HRR	.03	.09	.10	.30 *	.21
SCR & HR	.08	.15	.19	.09	.10
SCR & HRR	.08	.09	.16	.16	.24
HR & HRR	.35 *	.43 **	.36 **	.61 ***	.65 ***

Note: SCR = skin conductance response, HR = heart rate, HRR = heart rate reaction, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

3.3.3.2 Correlations between components of fear response

Analogous to the previous study, in order to test whether the different measures of the fear response (fear ratings, SCR, HR, and HRR) were associated with each other, correlations between these measures were calculated for each height level separately (see Table 7). Fear ratings and SCR correlated significantly positive from level 3 (5 m) on upwards. Fear ratings and HR did not correlate with each other. For fear ratings and HRR, there was only one significant positive correlation for level 4 (10 m), although the correlations were also positive for all other height levels. SCR and HR, as well as SCR and HRR, did not correlate significantly, but all correlation coefficients were positive. HR and HRR correlated significantly positive on each height level.

Correlations between presence and fear

The correlations between presence (measured by the IPQ) and the fear rating at 20 m height were positive but not significant: IPQ Spatial Presence, $r(48) = .16$, $p = .272$; IPQ Involvement, $r(48) = .25$, $p = .086$; IPQ Experienced Realism, $r(48) = .04$, $p = .804$; and IPQ General, $r(48) = .07$, $p = .636$.

3.3.4 Discussion

The present study investigated the specificity of verbal and physiological fear responses towards a virtual height situation, i.e., whether the strength of fear responses is a function of both height level and height-fearfulness. To this end, participants with differing levels of height-fearfulness were immersed into virtual environments of differing height in a randomized order. Fear responses were measured by subjective report, SCR, HR, and a HR reaction parameter.

3.3.4.1 Specificity of fear responses

Results showed that fear ratings and SCR were specific fear responses, i.e., both measures increased with the height level and were higher in more height-fearful participants. This confirmation of specificity had been an issue in earlier VR exposure studies (Diemer et al., 2014). The influence of height level on fear responses was however stronger than the influence of trait height-fearfulness. This might explain why a previous study found an effect of height level, but not of height-fearfulness, on skin conductance (Diemer et al., 2016). HR and HRR were not specific, meaning that interindividual variability in HR and HRR was not attributable to height level and height-fearfulness.

3.3.4.2 HR as an index of fear in VR exposure

Rapid heartbeat in height situations is a frequently mentioned symptom of fear in patients with acrophobia. Furthermore, it is listed as one of the vegetative symptoms for the diagnosis of specific phobia (World Health Organization, 2016). In contrast, the present study showed only little empirical support for increased HR with increased virtual height and increased height-fearfulness. Several explanations for this finding have to be considered. First, as proposed by Wilhelm et al. (2005), fear exposure in VR might differ from exposure *in vivo* with respect to fear activation patterns. Like in the present study, Wilhelm et al. (2005) found increases in skin conductance, but not in HR, during VR height exposure. Wilhelm et al. (2005) interpret their findings that VR might selectively activate the Behavioral Inhibition System (for which skin conductance is a measure), but not the Behavioral Activation System (for which HR is a measure; Fowles, 1980). However, contrary to the findings in Wilhelm et al. (2005), other studies did find HR increases in fear-relevant situations (Diemer et al., 2016; Mühlberger et al., 2007, 2008). For this reason, it could also be the case that null findings in HR are due to differences in the virtual environments used for exposure. Second, HR, in comparison to skin conductance, might not simply increase in response to threatening stimuli or situations (Diemer et al., 2014). The defense cascade model (Bradley et al., 2001) proposes that cardiac responses towards threat are characterized by an initial deceleration, which indicates an orientation reaction, and a subsequent acceleration, i.e., a preparation for action (fight of flight). The shift from cardiac deceleration to acceleration is thought to be dependent on the imminence of threat. The HR data from the current study, averaged over trials and participants supports this shift from initial deceleration to acceleration (see Appendix H). Furthermore, the absolute amplitude of the acceleration seems to be dependent on the height level, with higher amplitudes with ascending height (see also Appendix H). However, the interindividual and intertrial variability in the HR reaction parameter, which specifically targeted the amplitude of acceleration after the initial deceleration, was too large to detect statistically significant patterns in HR in response to the virtual heights. Third, Diemer et al. (2014) suggest that “the physiological regulation of HR during fear is more complex than

the electrodermal activation" (Diemer et al., 2014, p. 439). In a study using fear-inducing pictures, Kreibig, Wilhelm, Roth, and Gross (2007) could also find no differences in HR towards neutral vs. fear-inducing pictures, but again an effect of the different pictures on SCL. However, other cardiovascular parameters (e.g., blood pressure, finger skin temperature) showed a differentiation between neutral and fear-inducing pictures, suggesting that it may be important to consider further cardiovascular measures of fear in future VR exposure studies.

3.3.4.3 Relationships between components of the fear response

Correlations between the components of the fear response in the current study showed a concordance between fear ratings and SCR from 5 m on upwards. Fear ratings and HR were discordant. Although the correlation coefficients between fear ratings and HRR were all positive, only the correlation at a height of 10 m was statistically significant. Correlations within the physiological response domain were all positive, but only statistically significant between HR and HRR.

Compared to the previous study, where the correlations between fear ratings and skin conductance were also positive but non-significant, the current study, probably due to the increased experimental control, could demonstrate a concordance between both components of the fear response.

3.3.4.4 Limitations

Some limitations to this study need to be taken into account. First, although the study included participants with differing levels of height-fearfulness, the sample was not systematically stratified and therefore clinical levels of height-fearfulness might be under-represented in the current study sample. However, since linear mixed models were used for data analysis and both fear ratings and SCR increased linearly with higher values on the AQ Anxiety subscale, one can assume that reactions of diagnosed acrophobics point into the same direction.

Second, compared with other studies (e.g., Diemer et al., 2016), exposure durations were relatively short (11 s per trial) and also the time between the exposures was relatively brief (6–8 s). One can assume that fear responses do not necessarily reach their peak within this narrow time frame and that longer exposure durations might have allowed to also find effects on HR. For example, the cognitive theory of panic disorder (Clark & Ehlers, 1993) assumes that a panic attack builds itself up over time through a vicious cycle of catastrophic interpretations towards bodily sensations, which in turn result in stronger bodily responses.

3.3.4.5 Conclusions

To my knowledge, this is the first study that established the specificity of fear responses in VR fear exposure. Subjective fear and SCR increased linearly with ascending height and

were higher in more height-fearful individuals. Cardiovascular responses were not a specific component of the fear response. Together with the first two studies of this thesis, this study confirms that fear in VR is dependent upon the level of trait height-fearfulness, one of the variables proposed in the model of fear in VR (see Figure 4). In the next study, the second variable, presence, will be investigated. Specifically, the study aims to unravel the causal relationship between presence and fear in VR.

3.4 Study 4: The Causal Relationship Between Presence and Fear

Parts of the following section have already been published as

> Gromer, D., Reinke, M., Christner, I., & Pauli, P. (2019). Causal Interactive Links Between Presence and Fear in Virtual Reality Height Exposure. *Frontiers in Psychology*, *10*. doi: 10.3389/fpsyg.2019.00141

3.4.1 Introduction

As described in the introduction of the thesis, presence—the sense of 'being there' in the virtual environment—has been shown to correlate positively with fear ratings in VR, i.e., participants who experience a strong sense of presence in VR also report strong fear responses (Ling et al., 2014, see also 2.4.2.3). However, it is still unclear whether there is a causal link underlying this correlation (Diemer et al., 2015; Peperkorn et al., 2015; Riva et al., 2015). Previous studies indicate both a fear → presence (i.e., experiencing fear in VR leads to more presence; Bouchard et al., 2008) and a presence → fear relationship (i.e., being present in VR leads to stronger fear responses; Peperkorn et al., 2015), but non of these studies has experimentally manipulated *both* presence and fear.

Experimental manipulations of fear are typically based on presenting stimuli and environments relevant vs. irrelevant to a given phobia (Alsina-Jurnet & Gutiérrez-Maldonado, 2010; Bouchard et al., 2008), or by investigating low- vs. high-fearful participants (Alsina-Jurnet & Gutiérrez-Maldonado, 2010; Robillard et al., 2003). To investigate the effects of height-related fear responses on presence in the current study, height vs. non-height situations in VR will be used to experimentally manipulate fear levels.

Experimental manipulation of presence is usually achieved by changing characteristics of the VR system. Increased field of view, use of stereoscopy, and increased levels of user-tracking show the strongest effects on presence (Cummings & Bailenson, 2016). Mixed results have been shown for quality of visual and auditory content (Cummings & Bailenson, 2016). In order to gain further insights into these effects of sensory realism, a manipulation of visual and auditory realism will be used to experimentally manipulate presence levels in the present study. As a definition, Christou and Parker (1995) state that *visual realism* "can be equated with how closely the artificial world resembles a corresponding possible real world" (Christou & Parker, 1995, p. 53). Visual realism in virtual environments therefore relates to the quality of geometry (e.g., vertex count), lighting (e.g., static vs. dynamic shadows, soft vs. hard shadows), and material properties (e.g., texture resolution, use of normal maps; Reinhard, Efros, Kautz, & Seidel, 2013; Slater, Khanna, Mortensen, & Yu, 2009). Previous research revealed mixed findings regarding effects of visual realism on presence. Some studies found increased presence with higher visual realism (Kwon, Powell, & Chalmers, 2013; Slater et

al., 2009; Welch, Blackmon, Liu, Mellers, & Stark, 1996), whereas other studies did not find such an effect (Dinh, Walker, Hodges, Song, & Kobayashi, 1999; Lee, Rincon, Meyer, Höllerer, & Bowman, 2013; Lugrin, Wiedemann, Bieberstein, & Latoschik, 2015; Mania & Robinson, 2004; Zimmons & Panter, 2003). Studies on the effects of auditory content (e.g., absence vs. presence of sound, stereo vs. spatial sound) on presence showed mixed findings as well. On the one hand are studies showing a positive effect of audio on presence (Brinkman, Hoekstra, & Van, 2015; Dinh et al., 1999; Hendrix & Barfield, 1996; Larsson, Västfjäll, Olsson, & Kleiner, 2007). On the other hand are studies that could not find such an effect (Keshavarz & Hecht, 2012a, 2012b; Nichols, Haldane, & Wilson, 2000). It is therefore still subject to debate whether investments in increased quality of visual and auditory content of virtual environments are necessary to achieve high levels of presence. For creating new virtual environments for VRET, it would be important to know about the relevance of sensory realism. If sensory realism's effects on presence and fear are marginal, investigating effort in creating highly realistic virtual environments may not be necessary.

3.4.1.1 Aim of the study

The aim of the present study was twofold: (1) to test whether the quality of visual and auditory content of the virtual environment has an influence on presence, and to explore the causal relationship between presence and fear in VR. Specifically (2a) whether manipulation of presence by means of visual realism and auditory content has an influence on fear (presence → fear) and (2b) whether manipulation of fear levels has an influence on reported sense of presence (fear → presence). In addition to subjective measures of fear, physiological reactions, i.e., skin conductance and heart rate, were recorded.
First, a pilot experiment evaluated a manipulation of visual realism and auditory content and established the paradigm to identify causal links. Findings from this experiment were used to refine the manipulation in the second experiment.

3.4.2 Experiment 1

3.4.2.1 Methods

Sample

Public advertisement and the university subject pool were used to recruit participants. Before being invited to the study, potential participants were screened for fear of heights using a subset of the AQ to predict AQ scores. Volunteers with estimated scores between 20 and 50 (targeting a height-fearful but non-clinical population) were invited to the study and 66 participants were included. Two participants had to be excluded from data analysis due to simulator sickness, therefore the final sample consisted of 64 participants (age: $M = 24.44$,

SD = 4.93; 40 female participants). Participants received either 10 EUR or course credit for participation.

Apparatus

The hardware and software for presentation of the virtual environment and recording of physiological signals were the same as in the second and third study (see 3.2.2.2).

Experimental design and procedure

A 2 × 3 mixed design was used for the study. Experimental manipulations were *sensory realism* (low vs. high, *between factor*) and *situation* (control 1 vs. height vs. control 2, *within factor*) (see Figure 15). Participants were randomly assigned to the between-subject factor.
For the situation manipulation, three different environments were created: a pebble path in an open countryside surrounded by trees and large rocks (control situation 1 and 2), and a canyon with a wooden plank laid across the abyss (height situation). The sensory realism manipulation was realized by deriving the low sensory realism virtual environment from the high sensory realism virtual environment through (1) scaling up the textures of the virtual objects to achieve pixelated and blurred textures, (2) replacing rock meshes with simple cubes, and tree meshes with 2d sprites, (3) removing grass sprites, (4) displacing pebble path decals, and (5) turning sound off (see Figure 15 for demonstration of the different conditions). Sound in the high sensory realism condition consisted of wind noise, rustling of trees, and bird's twittering in the control situations, and creaking of the wooden plank and sound of a rushing stream in the height situation.
At the beginning of the session, participants first read and signed the informed consent (see Appendix I and Appendix C). Subsequently, participants were equipped with electrodes for EDA and ECG measurement. During a baseline measure of 5 min, participants filled out questionnaires (demographics, AQ, ATHQ and STAI). Next, participants were helped to put on the HMD and headphones and were placed in front of the VR tracking camera. The VR experiment consisted of three trials (control situation 1, height situation, and control situation 2). Each trial consisted of walking to the situation (i.e., virtual bench or virtual plank), a one-minute exploration phase where participants were asked to look around, and a rating phase where participants were asked to give their SUDS and presence ratings. After taking off the HMD and headphones, participants filled out the second set of questionnaires (STAI State, SSQ, and IPQ).

Measures

Questionnaires and ratings. For descriptions of the questionnaires Acrophobia Questionnaire (AQ), State-Trait Anxiety Inventory (STAI), Simulator Sickness Questionnaire (SSQ),

Figure 15: Screenshots of the control situation (left) and height situation (right) with low (top) and high (bottom) sensory realism in experiment 1. Examples for the "control situation 2" are omitted from the figure.

and Igroup Presence Questionnaire (IPQ) see 3.1.2.5, for description of the Attitudes Towards Height Questionnaire (ATHQ) see 3.2.2.4.
Ratings of fear (SUDS) and presence were assessed analogously to the previous studies (see 3.1.2.5).

Physiological measures. *Skin Conductance Level (SCL).* The EDA was derived using two 13/7 mm Ag/AgCl electrodes filled with 0.5 % NaCl gel. The electrodes were placed on the thenar and hypothenar of the right hand and the signal was recorded at a samplerate of 500 Hz. The recorded EDA signal was later processed with the R package `phyr6` (see `https://github.com/dgromer/phyr6`). First, the signal was segmented into training phase, control situation 1, height situation, and control situation 2. Second, the mean of each segment (SCL in μS) was calculated. Third, the means were added to 1 and logarithmised to control for skewness (SCL in $\log(\mu S + 1)$). Fourth, a baseline correction was applied by substracting the training phase value from the others (ΔSCL in $\log(\mu S + 1)$).
Heart rate (HR). The ECG was derived using three Ag/AgCl electrodes placed under the right collarbone, on the lower left costal arch (reference electrode), and on the lower left back

(ground electrode), recorded at a samplerate of 500 Hz. The ECG was filtered offline with a 50 Hz notch filter and a 2.5 Hz highpass filter. Detection of R waves and correction of interbeat interval artifacts was done in PeakMan 0.3.0 (see `https://github.com/dgromer/PeakMan`). The sequence of interbeat intervals was later processed with the R package phyr6 (see `https://github.com/dgromer/phyr6`). Segmentation of the sequence of interbeat intervals was done analogous to the EDA signal. The HR (in bpm) for each phase was calculated by (1) computing the mean over the sequence of interbeat intervals per segment, (2) transforming the mean interbeat interval value to HR (60000/IBI), and (3) applying a baseline correction analogous to the SCL, yielding the mean heart rate change (ΔHR in bpm).

Data analysis

All statistical analyses were conducted with R 3.2.3 (R Core Team, 2016) and afex (Singmann et al., 2016) was used for ANOVA with type 3 sum of squares (with Greenhouse-Geisser correction if sphericity was violated), and the `lsmeans` package (Lenth, 2016) was used for post-hoc comparisons (using Tukey's method for alpha adjustment for multiple comparisons).

3.4.2.2 Results

Group characteristics

Participants in the two experimental conditions did differ in sex, $\chi^2(1) = 5.40$, $p = .020$, with more female participants in the high sensory realism condition, and in symptoms of nausea after the experiment, with more symptoms of nausea in the high sensory realism condition. Participants did not differ with regards to age, height-fearfulness, trait and state anxiety, as well as the SSQ subscales except for nausea (see Table 8).

Validation of the virtual environment

Testing whether the virtual environment was suited for inducing height-related fear, the correlation between the AQ Anxiety subscale and the fear ratings in the fear situation was computed. The relationship was significant, $r(62) = .37$, $p = .002$, indicating higher fear ratings among participants with higher levels of trait height-fearfulness.

Influence of sensory realism on presence

In order to test whether the manipulation of presence was successful, a two sample t-test on the presence rating in the first control situation was conducted. The test showed no difference between sensory realism conditions, $t(62) = -0.26$, $p = .799$, $d = -0.06$, indicating that manipulation of presence by altering the visual quality and auditory stimuli of the virtual environment failed (see Figure 16 A).

Table 8
Questionnaire data of experiment 1

	Low sensory realism		High sensory realism			
	M	***SD***	***M***	***SD***	***t***	***p***
Age	25.34	5.92	23.53	3.55	1.49	.144
AQ Anxiety	38.72	11.97	38.78	12.65	-0.02	.984
AQ Avoidance	7.53	3.55	8.91	3.86	-1.48	.143
ATHQ	28.31	11.27	31.44	10.44	-1.15	.254
STAI State t_1	36.16	6.09	35.72	6.36	0.28	.780
STAI State t_2	37.88	9.23	42.28	9.67	-1.86	.067
STAI Trait	37.78	9.64	37.31	8.16	0.21	.834
SSQ Total	44.76	35.04	56.33	39.52	-1.24	.220
SSQ Nausea	34.88	29.14	53.36	40.54	-2.09	.041
SSQ Oculomotor Problems	30.32	23.18	36.01	21.78	-1.01	.316
SSQ Disorientation	60.03	54.37	65.69	60.03	-0.39	.694

Note: AQ = Acrophobia Questionnaire; ATHQ = Attitudes Towards heights Questionnaire; STAI = State-Trait Anxiety Inventory (t_1 = at the beginning and t_2 = in the end of the experiment); SSQ = Simulator Sickness Questionnaire.

Causal relationship between presence and fear

Following the hypothesis of the study, ANOVA were computed for both presence and fear measures with sensory realism as between factor and situation as within factor. For presence, the ANOVA showed neither main effects of sensory realism, $F(1, 62) = 0.45$, $p = .505$, $\eta_p^2 < .01$, and situation, $F(1.80, 111.69) = 0.58$, $p = .545$, $\eta_p^2 < .01$, nor an interaction effect, $F(1.80, 111.69) = 0.72$, $p = .473$, $\eta_p^2 = .01$.

For fear, the ANOVA revealed no main effect of sensory realism, $F(1, 62) = 1.23$, $p = .272$, $\eta_p^2 = .02$, a significant main effect of situation, $F(1.54, 95.19) = 114.29$, $p < .001$, $\eta_p^2 = .65$, and a significant sensory realism × situation interaction, $F(1.54, 95.19) = 10.83$, $p < .001$, $\eta_p^2 = .15$. For the significant main effect of situation, post-hoc pairwise comparisons (alpha adjustment with Tukey's method) between situations yielded a significant difference between control situation 1 and the height situation, $t(124) = -12.91$, $p < .001$, a significant difference between the height situation and the control situation 2, $t(124) = 13.269$, $p < .001$, and no difference between control situation 1 and control situation 2, $t(124) = 0.36$, $p = .932$. Fear ratings in the height situation were higher than in both control situations. For the significant interaction effect, post-hoc pairwise comparisons (alpha adjustment with Tukey's method) further revealed a difference in fear ratings in the height situation between low and high sensory realism, $t(115) = -3.41$, $p = .011$ (see Figure 16 B).

Since the manipulation check was not successful, it was not possible to further test the hypothesized causal link between presence and fear in the planned way. For the fear ratings, however, the expected pattern was found.

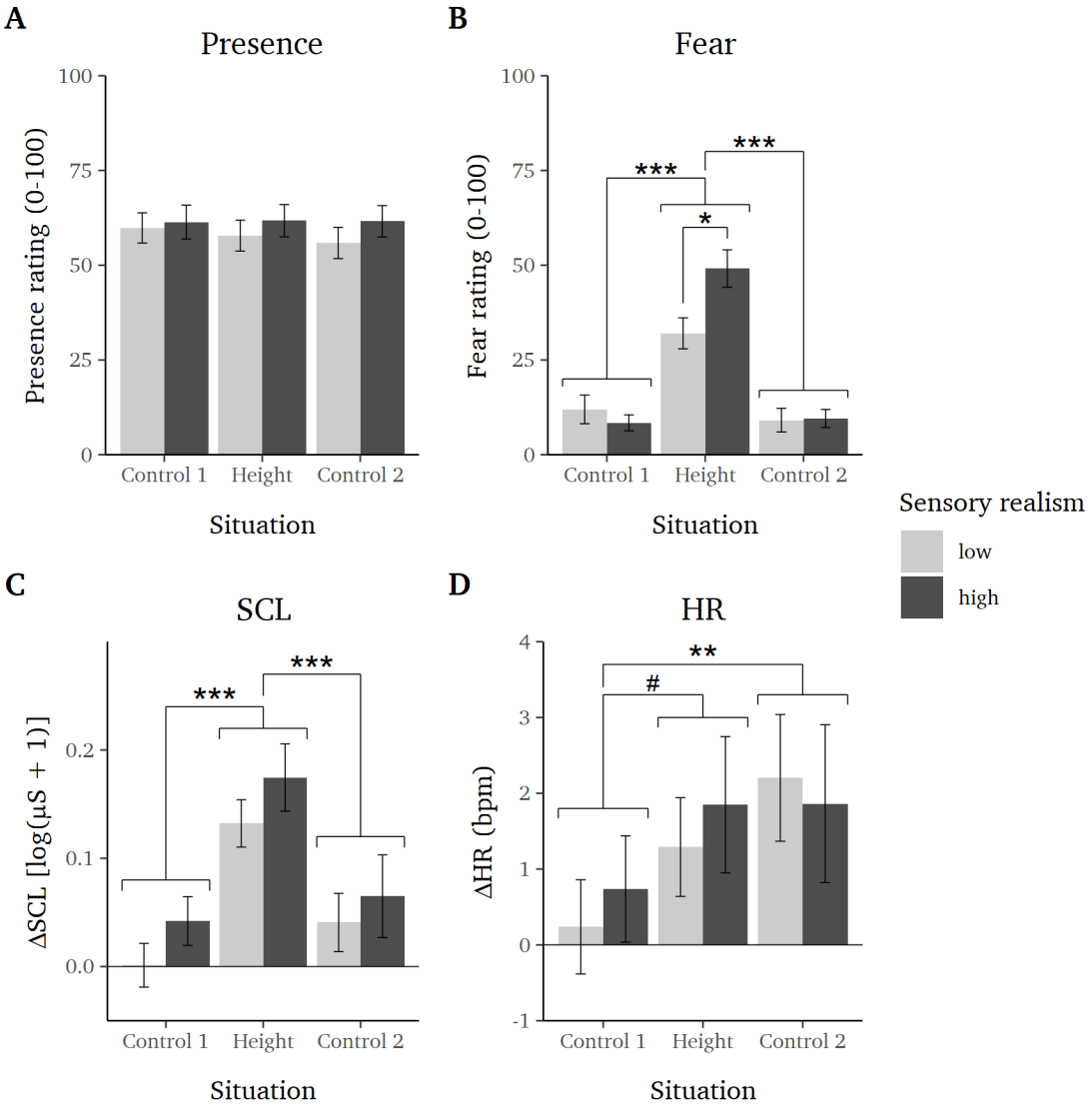


Figure 16: Mean ratings (± standard error) of presence (A) and subjective fear (B), and mean changes (± standard error) in skin conductance level (SCL) (C) and heart rate (HR) (D). *$p < .05$, **$p < .01$, ***$p < .001$.

Physiological reactions

Analogous to the fear ratings, ANOVA were conducted for both SCL and HR with sensory realism as between factor and situation as within factor. For SCL, there was no significant main effect of sensory realism, $F(1, 60) = 1.04$, $p = .311$, $\eta_p^2 = .02$, a significant main effect of situation, $F(2, 120) = 49.39$, $p < .001$, $\eta_p^2 = .45$, and no sensory realism × situation interaction, $F(2, 120) = 0.26$, $p = .770$, $\eta_p^2 < .01$. For the significant main effect of situation, post-hoc pairwise comparisons (alpha adjustment with Tukey's method) between situations yielded a significant difference between control situation 1 and the height situation, $t(120) = -9.51$, $p < .001$, a significant difference between the height situation and the control situation 2, $t(120) = 7.26$, $p < .001$, and no difference between control situation 1 and

control situation 2, $t(120)$ = -2.26, $p = .066$. SCL in the height situation was higher than in both control situations.

For HR, there was no significant main effect of sensory realism, $F(1, 58) = 0.06$, $p = .810$, $\eta_p^2 < .01$, a significant main effect of situation, $F(2, 116) = 5.85$, $p = .004$, $\eta_p^2 = .09$, and no sensory realism × situation interaction, $F(2, 116) = 0.59$, $p = .557$, $\eta_p^2 = .01$. For the significant main effect of situation, post-hoc pairwise comparisons (alpha adjustment with Tukey's method) between situations yielded a marginal significant difference between control situation 1 and the height situation, $t(116)$ = -2.34, $p = .055$, no significant difference between the height situation and the control situation 2, $t(116)$ = -0.99, $p = .579$, and a significant difference between control situation 1 and control situation 2, $t(116)$ = -3.33, $p = .003$. HR tended to increase within the experiment.

Correlations between components of the fear response

In order to test whether the different measures of the fear response (fear ratings, SCL, and HR) were associated with each other, correlations between these measures were calculated. The correlation between fear ratings and SCL in the height situation was significant, $r(60) = .39$, $p = .002$. The correlations between fear ratings and HR, $r(58) = .11$, $p = .418$, and SCL and HR, $r(58) = .25$, $p = .058$, were positive but not significant.

Correlations between presence and fear

The correlation between the online presence rating and the fear rating in the height situation was significant, $r(62) = .48$, $p < .001$. For the IPQ, the correlations with the fear rating in the height situation were: IPQ Spatial Presence, $r(62) = .25$, $p = .042$; IPQ Involvement, $r(62) = .21$, $p = .094$; IPQ Experienced Realism, $r(62) = .48$, $p < .001$; and IPQ General, $r(62) = .39$, $p = .001$.

3.4.2.3 Discussion of experiment 1

The present experiment thought to shed light on a possible causal relationship between presence and fear responses in VR, i.e., whether feeling more present in VR increases fear responses and whether experiencing fear in VR increases presence. To this end, both presence and fear were manipulated experimentally. Presence was manipulated via the visual and auditory realism of the virtual environment and fear was manipulated by presenting height and non-height situations.

The manipulation check showed that the manipulation of presence was not successful, i.e., participants in the high and low sensory realism conditions did not differ in their presence ratings towards the virtual environment. Possible explanations for the failure of the manipulation need to be discussed. First, the manipulation might not have been strong enough or the manipulation might not have produced marked visual differences on

the Oculus DK2's low resolution display. These problems could be tackled by using, for example, photogrammetry quality assets vs. simple shaped assets in combination with a higher fidelity HMD display (e.g., the HTC VIVE headset). Second, Wirth et al. (2007) argue that "if immersive impulses are not provided by the media product, internal processes, for example, imagination, can compensate for that deficit in external stimulation" (Wirth et al., 2007, p. 496). This suggests that participants' imagination might have compensated for the lower visual and auditory realism in the low sensory realism condition (e.g., textured cube → boulder), thereby increasing presence. To contrast these two possibilities, the second experiment will test the first explanation by using a stronger manipulation of visual realism in combination with a higher resolution HMD.

Although the manipulation check for sensory realism was not successful, a nonetheless interesting finding is that the experimental manipulation of sensory realism increased fear ratings in the height situation. In retrospect, this was, however, most likely caused by the creaking sound of the wooden plank, as this was noted by several participants. If this explanation holds true, the cause for increased fear should not be attributed to increased sensory realism per se, but to this specific sound. In order to test this assumption, experimental manipulation of sound will be limited to subtle wind sounds in the second experiment.

3.4.3 Experiment 2

3.4.3.1 Methods

Sample

Local advertisement and the university subject pool were used to recruit volunteers for the study. Prior to participation, an online screening for fear of heights using a subset of the AQ was used to predict AQ scores. Volunteers for which the online screening estimated AQ scores between 20 and 50 were invited to the study. Forty-nine participants (age: $M = 26.84$, $SD = 10.94$; 37 female) were included in the study. All participants gave their written informed consent. Participants received either 8 EUR or course credit for participation.

Apparatus

The experiment was built in Unreal Engine 4.12 (Epic Games, Cary, North Carolina, USA) using the free Open World Demo Collection assets from the UE4 marketplace[2]. The virtual environments were displayed on a HTC Vive (HTC, New Taipei City, Taiwan) with a resolution of 1080 × 1200 pixels per eye at 90 Hz, and a 100° field of view. The experiment ran on a Windows 10 64-bit machine with an Intel Core i5-6600k, 16 GB RAM, and a Nvidia GTX 970. A Sennheiser HD 439 (Sennheiser, Wedemark-Wennebostel, Germany) was used for

[2] https://www.unrealengine.com/marketplace/en-US/slug/open-world-demo-collection

Table 9
Questionnaire data of experiment 2

	Low sensory realism		**High sensory realism**			
	M	***SD***	***M***	***SD***	***t***	***p***
Age	27.64	11.48	26.00	10.53	0.52	.605
AQ Anxiety	36.28	14.35	39.09	13.81	-0.68	.498
AQ Avoidance	7.48	4.82	8.96	3.51	-1.22	.229
STAI State t_1	35.60	6.53	33.46	5.53	1.24	.221
STAI State t_2	39.43	10.81	35.52	7.22	1.44	.157
STAI Trait	37.00	7.36	37.75	10.13	-0.29	.771
SSQ Total	26.80	30.26	25.56	24.15	-0.16	.875
SSQ Nausea	21.46	24.40	21.37	27.85	0.01	.990
SSQ Oculomotor problems	19.27	17.74	19.40	15.64	-0.03	.977
SSQ Disorientation	28.42	31.39	35.38	49.59	-0.58	.565

Note: AQ = Acrophobia Questionnaire; STAI = State-Trait Anxiety Inventory (t_1 = at the beginning and t_2 = in the end of the experiment); SSQ = Simulator Sickness Questionnaire. Table adapted from Gromer, Reinke, Christner, and Pauli (2019) (CC BY 4.0).

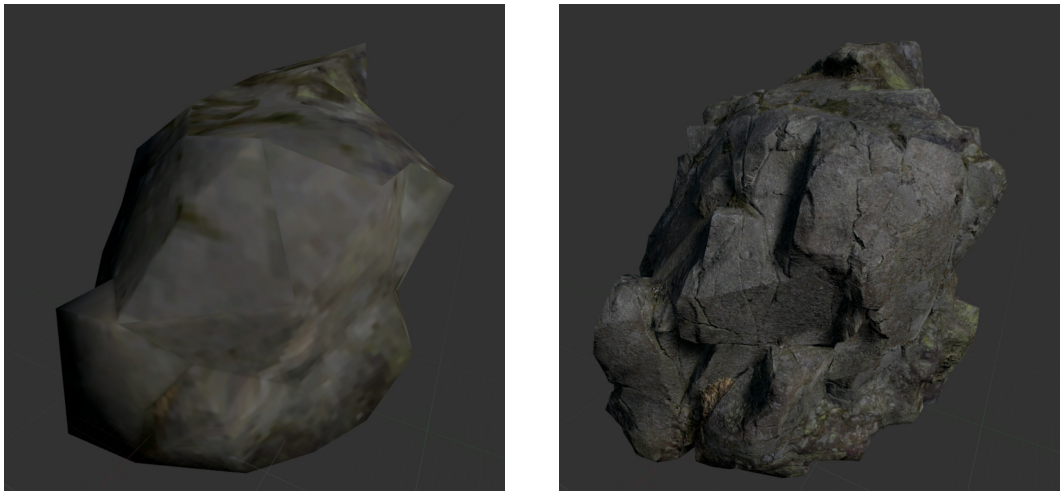


Figure 17: Example for the manipulation of visual realism. In the low and high sensory realism conditions, the rock was rendered with 152 vertices and simplified texture (left), and 2,342 vertices and fine-grained texture (right) respectively. Figure from Gromer et al. (2019) (CC BY 4.0).

audio presentation. Physiological signals (EDA and ECG) were recorded by a Brainproducts V-AMP 16 and the Vision Recorder 1.2 software (Brain Products, München, Germany).

Experimental design and procedure

The study was based on a 2 × 3 mixed design. The two experimental manipulations were *sensory realism* (low vs. high, *between factor*) and *situation* (control 1 vs. height vs. control 2, *within factor*). Participants were randomly assigned to low or high sensory realism condition.

Figure 18: Screenshots of the control situation (left) and height situation (right) with low (top) and high (bottom) sensory realism in experiment 2. Figure from Gromer et al. (2019) (CC BY 4.0).

The manipulation of sensory realism was realized by modifying both the visual realism of the virtual environment as well as the auditory content. The low sensory realism condition was based on the high sensory realism condition with the following modifications: (1) reducing mesh complexity by scaling down the vertex count of meshes to 5-10% using the Decimate modifier in Blender, (2) decreasing texture quality by applying both a Mosaic filter and Surface Blur filter to the textures in Photoshop (see Figure 17), (3) replacing tree meshes with two-dimensional bitmaps (sprites), and (4) turning sound off. For the situation manipulation, two different environments were created: a *control situation* which was located in a forest environment surrounded by rocks and trees, and a *height situation* which was located next to the edge of a 30 m deep canyon (see Figure 18 for demonstration of the different conditions). After arriving in the laboratory, participants read an information letter (see Appendix J) and gave their informed consent (see Appendix C). Next, participants were equipped with electrodes for measuring physiological signals. During the baseline measure of the physiology (5 min), participants filled in questionnaires (demographics, AQ, and STAI) and read another information letter describing the concept and measurement of presence in VR. Subsequently, participants were helped to put on the HMD and headphones and were placed in the center of the VR tracking area. The VR experiment consisted of three trials (control situation 1, height situation, and control situation 2). Each trial consisted of a fade-in of the virtual environment,

a one-minute exploration phase where participants were asked to look around, and a rating phase where participants were asked to give their SUDS and presence ratings, followed by a fade-out. After taking off the HMD, participants filled in another set of questionnaires (STAI State, SSQ, and MEC-SPQ).

Measures

Questionnaires and ratings. For descriptions of the questionnaires Acrophobia Questionnaire (AQ), State-Trait Anxiety Inventory (STAI), and Simulator Sickness Questionnaire (SSQ) see 3.1.2.5.
MEC Spatial Presence Questionnaire (MEC-SPQ; Vorderer et al., 2004). A self-report questionnaire that measures different constructs related to spatial presence. It is built upon the process model of spatial presence by Wirth et al. (2007) and has a total of eight subscales. Each subscale is measured by either 4, 6, or 8 items which are rated on a five-point Likert scale ranging from 1 ("I do not agree at all") to 5 ("I fully agree"). In the present experiment, five of the eight subscales were used in their 8-item versions: *Attention Allocation* (e.g., "I devoted my whole attention to the virtual environment"), *Spatial Situation Model* (e.g., "I had a precise idea of the spatial surroundings presented in the virtual environment"), *Spatial Presence: Self Location* (e.g., "I felt as though I was physically present in the environment of the presentation"), *Spatial Presence: Possible Actions* (e.g., "I had the impression that I could be active in the environment of the presentation"), and *Suspension of Disbelief* (e.g., "I concentrated on whether there were any inconsistencies in the virtual environment"). The three remaining subscales *Higher Cognitive Involvement*, *Domain Specific Interest*, and *Visual Spatial Imagery* were not measured. The questionnaire therefore consisted of 40 items.
Ratings of fear (SUDS) and presence were assessed analogously to the previous studies (see 3.1.2.5).

Physiological measures The SCL (ΔSCL in $\log(\mu S + 1)$) and HR (ΔHR in bpm) were measured and processed analogously to the first experiment of the present study (see 3.4.2.1).

Data analysis

R 3.5.0 (R Core Team, 2016) was used to conduct all statistical analyses. The `afex` package (Singmann et al., 2016) was used for ANOVA with type 3 sum of squares (with Greenhouse-Geisser correction if sphericity was violated) and the `emmeans` package (Lenth, 2018) was used for post-hoc comparisons (using Tukey's method for alpha adjustment for multiple comparisons). The cross-lagged panel model was fitted using the `lavaan` package (Rosseel, 2012) and displayed with the `semPlot` package (Epskamp, 2017).

3.4.3.2 Results

Influence of sensory realism on presence

A two-sample t-test on the presence ratings in the first control situation was conducted as a manipulation check to test whether manipulation of presence was successful. The test showed a significant difference between the two sensory realism conditions, $t(46.93) = 2.31$, $p = .026$, $d = 0.66$, indicating higher presence ratings in the high sensory realism condition compared to the low sensory realism condition (see Figure 19 A). For the MEC-SPQ scores, a one-way MANOVA with the five subscales as dependent variables and sensory realism as independent variable revealed no main effect of sensory realism, Wilks' $\lambda = .94$, $F(5, 41) = 0.56$, $p = .726$.

Causal relationship between presence and fear

Following the hypotheses of the study, mixed ANOVA were calculated for both the presence and fear ratings with sensory realism as the between factor and situation as the within factor. The hypothesis for a causal effect of fear → presence expected presence ratings to be higher in the height situation compared to the control situations. The ANOVA showed a significant main effect of sensory realism, $F(1, 46) = 5.70$, $p = .021$, $\eta_p^2 = .11$, a significant main effect of situation, $F(1.73, 79.40) = 13.01$, $p < .001$, $\eta_p^2 = .22$, and no interaction effect, $F(1.73, 79.40) = 0.07$, $p = .905$, $\eta_p^2 < .01$ (see Figure 19 A). For the significant main effect of sensory realism, means indicate higher presence ratings in the high sensory realism compared to the low sensory realism condition. For the significant main effect of situation, post-hoc pairwise comparisons (alpha adjustment with Tukey's method) between situations yielded a significant difference between control situation 1 and the height situation, $t(46) = -4.36$, $p < .001$, a significant difference between the height situation and the control situation 2, $t(46) = 3.43$, $p = .004$, and no difference between control situation 1 and control situation 2, $t(46) = -1.69$, $p = .220$. Results thus confirmed the fear → presence hypothesis, i.e., presence ratings in the height situation were higher than in both control situations.

The hypothesis for a causal effect of presence → fear expected fear ratings in the height situation to be higher for participants in the high sensory realism condition than for participants in the low sensory realism condition. The ANOVA on fear ratings revealed no main effect of sensory realism, $F(1, 47) = 1.02$, $p = .317$, $\eta_p^2 = .02$, a significant main effect of situation, $F(1.10, 51.62) = 161.63$, $p < .001$, $\eta_p^2 = .77$, and no interaction effect, $F(1.10, 51.62) = 0.92$, $p = .350$, $\eta_p^2 = .02$ (see Figure 19 B). Post-hoc pairwise comparisons (alpha adjustment with Tukey's method) between situations yielded a significant difference between control situation 1 and the height situation, $t(47) = -12.86$, $p < .001$, a significant difference between the height situation and the control situation 2, $t(47) = 12.98$, $p < .001$, and no difference between control situation 1 and control situation 2, $t(94) = -1.18$, $p = .469$. Fear ratings in

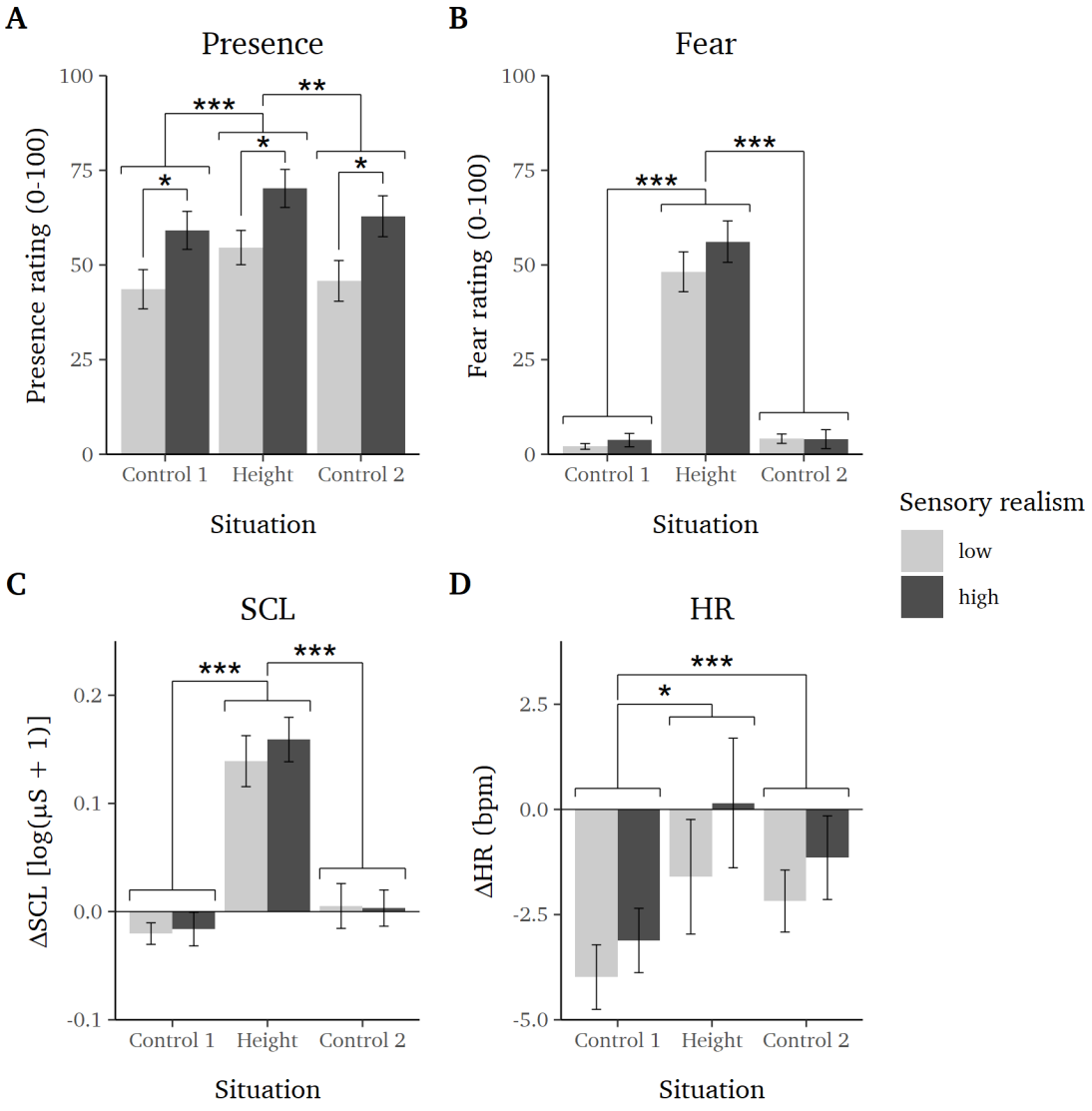


Figure 19: Mean ratings (± standard error) of presence (A) and subjective fear (B), and mean changes (± standard error) in skin conductance level (SCL) (C) and heart rate (HR) (D). *$p < .05$, **$p < .01$, ***$p < .001$. Figure adapted from Gromer et al. (2019) (CC BY 4.0).

the height situation were higher than in both control situations. As there was no significant interaction effect, results did not confirm the presence → fear hypothesis.

Physiological reactions

SCL and HR were analyzed analogous to the ratings using mixed ANOVA. The ANOVA for SCL revealed no main effect of sensory realism, $F(1, 46) = 0.13$, $p = .717$, $\eta_p^2 < .01$, a significant main effect of situation, $F(2, 92) = 81.10$, $p < .001$, $\eta_p^2 = .64$, and no interaction effect, $F(2, 92) = 0.31$, $p = .731$, $\eta_p^2 < .01$ (see Figure 19 C). Post-hoc pairwise comparisons (alpha adjustment with Tukey's method) between situations yielded a significant difference between

control situation 1 and the height situation, $t(46) =$ -10.71, $p < .001$, a significant difference between the height situation and the control situation 2, $t(46) = 11.06$, $p < .001$, and no difference between control situation 1 and control situation 2, $t(92) =$ -1.61, $p = .251$. SCL values in the height situation were higher than in both control situations.
For the HR, the ANOVA showed no main effect of sensory realism, $F(1, 47) = 0.92$, $p = .341$, $\eta_p^2 = .02$, a significant main effect of situation, $F(1.32, 61.99) = 7.97$, $p = .003$, $\eta_p^2 = .14$, and no interaction, $F(1.32, 61.99) = 0.21$, $p = .713$, $\eta_p^2 < .01$ (see Figure 19 D). Post-hoc pairwise comparisons (alpha adjustment with Tukey's method) between situations yielded a significant difference between control situation 1 and the height situation, $t(47) =$ -3.05, $p = .010$, no difference between the height situation and the control situation 2, $t(47) = 1.35$, $p = .377$, and a significant difference between control situation 1 and control situation 2, $t(47) =$ -4.07, $p < .001$. Heart rate in the height situation and control situation 2 were higher than in control situation 1.

Correlations between components of the fear response

In order to test whether the different measures of the fear response (fear ratings, SCL, and HR) were associated with each other, correlations between these measures were calculated. The correlation between fear ratings and HR in the height situation was significant, $r(47) = .36$, $p = .012$. The correlations between fear ratings and SCL, $r(46) = .26$, $p = .075$, and SCL and HR, $r(46) = .17$, $p = .249$, were positive but not significant.

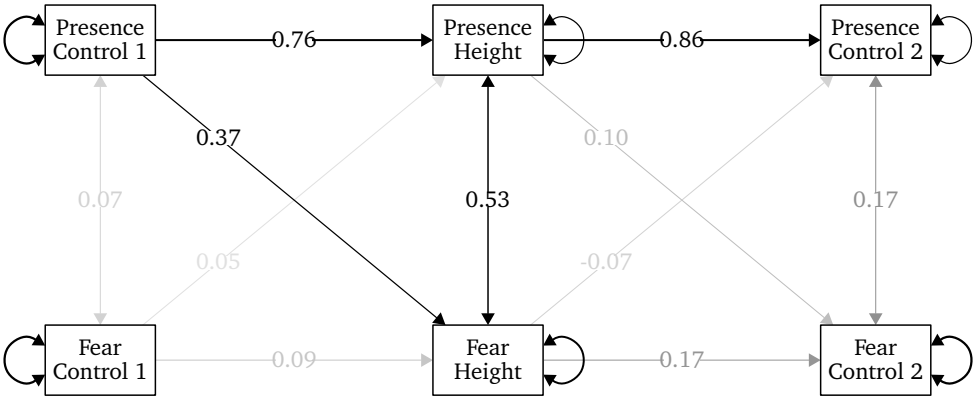
Correlations between presence and fear

The correlation between the online presence rating and the fear rating in the height situation was significant, $r(47) = .62$, $p < .001$. For the MEC-SPQ, the correlations with the fear rating in the height situation were: Attention Allocation, $r(47) = .11$, $p = .468$; Spatial Situation Model, $r(46) = .30$, $p = .036$; Spatial Presence: Self Location, $r(47) = .44$, $p = .002$, Spatial Presence: Possible Actions, $r(47) = .36$, $p = .011$; and Suspension of Disbelief, $r(46) = .66$, $p < .001$.

Exploratory cross-lagged panel model

In an exploratory analysis, presence and fear ratings were fitted in a cross-lagged panel model to test whether presence and fear ratings would predict ratings in successive trials (see Figure 20 A). A similar, but correlational approach, was taken in Peperkorn et al. (2015).
The significant paths were (1) the autoregressive paths for presence: presence in the height situation was predicted by presence in the control situation 1, $\beta_{std} = .76$, $p < .001$, and presence in the control situation 2 was predicted by presence in the height situation, $\beta_{std} = .86$, $p < .001$; (2) the regression coefficient where presence in the control situation 1 predicted

A



B

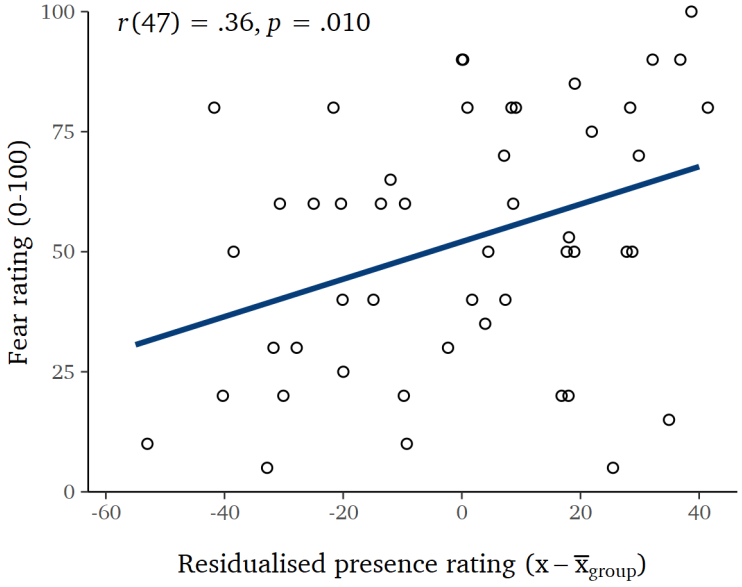


Figure 20: (A) Cross-lagged panel model with presence and fear ratings measured at three time points: control situation 1, height situation, and control situation 2. Black lines indicate significant paths at $p < .01$, grey lines indicate non-significant paths. Labels display standardized path coefficients. (B) Scatter plot displaying the correlation between residualised presence ratings in the control situation 1 and fear ratings in the height situation. The residualised presence ratings were calculated by substracting the corresponding group mean from each presence rating. Figure adapted from Gromer et al. (2019) (CC BY 4.0).

fear in the height situation, $\beta_{std} = .37$, $p = .006$; and (3) the correlation between presence and fear in the height situation, $r = .53$, $p = .001$.
For further visualization of the regression where presence predicted later fear ratings, the correlation between residualised presence ratings in the first control situation and fear ratings in the height situation were calculated and displayed in Figure 20 B. The residualised presence ratings were calculated by subtracting the respective group means from each presence rating in order to subtract out the effect of the presence manipulation.

3.4.4 Discussion

The present study investigated the causal relationship between presence and fear in VR, specifically whether experiencing fear would lead to higher presence and/or whether higher presence would lead to stronger fear responses. For this purpose, both presence and fear were manipulated experimentally in VR. In two experiments, height-fearful participants were immersed into a virtual height situation and control situations (fear manipulation) with either high visual realism and auditory content, or low visual realism and no auditory content (presence manipulation). The dependent variables were fear and presence ratings, as well as physiological measures (SCL and HR).

3.4.4.1 Effects of visual realism and auditory content on presence

After the presence manipulation in experiment 1 was not successful, a more potent differentiation between high and low sensory realism was worked out. Using a higher resolution HMD, photogrammetry-quality assets vs. simpler shapes (see Figure 17), and sound vs. no sound, the manipulation of presence ratings was successful in experiment 2. This finding supports previous research (Brinkman et al., 2015; Dinh et al., 1999; Hendrix & Barfield, 1996; Kwon et al., 2013; Larsson et al., 2007; Slater et al., 2009; Welch et al., 1996) with a similar effect size (small to medium) as reported in a recent meta-analysis (Cummings & Bailenson, 2016). Inconsistent with the verbal ratings of presence, the scores on the presence questionnaire, measured after the immersion, did not reveal a difference between groups. Previous research suggests, that such discrepancies between different measures of presence are not uncommon (Kober & Neuper, 2013). Given the effort it takes to generate highly realistic virtual environments, together with an only small to medium effect size in the present study, manipulation of visual realism and auditory content may not be the most cost-effective means to increase presence.

3.4.4.2 Effects of fear on presence

In experiment 2, the experimental fear manipulation led to an increase in presence ratings (fear → presence). This result supports the hypothesis that experiencing emotional responses in VR leads to stronger feelings of actually being there in the virtual environment (Riva et

al., 2007) and is in line with several previous studies (Alsina-Jurnet & Gutiérrez-Maldonado, 2010; Bouchard et al., 2008; Peperkorn, Diemer, Alpers, & Mühlberger, 2016). In their *interoceptive attribution model* of presence, Diemer et al. (2015) postulate that presence is a function of both immersion (i.e., the technological characteristics of the VR system) and arousal. The findings of experiment 2 fully support this model as presence ratings were increased by both the manipulation of visual realism and auditory content (i.e., immersion), as well as during the height situation compared to the control situation (i.e., in an environment that elicited higher arousal as indicated by the skin conductance measure). Of note, two previous studies (Diemer et al., 2016, and Study 1 of the thesis) seem to contradict the present findings and assumptions of the interoceptive attribution model as both studies did not find presence differences in high vs. low height-fearful participants towards virtual height situations (assuming that high height-fearful participants experience stronger arousal and hence should report higher presence). However, in the study by Diemer et al. (2016), skin conductance measures indicated equal levels of physiological arousal in high and low height-fearful participants. As a result, the interoceptive attribution model would predict similar levels of presence in both groups, which corresponds to the findings of the study. In Study 1 of the present thesis, no physiological measure of arousal was collected. It is therefore not possible to make conclusions from this finding within the framework of the interoceptive attribution model.

3.4.4.3 Effects of presence on fear

Regarding the causal effect of presence on fear, the experimental manipulation of presence in experiment 2 did not lead to increased levels of fear in the virtual height situation (presence $\not\rightarrow$ fear). This finding has several possible explanations. First, fear in VR might not be dependent upon the level of presence. When designing virtual environments for use in VRET, this would mean that putting much effort in creating highly realistic environments is not necessary. as simpler environments might also trigger enough fear. Second, although the presence manipulation was stronger in experiment 2 (compared to experiment 1), it might still have been not strong enough to detect effects of presence on fear. In support of this argument, comparing effect sizes for the manipulation of presence ($\eta_p^2 = .11$) and fear ($\eta_p^2 = .77$) shows that the effect of the presence manipulation was clearly less powerful than the fear manipulation. Third, the findings might be explained by the presence-as-a-gateway hypothesis (Felnhofer et al., 2014). The hypothesis states that fear does not increase linearly with increases in presence, but a certain level of presence is necessary to trigger fear responses and from then on further increases in presence do not further affect fear. In the present study, both the high and low sensory realism conditions might have reached this plateau, resulting in similar fear responses in both groups.

Interestingly, and in accordance with findings by Peperkorn et al. (2015), the initial presence ratings in the control situation across all participants predicted fear ratings in the height situation, indicating an effect of interpersonal variability in presence on fear. This finding cannot be explained with the interoceptive attribution model of presence by Diemer et al. (2015), as it postulates presence as a function of only immersion and arousal. The current finding, therefore, highlights the relevance of user characteristics in the emergence of presence (IJsselsteijn, Ridder, Freeman, & Avons, 2000; Wirth et al., 2007). User characteristics that have been thought to affect presence include immersive tendencies (Kober & Neuper, 2013; Ling, Nefs, Brinkman, Qu, & Heynderickx, 2013; Murray, Fox, & Pettifer, 2007; Phillips, Interrante, Kaeding, Ries, & Anderson, 2012; Robillard et al., 2003; Witmer & Singer, 1998), absorption (Baños et al., 1999; Kober & Neuper, 2013; Ling et al., 2013; Murray et al., 2007; Phillips et al., 2012; Schuemie, Abel, van der Mast, Krijn, & Emmelkamp, 2005; Wirth, Hofer, & Schramm, 2012), dissociation (Baños et al., 1999; Murray et al., 2007; Phillips et al., 2012; Williams, 2014), spatial abilities (Alsina-Jurnet & Gutiérrez-Maldonado, 2010; Coxon, Kelly, & Page, 2016), and personality (Alsina-Jurnet & Gutiérrez-Maldonado, 2010; Kober & Neuper, 2013).

3.4.4.4 Limitations

Some limitations of the present study should be discussed. Although the presence manipulation in experiment 2 was successful for subjective ratings, comparing its effect size to that of the fear manipulation reveals that the effect of the manipulation was much smaller. For this reason, similar future studies should use multiple and/or stronger presence manipulations (see e.g., Cummings & Bailenson, 2016) to aim for comparable effects of the presence and fear manipulations.

Second, the cross-lagged panel model in experiment 2 was conducted post-hoc in an exploratory manner and on the whole sample (ignoring the presence manipulation). To control for presence differences between groups, I also calculated the correlation between residualised presence ratings (subtracting out the effect of the presence manipulation) and fear ratings. However, to corroborate the findings, a further study without presence manipulation should be planned and conducted with a priori hypotheses about the relationships within the cross-lagged panel model.

Third, the present study investigated only height-fearful participants. A recent meta-analysis revealed differences in the magnitude of the correlation between presence and fear between different phobias (Ling et al., 2014). It is therefore crucial to replicate the findings regarding causal links between presence and fear in other phobias.

3.4.4.5 Conclusion

The present study investigated the causal links between presence and fear in VR. Experimental manipulation of both presence and fear in experiment 2 revealed an effect of fear on presence and supports with it the hypothesis that arousal is an important factor in the formation of presence in VR (Diemer et al., 2015). The study did not reveal an effect of experimentally manipulated presence on fear. Nonetheless, the exploratory analysis of interpersonal variability in presence revealed a positive cross-lagged link between presence (in a safe situation) and fear (in a later height situation). This finding indicates that there may indeed be a causal link of presence on fear, but that the study's paradigm was not suitable for demonstrating the link experimentally. The finding further highlights the importance of user characteristics in the formation of presence. Future studies are needed to extend the current findings, using stronger experimental (e.g., use of stereoscopy) or quasi-experimental manipulations of presence (e.g., users with different characteristics) to investigate the effects on fear responses.

Chapter 4

Mechanisms of Exposure Therapy

4.1 Study 5: Habituation vs. Expectancy Violation in Exposure Therapy

4.1.1 Introduction

Exposure to feared stimuli or situations is a key component of cognitive-behavioral treatments for anxiety disorders. However, despite being one of the best-studied psychotherapeutic techniques with well-documented efficacy (e.g., Choy et al., 2007; Sánchez-Meca, Rosa-Alcázar, Marín-Martínez, & Gómez-Conesa, 2010), there is still a controversy about the underlying mechanisms of change by which exposure therapy operates (Cooper, Clifton, & Feeny, 2017), and in consequence, how exposure should be implemented optimally. One such controversy revolves around the question whether the main focus of an exposure session should be put on the decline in fear responses (i.e., fear habituation; Benito & Walther, 2015) or on the non-occurrence of expected aversive outcomes (Salkovskis, Hackmann, Wells, Gelder, & Clark, 2007). The assumption that habituation of fear responses during an exposure session is central to efficacious exposure is based on the EPT (Foa & Kozak, 1986), which defines WSH as an indicator for successful exposure. However, studies could not find strong support for WSH as a predictor of treatment outcome (see 2.3.1). Therefore, the view that habituation during exposure is necessary has been challenged in the recent years (Baker et al., 2010; Salkovskis et al., 2007), and the inhibitory learning model (Craske et al., 2008, 2014, see 2.3.2) has been put forward as an alternative theory for the mechanisms of change in exposure therapy. According to the inhibitory learning model, the central mechanism by which exposure therapy operates is not habituation of fear responses, but a violation of expectancies regarding the feared outcomes (e.g., “I will fall off the bridge”). However, also for the hypothesis that expectancy violation underlies exposure efficacy, studies show a somewhat mixed picture (see 2.3.2.1). So far, there has only been a single pilot study that directly compared a habituation-based exposure vs. an exposure that focused on disconfirmation of feared outcomes (Salkovskis et al., 2007). This study showed better

outcomes for the belief disconfirmation approach; however, both conditions also differed in whether safety behaviors were prevented or not, which is why no definite conclusion can be drawn from the study.

4.1.1.1 Aim of the study

This study is the first to compare a habituation-based vs. an expectancy violation-based VRET for acrophobia. Patients in the habituation condition will focus on the decline in fear responding during exposure sessions, whereas patients in the expectancy violation condition will test their CS–US associations (e.g., "I will fall"). To this end, patients will receive two sessions of VRET in a CAVE and their fear of heights will be measured before and after treatment.

4.1.2 Methods

4.1.2.1 Sample

Seventy-nine volunteers were recruited via public advertisement and contacted for a telephone screening (see Appendix K). Thirty-six participants fulfilled inclusion criteria (age 18–65, subjective rating of height-fearfulness and avoidance of height situations > 5 on a scale of 0–10). Exclusion criteria were cardiovascular diseases, asthma, epilepsy, pregnancy, current episode of major depression, a disorder within the schizophrenic spectrum, and intense nausea when watching 3D-movies. Two participants did not complete the exposure sessions due to strong simulator sickness in one participant and no fear during exposure in the other participant and exited the study prematurely. Therefore, thirty-four participants entered data analysis.

4.1.2.2 Apparatus

The present study was conducted in the same CAVE as the first study (see 3.1.2.2 for the description of the apparatus). Physiological data (EDA, ECG, and respiration) was recorded with a Biopac MP150, two BioNomadix transmitter/amplifiers, and the Acqknowledge 4.4 software (Biopac Systems Inc., Goleta, CA, USA).

4.1.2.3 Virtual environment

The same virtual environment as in the first study was used during exposure sessions (see 3.1.2.3). Two modifications to the virtual environment were made: At the tower's top level and the level below, parts of the railing were removed and replaced with a chain and cones. This modification was made to have situations with increased difficulty.

4.1.2.4 Experimental design and procedure

A mixed design was used for the study. Patients were randomly assigned to the between-subject factor *treatment condition* (*expectancy violation* vs. *habituation*). Measurement of outcome variables took place before and after treament (*pre* vs. *post*, within-subject factor). The study consisted of four sessions: (1) pre-test and explanation of the treatment rationale, (2 + 3) exposure sessions, and (4) post-test. The four sessions were scheduled to be within a two-week time frame ($M = 11.83 \pm 4.19$ days from the first to the last session, with no difference between experimental conditions, $t(28.45) = 0.13$, $p = .895$).

Session 1: pre-test, clinical interview, and treatment rationale

Patients read an information letter (see Appendix L) and gave their informed consent (see Appendix C). Then they filled in questionnaires (demographics, AQ, ATHQ, and a modified Heights Interpretation Questionnaire). Subsequently, a SCID-I interview was conducted for the diagnosis of specific phobia and exclusion of cases with a current episode of Major Depression or any disorder from the schizophrenic spectrum. After the interview, the treatment rationale was explained to the patients (see Appendix M). For both groups, the treatment rationale contained general information about fear, the vicious cycle of pathological fears, and information on the development of acrophobia. The section describing how exposure therapy works and what process underlies exposure sessions differed between experimental conditions:

Expectancy violation. Patients learned that in acrophobia, height situations automatically trigger threat expectancies (CS–US association), e.g., "I will fall". The patients were further told that during exposure therapy, these threat expectancies were put to the test and that a violation, i.e., a mismatch between what is expected and what occurs (e.g., staying on a balcony without falling off), leads to so-called safety learning (CS–noUS association). Finally, patients were informed that once these new associations have been established, they can actively inhibit the old threat expectancies.

Habituation. The therapist explained to the patients the course of fear during an exposure session. Information included that, at the beginning of the exposure, fear typically rises to high levels (IFA) but with time declines on its own (WSH). Furthermore, patients were informed that by experiencing the decline of fear, learning takes places and subsequent exposures will result in less fear (BSH). Finally, to facilitate this process, patients were informed that it is essential to pay close attention to the fear symptoms during the exposure session.

After psychoeducation was finished, the patient and therapist left the building to conduct the first BAT (see section 4.1.2.5).

Sessions 2 & 3: therapy sessions

Patients came into the 3D multisensory laboratory and were shown the CAVE. Subsequently, the therapist and patient planned the upcoming exposure session: For patients in the expectancy violation condition, the therapist and the patient decided on a specific expectancy to test in the current exposure session (e.g., "I could fall off" or "I freeze and can't move anymore"). The therapist reminded the patient that it is essential to be aware of the situation in which the patient is while simultaneously registering that the expected threat about the situation does not occur (i.e., focus on the CS and non-occurrence of the US). In the habituation condition, patients were reminded that their task during the exposure session was observe their fear symptoms attentively and register how they change over time.
Patients were then equipped with EDA electrodes, ECG electrodes, the respiration strap, and transmitters for wireless physiology measurement. Subsequently, patients were provided with interference glasses (for stereoscopic vision of the virtual environment), a gamepad for navigation, and a microphone for communication with the therapist.
After patients had entered the CAVE, the door was closed, and patients were immersed in a training environment where they could get used to the virtual environment and train the navigation by both virtual movement using the gamepad and real movement in the CAVE.
After completing the training environment, patients were immersed into a hilly landscape with a look-out at the center of the scene (see also Figure 5). Patients were asked to walk to the base of the look-out and then climb the stairs while focussing on either their threat expectancy about the situation (expectancy violation condition) or on their fear symptoms (habituation condition).
In the expectancy violation condition, patients were continuously reminded in what situation they were and that they should try to test their expectancy about the situation. A patient believing to fall off when leaning over the railing of the look-out, for example, was asked to try to perform the feared action and register that she does not lose control over her posture. After the exposure session, patient and therapist discussed what was learned about the expectancies of feared outcomes in the height situation.
In the habituation condition, patients were asked about their fear level while climbing the look-out. When patients reached a situation where they did not want to go any higher, they were asked to try to stay in the situation and watch their fear and bodily sensations. They were periodically asked to rate their subjective distress to become aware of getting accustomed to the situation.
Immersion into the virtual height environment lasted for about 30 minutes per session in both conditions.

Session 4: Post-test

At the last session, patients filled in questionnaires (AQ, ATHQ, HIQ, ACQ-R, and PATHEV) and conducted the BAT for the second time.

4.1.2.5 Measures

Questionnaires

For descriptions of the questionnaires Acrophobia Questionnaire (AQ), State-Trait Anxiety Inventory (STAI), Igroup Presence Questionnaire (IPQ), and Simulator Sickness Questionnaire (SSQ) see the methods section of the first study (3.1.2.5), and for the Attitudes Towards Heights Questionnaire (ATHQ) see the methods section of the second study (3.2.2.4) respectively.

Modified Heights Interpretation Questionnaire (HIQ; Steinman & Teachman, 2011). The HIQ is a 16-item self-report questionnaire that measures the expectancy of aversive events in height situations. Participants are asked to imagine themselves in two height situations (climbing a ladder and standing on a balcony) and to rate the probability of the occurrence of eight aversive events per situation (e.g., "You will panic and lose control"). In the original HIQ, participants are asked to give their ratings on a five-point Likert scale ranging from "not likely" to "very likely." In the present study, participants were asked to rate the probability of aversive events in percent. The total score is calculated by averaging over all ratings and has a range of 0–100%.

Anxiety Control Questionnaire Revised (ACQ-R; Brown, White, Forsyth, & Barlow, 2004; Hoyer & Helbig, 2005). The ACQ-R is a 15-item self-report questionnaire based on the Anxiety Control Questionnaire (Rapee, Craske, Brown, & Barlow, 1996) that assesses a persons' perceived level of control over stressful situations. The questionnaire consists of three subscales: *emotion control* (e.g., "I am able to control my level of anxiety"), *threat control* (e.g., "There is little I can do to change frightening events"), and *stress control* (e.g., "When I am put under stress, I am likely to lose control"). Items are rated on a six-point Likert scale ranging from "strongly disagree" to "strongly agree." The resulting sum scores have a range of 0–25 (emotion control), 0–30 (threat control), and 0–20 (stress control).

Patients' Therapy Expectation and Evaluation questionnaire (PATHEV; Schulte, 2005, 2008). A self-report questionnaire that measures patients' outcome expectancies and opinion on the suitability of a given treatment. The questionnaire comprises eleven items rated on a five-point Likert scale ranging from "absolutely wrong" to "absolutely right." The PATHEV measures three subscales: *hope of improvement* (e.g., "Even with therapy, my problems will not change very much"), *fear of change* (e.g., "Sometimes I'm afraid that the therapy will

change me more than I want"), and *suitability* (e.g., "This treatment seems to be appropriate to my problems"). The resulting mean scores have a range of 1–5. For the present study, only the suitability subscale was used.

Structured Clinical Interview for DSM-IV Axis I Disorders (SCID-I; Wittchen, Zaudig, & Fydrich, 1997)

The SCID-I is a structured interview for clinical diagnostics of mental disorders. The interview consists of a brief exploration of current and past symptoms, and ten sections for the diagnosis of mental disorders based on the diagnostic criteria by the Diagnostic and Statistical Manual of Mental Disorders IV (DSM-IV; American Psychiatric Association, 2000).

Behavioral avoidance test (BAT)

The BAT was conducted at the external staircase of a four-story parking lot. Patients were asked to climb the staircase as high as they could (0–56 stairs). Furthermore, patients were asked to rate their subjective distress (0–100) at each level while standing in the center of the platform and when leaning over the railing and looking down. The BAT resulted in two measures: the peak fear rating (BAT fear) and the number of steps climbed (BAT nr. of steps).

Online rating of subjective distress

In the habituation condition, fear ratings by means of SUDS (0–100) were assessed to track the process of decline in fear (see also 3.1.2.5).

Physiological measures

Frequent connection losses of the wireless signal of the physiological acquisition device led to unusable data. The connection problems were most likely caused by interference of the metal frame of the CAVE with the wireless signal. For this reason, no physiological process measures could be calculated and are therefore omitted from the data analysis.

4.1.2.6 Data analysis

All statistical analyses were conducted with R 3.5.1 (R Core Team, 2016) The `afex` package (Singmann et al., 2016) was used for ANOVA with type 3 sum of squares and the `emmeans` package (Lenth, 2018) was used for post-hoc tests.

Fear indices

For an exploratory analysis, the fear indices IFA, WSH, BSH, and variability in fear levels (VAR) were calculated for each patient in the habituation condition using the fear ratings

Table 10
Implementations of fear indices

Index	Name	Description
IFA	fear_1	The first fear rating, averaged across sessions (Beckham et al., 1990)
	fear_{max}	The peak fear rating, averaged across sessions (Foa et al., 1995)
	$\text{fear}_{\Sigma(\Delta>0)}$	The sum of the positive differences between each two successive fear ratings, summed across sessions
WSH	$\text{fear}_{\text{max}-\text{end}}$	The peak fear rating minus the last fear rating, averaged across sessions (Jacoby et al., 2019)
	$\text{fear}_{1^{st}-4^{th}\text{quartile}}$	The mean of the 1^{st} quartile of fear ratings minus the mean of the 4^{th} quartile of fear ratings, averaged across sessions (Baker et al., 2010)
	$\text{fear}_{\Sigma(\Delta<0)}$	The sum of the negative differences between each two successive fear ratings, summed across sessions
BSH	$\text{fear}_{\text{max}_{t1}} - \text{fear}_{\text{max}_{t2}}$	The peak fear rating in session 1 minus the peak fear rating in session 2 (Peterman et al., 2016)
	$\text{fear}_{\text{mean}_{t1}} - \text{fear}_{\text{mean}_{t2}}$	The mean fear rating in session 1 minus the mean fear rating in session 2 (Gallagher & Resick, 2012)
VAR	$SD(\text{fear})$	The standard deviation of fear ratings, averaged across sessions (Kircanski, Mortazavi, et al., 2012)
	$AR(\text{fear})$	The autoregressive parameter of a first-order autoregressive time series model fitted to fear ratings, averaged across sessions (Jacoby, 2016)
	$\text{fear}_{\text{max}-\text{min}}$	The peak fear rating minus the lowest fear rating, averaged across sessions (Kircanski & Peris, 2015)
	$\text{fear}_{\Sigma\Delta}$	The sum of the absolute differences between each two successive fear ratings (Brown et al., 2016), averaged across sessions.

Note: IFA = initial fear activation, WSH = within-session habituation, BSH = between-session habituation, VAR = variability. Citations after the descriptions give an example study where the respective index was used. The two indices without references were developed for the current study.

acquired during exposure sessions. For every index, multiple different operationalizations were used (see Table 10).

Table 11
Questionnaire data

	Expectancy violation		Habituation			
	M	***SD***	***M***	***SD***	***t***	***p***
Age	51.82	7.92	47.71	12.15	1.17	.252
STAI Trait	36.12	8.12	39.07	13.17	-0.75	.461
AQ Anxiety	52.06	21.35	54.88	16.31	-0.43	.668
AQ Avoidance	13.71	6.48	14.88	5.16	-0.59	.562
ATHQ	42.53	13.84	41.24	10.66	0.31	.762
HIQ	29.17	12.76	36.35	16.41	-1.40	.173
ACQ-R Emotional Control	8.88	2.91	10.00	3.92	-0.94	.353
ACQ-R Threat Control	17.82	4.82	17.62	3.48	0.14	.893
ACQ-R Stress Control	10.47	3.37	11.24	3.99	-0.60	.551

Note: STAI = State-Trait Anxiety Inventory; AQ = Acrophobia Questionnaire; ATHQ = Attitudes Towards Heights Questionnaire; HIQ = Heights Interpretation Questionnaire; ACQ-R = Anxiety Control Questionnaire Revised.

4.1.3 Results

4.1.3.1 Group characteristics

Patients in the two experimental conditions did not differ in sex, $\chi^2(1) = 1.09$, $p = .296$, and age. Furthermore, before treatment, patients did not differ with regards to trait anxiety, height-fearfulness, and perceived level of control over stressful situations (see Table 11).

4.1.3.2 Treatment outcome

All treatment outcome measures were analyzed with separate mixed-design ANOVAs with treatment condition (expectancy violation vs. habituation) as between-subject factor and time (pre vs. post) as within-subject factor.

Acrophobia-related questionnaires

For the AQ Anxiety subscale, the ANOVA showed no main effect of group, $F(1, 32) = 1.14$, $p = .293$, $\eta_p^2 = .03$, a significant main effect of time, $F(1, 32) = 35.51$, $p < .001$, $\eta_p^2 = .53$, and no interaction effect, $F(1, 32) = 0.67$, $p = .419$, $\eta_p^2 = .02$ (see Figure 21 A). Means indicate lower height-fearfulness at post-test compared to pre-test. The magnitude of the effect for the pre-post comparison was $d = 1.03$.
For the AQ Avoidance subscale, the ANOVA showed no main effect of group, $F(1, 32) = 1.77$, $p = .193$, $\eta_p^2 = .05$, a significant main effect of time, $F(1, 32) = 38.95$, $p < .001$, $\eta_p^2 = .55$, and no interaction effect, $F(1, 32) = 0.37$, $p = .549$, $\eta_p^2 = .01$ (see Figure 21 B). Means indicate less avoidance of height situations at post-test compared to pre-test. The magnitude of the effect for the pre-post comparison was $d = 1.08$.

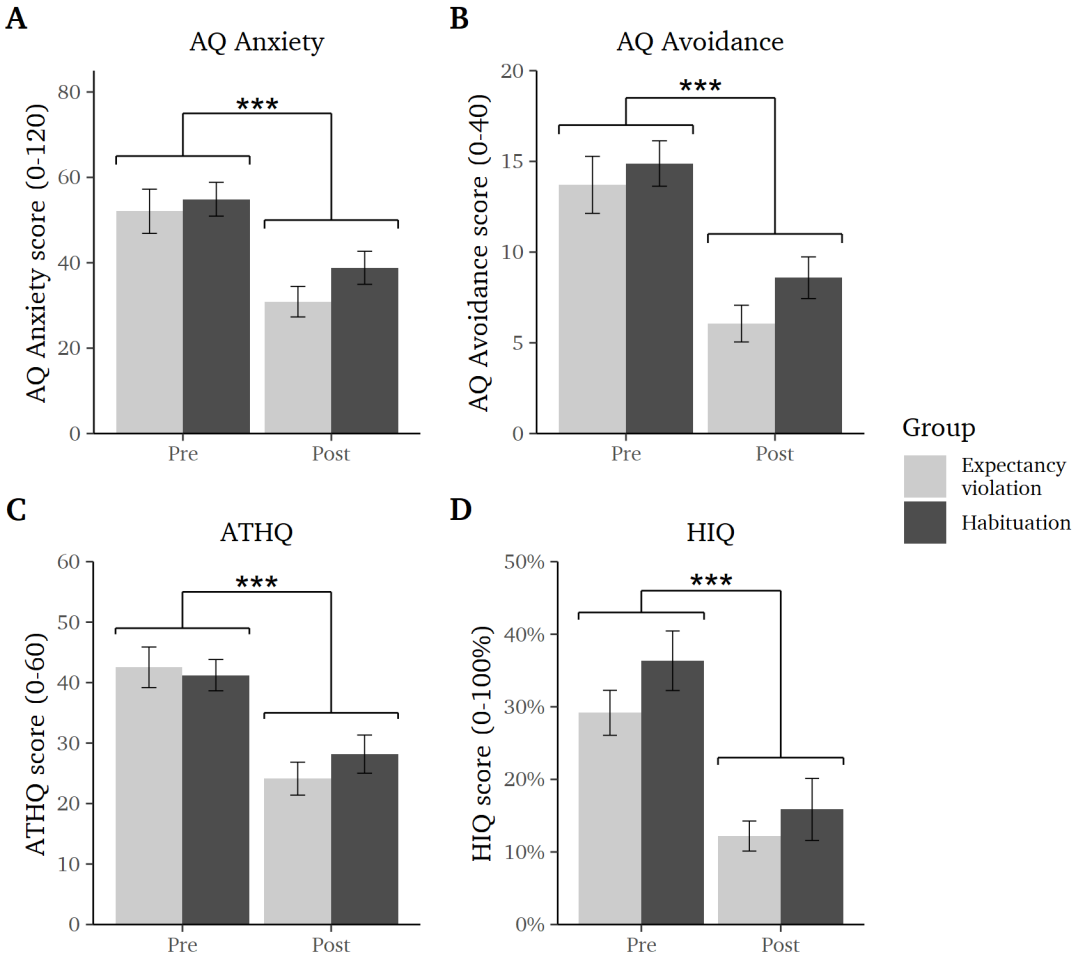


Figure 21: Mean scores (± standard error) before and after virtual reality exposure therapy on Acrophobia Questionnaire Anxiety subscale (A) and Avoidance subscale (B), Attitudes Towards Heights Questionnaire (C), and Heights Interpretation Questionnaire (D). ***$p < .001$.

For the ATHQ scores, the ANOVA showed no main effect of group, $F(1, 32) = 0.19$, $p = .669$, $\eta_p^2 < .01$, a significant main effect of time, $F(1, 32) = 33.41$, $p < .001$, $\eta_p^2 = .51$, and no interaction effect, $F(1, 32) = 0.97$, $p = .333$, $\eta_p^2 = .03$ (see Figure 21 C). Means indicate less negative attitudes towards heights at post-test compared to pre-test. The magnitude of the effect for the pre-post comparison was $d = 0.99$.

For the HIQ scores, the ANOVA showed no main effect of group, $F(1, 31) = 1.63$, $p = .211$, $\eta_p^2 = .05$, a significant main effect of time, $F(1, 31) = 60.08$, $p < .001$, $\eta_p^2 = .66$, and no interaction effect, $F(1, 31) = 0.53$, $p = .474$, $\eta_p^2 = .02$ (see Figure 21 D). Means indicate less expectancies of aversive events in height situations at post-test compared with pre-test. The magnitude of the effect for the pre-post comparison was $d = 1.38$.

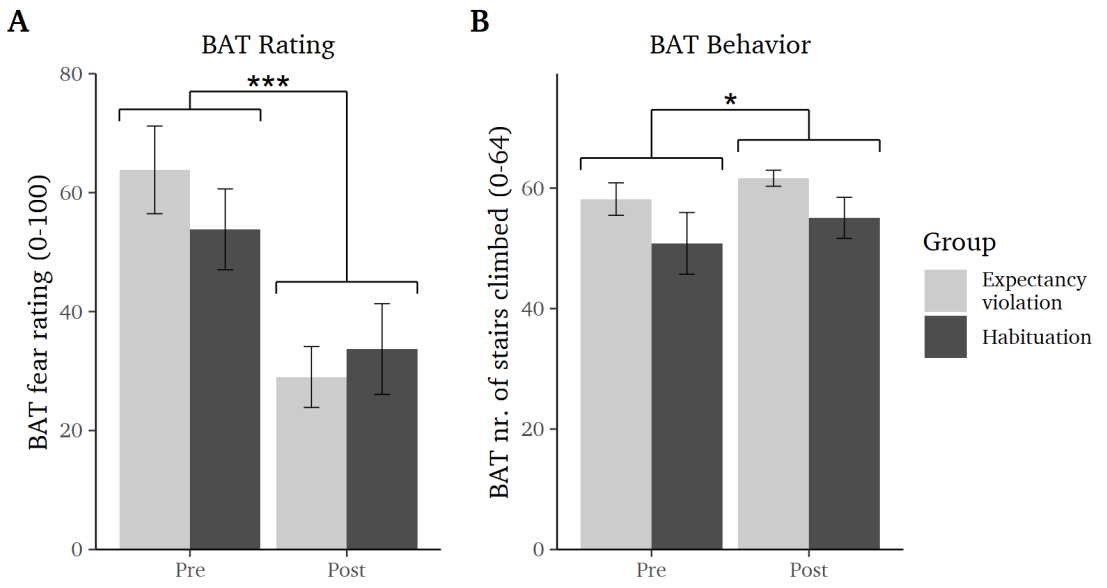


Figure 22: Mean fear rating (A) and number of steps climbed (B) (± standard error) during the behavioral avoidance test (BAT) before and after virtual reality exposure therapy. $*p < .05$, $***p < .001$.

Behavioral avoidance test

For the BAT fear ratings, the ANOVA showed no main effect of group, $F(1, 32) = 0.10$, $p = .759$, $\eta_p^2 < .01$, a significant main effect of time, $F(1, 32) = 39.53$, $p < .001$, $\eta_p^2 = .55$, and no interaction effect, $F(1, 32) = 2.83$, $p = .102$, $\eta_p^2 = .08$ (see Figure 22 A). Means indicate lower fear ratings at post-test compared with pre-test. The magnitude of the effect for the pre-post comparison was $d = 1.05$.

For the BAT nr. of steps climbed, the ANOVA showed no main effect of group, $F(1, 32) = 2.35$, $p = .135$, $\eta_p^2 = .07$, a significant main effect of time, $F(1, 32) = 5.13$, $p = .030$, $\eta_p^2 = .14$, and no interaction effect, $F(1, 32) = 0.05$, $p = .824$, $\eta_p^2 < .01$ (see Figure 22 B). Means indicate that patients climbed more stairs at post-test compared with pre-test. The magnitude of the effect for the pre-post comparison was $d = 0.39$.

Anxiety control

For the ACQ-R Emotional Control subscale, the ANOVA showed no main effect of group, $F(1, 32) = 0.01$, $p = .930$, $\eta_p^2 < .01$, a significant main effect of time, $F(1, 32) = 37.44$, $p < .001$, $\eta_p^2 = .54$, and no interaction effect, $F(1, 32) = 2.73$, $p = .108$, $\eta_p^2 = .08$ (see Figure 23 A). Means indicate higher control over emotional responses in stressful situations at post-test compared with pre-test. The magnitude of the effect for the pre-post comparison was $d = 1.02$.

For the ACQ-R Threat Control subscale, the ANOVA showed no main effect of group, $F(1, 31) = 0.16$, $p = .688$, $\eta_p^2 < .01$, a significant main effect of time, $F(1, 31) = 12.02$,

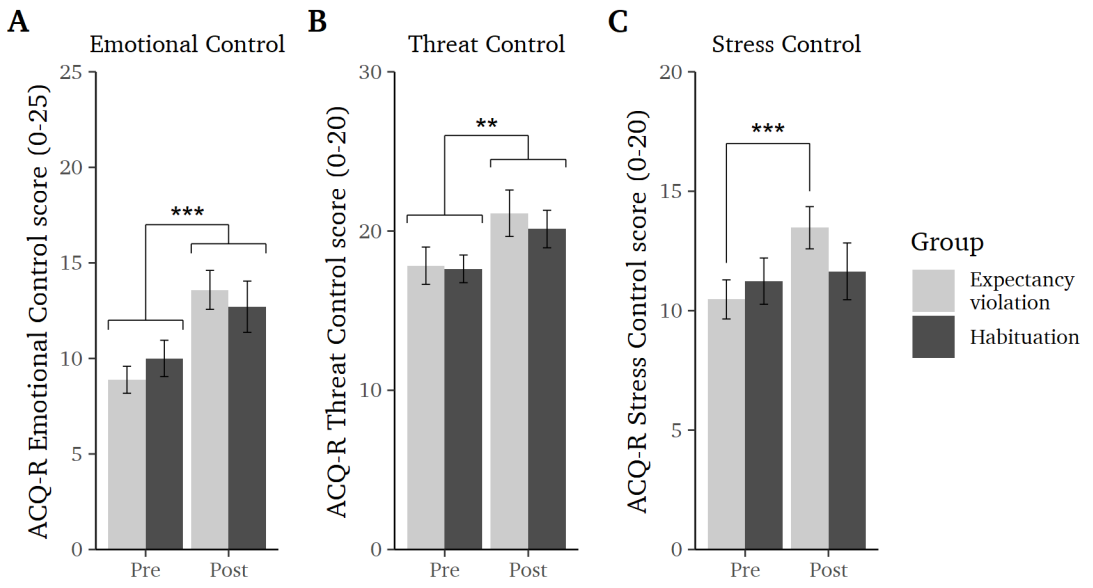


Figure 23: Mean scores (± standard error) before and after virtual reality exposure therapy on the Anxiety Control Questionnaire subscales Emotional Control (A), Threat Control (B), and Stress Control (C). $^{**}p < .01$, $^{***}p < .001$.

$p = .002$, $\eta_p^2 = .28$, and no interaction effect, $F(1, 31) = 0.23$, $p = .638$, $\eta_p^2 < .01$ (see Figure 23 B). Means indicate higher control over threatening events at post-test compared with pre-test. The magnitude of the effect for the pre-post comparison was $d = 0.61$.

Lastly, for the ACQ-R Stress Control subscale, the ANOVA showed no main effect of group, $F(1, 32) = 0.18$, $p = .675$, $\eta_p^2 < .01$, a significant main effect of time, $F(1, 32) = 8.65$, $p = .006$, $\eta_p^2 = .21$, and a significant interaction effect, $F(1, 32) = 4.98$, $p = .033$, $\eta_p^2 = .13$. Follow-up *post hoc* contrasts revealed a significant increase in the ACQ-R Stress Control score from pre to post in the expectancy violation group, $t(32) = -3.66$, $p < .001$, but not in the habituation group, $t(32) = -0.50$, $p = .619$ (see Figure 23 C). The magnitude of the effect for the pre-post comparison for both groups combined was $d = 0.48$.

Treatment outcome summary

In summary, all four acrophobia-related questionnaire outcome measures showed a significant effect of the treatment on height-fearfulness but no differences between treatment conditions. The same was true for the BAT outcome measures. In the more general anxiety-related measures, two out of three measures showed the same pattern. In the last outcome measure, the ACQ-R Stress Control scale, only patients in the expectancy violation condition showed an improvement from treatment.

There was no difference between the treatment credibility ratings (measured by the PATHEV) at the post-test between treatment conditions, $t(28.16) = 1.34$, $p = .191$, $d = 0.46$.

4.1.3.3 Exploratory analyses

In two exploratory *post hoc* analyses, the relationship between treatment outcome and (1) fear levels during exposure as well as (2) presence was assessed. In these analyses, treatment outcome was operationalized as the absolute difference from pre-test to post-test for each measure, so that positive values indicate a better outcome.

Relationship between fear indices and treatment outcome

The correlations between fear indices and treatment outcome are displayed in Table 12. As uncorrected tests are used, the interpretation of the results must remain under caution. For IFA, fear_{max} and $\text{fear}_{\Sigma(\Delta>0)}$ correlated significantly positive with five and one out of nine outcome measures respectively, whereas fear_1 did not correlate significantly with any outcome measure. For WSH, $\text{fear}_{\text{max}-\text{end}}$ and $\text{fear}_{\Sigma(\Delta<0)}$ correlated significantly positive with three and one out of nine outcome measures, whereas $\text{fear}_{1^{st}-4^{th}\text{quartile}}$ did not correlate significantly with any outcome measure. For BSH, $\text{fear}_{\text{max}_{t1}} - \text{fear}_{\text{max}_{t2}}$ correlated significantly negative with two out of nine outcome measures. $\text{Fear}_{\text{mean}_{t1}} - \text{fear}_{\text{mean}_{t2}}$ did not correlate significantly with any treatment outcome measure, but correlation coefficients were also mostly negative. For VAR, SD(fear), $\text{fear}_{\text{max}-\text{min}}$, and $\text{fear}_{\Sigma\Delta}$ correlated significantly positive with three, two, and one outcome measures respectively. AR(fear) did not correlate significantly with any outcome measure.

Relationship between presence and treatment outcome

The correlations between presence and treatment outcome are displayed in Table 13. As uncorrected tests are used, the interpretation of the results must remain under caution. The analysis shows three significant associations: a positive correlation between the IPQ subscale Experienced Realism and the outcome on the ATHQ as well as the fear ratings during the BAT, and a positive correlation between the IPQ subscale Involvement and the fear ratings during the BAT. All other correlation coefficients are not significant but also point in the positive direction (with three exceptions).

4.1.4 Discussion

The present study compared two operationalizations of exposure therapy, following predictions from both the EPT and the inhibitory learning model. To this end, patients with acrophobia received two sessions of VRET in a CAVE, focussing either on the non-occurrence of feared events (expectancy violation) or on the decline in fear symptoms (fear habituation) during exposure. Treatment outcome was measured by questionnaires for height-fearfulness and for sense of control in stressful situations, as well as a BAT.

Table 12
Correlations between fear indices and treatment outcome

	△AQ Anxiety		**△AQ Avoidance**		**△ATHQ**	**△HIQ**		**△BAT Fear**		**△BAT Steps**		**△ACQ-R Emotional**	**△ACQ-R Threat**		**△ACQ-R Stress**
IFA: fear_{1}	-.28		-.33		-.31	.22	#	-.46	#	.26		-.28	-.19		-.21
IFA: fear_{max}	.75	***	.59	*	.23	.53	*	.08		.65	**	.05	.52	*	-.37
IFA: $\text{fear}_{\Sigma(\Delta>0)}$	.58	*	.44	#	.34	.31		.42		.14		.06	.45	#	-.14
WSH: $\text{fear}_{\text{max}-\text{end}}$	.69	**	.58	*	.32	.24		.15		.56	*	.25	.46	#	-.32
WSH: $\text{fear}_{1^{st}-4^{th}\text{quartile}}$	.10		.09		-.07	.07		-.07		.40		.24	-.09		-.24
WSH: $\text{fear}_{\Sigma(\Delta<0)}$	.62	*	.43	#	.34	.29		.39		.29		.08	.46	#	-.30
BSH: $\text{fear}_{\text{max}_{t1}} - \text{fear}_{\text{max}_{t2}}$	-.68	*	-.61	*	-.45	-.51	#	-.28		-.21		-.35	-.48		.03
BSH: $\text{fear}_{\text{mean}_{t1}} - \text{fear}_{\text{mean}_{t2}}$	-.40		-.41		-.34	-.32		-.37		.31		-.31	-.33		-.22
VAR: $SD(\text{fear})$	.70	**	.61	*	.38	.56	*	.26		.30		.07	.50	#	-.00
VAR: $AR(\text{fear})$	.02		.17		.10	.07		-.27		.23		.08	.01		.27
VAR: $\text{fear}_{\text{max}-\text{min}}$	.69	**	.57	*	.31	.48	#	.28		.35		.08	.49	#	-.12
VAR: $\text{fear}_{\Sigma\Delta}$	.57	*	.38		.25	.42		.38		.21		.01	.42	#	-.25

Note: IFA = initial fear activation, WSH = within-session habituation, BSH = between-session habituation, VAR = variability in fear levels, AQ = Acrophobia Questionnaire, ATHQ = Attitudes Towards Heights Questionnaire, HIQ = Heights Interpretation Questionnaire, BAT = Behavioral Avoidance Test, ACQ-R = Anxiety Control Questionnaire Revised. All outcome measures were coded so that a positive correlation indicates an association with improved outcome. #$p < .10$, *$p < .05$, **$p < .01$, ***$p < .001$.

Table 13
Correlations between presence and treatment outcome

	△AQ Anxiety	**△AQ Avoidance**	**△ATHQ**	**△HIQ**	**△BAT Fear**	**△BAT Steps**	**△ACQ-R Emotional**	**△ACQ-R Threat**	**△ACQ-R Stress**
IPQ Spatial Presence	.09	.23	-.01	-.32 #	.11	.07	-.04	.21	.05
IPQ Involvement	.10	.27	.21	.16	.36 *	.24	.25	.29	.01
IPQ Experienced Realism	.22	.32 #	.42 *	.28	.39 *	.18	.17	.05	.22
IPQ General	.02	.23	.31 #	.10	.17	.13	.24	.32 #	.04

Note: IPQ = Igroup Presence Questionnaire, AQ = Acrophobia Questionnaire, ATHQ = Attitudes Towards Heights Questionnaire, HIQ = Heights Interpretation Questionnaire, BAT = Behavioral Avoidance Test, ACQ-R = Anxiety Control Questionnaire Revised. All outcome measures were coded so that a positive correlation indicates an association with improved outcome. #$p < .10$, *$p < .05$.

4.1.4.1 Expectancy violation vs. fear habituation

Results revealed that both the focus on expectancy violation and fear habituation during exposure sessions led to positive treatment outcome. Effect sizes for the pre-post comparison were comparable to similar studies (Powers & Emmelkamp, 2008). There was no difference in treatment efficacy between the expectancy violation and fear habituation conditions. Only a single, not acrophobia-related, outcome measure showed a difference between both conditions. After the treatment, patients in the expectancy violation group reported a higher general sense of control over stressful situations. Patients in the fear habituation group did not improve in this measure. With regards to the acrophobia-specific questionnaires as well as the BAT, the two treatment conditions did, however, not produce different outcomes.
Only a few other studies compared expectancy violation with fear habituation during exposure. In a pilot study in patients with panic disorder with agoraphobia, Salkovskis et al. (2007) compared two exposure conditions. A "belief disconfirmation" condition was designed to maximally disconfirm feared catastrophes of patients, by dropping safety behaviors and specifically testing predicted outcomes. The "habituation" condition followed the rationale that avoidance of feared situations maintains the pathological fear and that staying in the feared situation and experiencing a decline in fear symptoms during exposure is necessary for positive treatment outcome. Patients in both conditions received about three hours of exposure. Results showed that the belief disconfirmation condition produced better outcomes compared to the habituation condition. Actually, the habituation-based treatment did not lead to any improvement at all in six out of seven outcome measures. Although this study shows a benefit of focusing on the violation of threat expectancies during exposure, it has also several limitations. Most importantly, it is unclear why the habituation-based treatment produced nearly no positive outcome, although earlier studies could show that habituation-based exposure in panic disorder with agoraphobia did lead to positive outcome (e.g., Michelson, Marchione, Greenwald, Testa, & Marchione, 1996). As a second study, Brown et al. (2016) compared the predictive validity of expectancy violation and habituation measures for fear extinction retention in a fear-conditioning study. Expectancy violation was operationalized as the variation of US expectancy ratings during fear extinction. Higher variation of US expectancy ratings predicted US expectancy ratings at a spontaneous recovery test but not after reinstatement. Also, variation in US expectancy ratings did neither predict startle response at spontaneous recovery or reinstatement test nor fear ratings at spontaneous recovery test. Fear habituation was operationalized as (1) the difference between the fear rating of the first and last trial of fear extinction and (2) as the slope of the startle response across trials. Both habituation parameters did not predict any outcome measure. Brown et al. (2016) conclude that WSH is not sufficient for retention of extinction learning and that models that focus on expectancy violation might lead to better outcomes. The study has however several drawbacks. First, the study did not include an experimental manipulation, but instead used correlational

analyses only. Second, the authors do not explain why the operationalizations for the three indices differ (variation vs. difference vs. slope). This is an important point as different operationalizations led to quite different results in the current study. Third, expectancy violation was only predictive for one out of three outcome measures for spontaneous recovery—that was US expectancy itself—and none for reinstatement. Therefore, to corroborate the findings, replication is essential.

In sum, both the studies by Salkovskis et al. (2007) and Brown et al. (2016) offer some evidence that exposure therapy based on an expectancy violation approach may lead to superior outcome. However, due to several methodological problems in these studies and an inconsistent finding in the current study, a final conclusion regarding the superiority of expectancy violation-based exposure cannot be made.

4.1.4.2 Predicting treatment outcome by fear indices

In an exploratory analysis, the fear indices IFA, WSH, BSH, and VAR were calculated and used to predict treatment outcome. Both the EPT (IFA, WSH, and BSH) and the inhibitory learning model (VAR) assume that these indices signal improved treatment outcome (Craske et al., 2014; Foa & Kozak, 1986). Since this was an uncorrected *post hoc* analysis, I will refrain from drawing conclusions about whether the indices are appropriate indicators for treatment outcome, but use the results to discuss methodological issues in the previous literature.

First, looking at the different measures for each index, it becomes evident that these differ strongly with regards to whether they would support the assumption that the index predicts treatment outcome in the current study (e.g., comparing the IFA indices fear_1 and fear_{max}). Second, looking at the different measures for treatment outcome, it becomes further evident that these would also lead to very different conclusions. For example, correlations using the AQ yielded eight out of twelve correlations significant, whereas correlations using the ATHQ yielded zero significant correlations. In previous studies, measures for both the fear indices and the treatment outcome have been mannifold (see, for example, Baker et al., 2010 and Kircanski, Mortazavi, et al., 2012 for different operationalizations of fear indices). Flake and Fried (2019) argue that this source of researcher degrees of freedom poses a serious threat to cumulative evidence. Furthermore, this variety of measures might, in part, be responsible for the ambiguous findings regarding the predictive validity of fear indices (see 2.3.1 and Figure 2). Flake and Fried (2019) recommend a more rigorous reporting of methods to resolve what they call "questionable measurement practices." Most importantly, previous research has failed to ascertain the validity of the fear indices.

4.1.4.3 The relationship between presence and treatment outcome

In a second exploratory analysis, the relationship between presence, the sense of 'being there' in the virtual environment, and treatment outcome was investigated. Again, I will not

draw strong conclusions from the results, as this was also an uncorrected *post hoc* analysis. Although only few of the tested correlations were significant, it is noteworthy that 33 out of 36 correlations pointed to the positive direction. A positive association between presence and treatment outcome has been suggested in the literature (Freeman et al., 2017; Wiederhold & Wiederhold, 2000), but study findings have been ambiguous (Krijn et al., 2004; Price et al., 2011; Quero et al., 2008; Schuemie et al., 2000). Drawing a careful conclusion, the present findings suggest that there may be a positive but likely small association between presence in VR during treatment and treatment outcome. The problem of questionable measurement practices discussed in the previous paragraph also applies to studies regarding the relationship between presence and treatment outcome, especially the diversity of different presence measures (see 2.4.2.2).

4.1.4.4 Limitations

Some limitations to this study need to be taken into account. First, being a pilot study, the treatment outcome was measured shortly after the treatment only. As the same is true for the study by Salkovskis et al. (2007), there are not yet any studies that examined the effects of exposure based on expectancy violation vs. fear habituation on long term follow-up outcomes. This leaves open the possibility that differences in treatment efficacy between conditions could have emerged at a longer time after treatment. Future studies should therefore include follow-up measurements.

Second, a possible critique of VRET is that it allows not all expectancies to be tested (Scheveneels, 2019). For example, in the virtual environment of the current study, it was not in the slightest possible to fall off from the tower, whereas this eventuality could exists in an exposure *in vivo*. Fewer testable expectancies could have limited the efficacy of the exposure based on expectancy violation. However, there are several research findings that do not support this assumption. Scheveneels (2019) found that the number of testable expectancies was not related to treatment outcome of VRET for fear of public speaking. Furthermore, meta-analyses did not find differences in efficacy between VRET and exposure *in vivo* (e.g., Carl et al., 2019).

Third, results of the behavioral measure of the BAT indicate a ceiling effect, implying that the BAT might have been too easy. This could have led to an treatment effect going undetected. However, as the results of the BAT show the same pattern as all other acrophobia measures, this seems not be very likely.

Fourth, the current study examined only persons with a fear of heights. One cannot rule out the possibility that differences between treatment conditions might emerge in different phobias or anxiety-related disorders.

4.1.4.5 Conclusion

In conclusion, this study expands the evidence that VRET is a suitable treatment for fear of heights. Manipulating the focus of the treatment, i.e., making either violation of threat expectancies or fear habitiation the goal of exposures, did not affect treatment efficacy. This means that the present study could not provide evidence for the superiority of a treatment that is either based on the EPT or the inhibitory learning model. How such a finding could influence the development of theories underlying the efficacy of exposure therapy will be discussed in the general discussion of the present thesis.

Chapter 5

General Discussion

Anxiety disorders are among the most frequent mental disorders (Kessler et al., 2007), causing significant costs for the health care system (Wittchen et al., 2011). Cognitive behavioral therapy (CBT) for anxiety disorders is an effective treatment (Carpenter et al., 2018; Hofmann & Smits, 2008). Recent findings, however, indicate that there is still room for improvement (Carpenter et al., 2018), especially because a considerable number of patients do not remit or have a relapse after successful treatment (Loerinc et al., 2015; Springer, Levy, & Tolin, 2018). In specific phobias, the main treatment compontent of CBT is exposure, the systematic confrontation to feared stimuli and situations (Abramowitz et al., 2012). Although exposure therapy has been found effective for the treatment of specific fears (Choy et al., 2007; Wolitzky-Taylor et al., 2008), there is also a significant number of patients who do not respond to exposure therapy or relapse after treatment (Loerinc et al., 2015; Rachman, 1989). For this reason, research has focused on unraveling the mechanisms underlying exposure therapy to enhance exposure therapy efficacy and maintenance of treatment gains. This research led to the development of different theories of exposure therapy, most notably the EPT (Foa & Kozak, 1986) and the inhibitory learning model (Craske et al., 2008, 2014). So far, however, the differential efficacy of implementations of these theories has not yet been compared.
Besides the limited efficacy of exposure therapy for some patients, a second issue concerns the fact that both therapists and patients express reservations about exposure therapy (Garcia-Palacios et al., 2007; Pittig, Kotter, & Hoyer, 2018). For example, one argument often put forward by therapists is that exposure therapy lacks practicability, as the patient and therapist usually need to leave the therapist's office and seek out the feared situation (Pittig, Kotter, & Hoyer, 2018). Further arguments against exposure *in vivo* include lack of replicability of exposures and low control of stimuli. VR provides means to overcome these issues. Using computer-generated environments for exposure has several advantages over exposure *in vivo*, e.g., greater control over stimuli, replicability of exposures, or not having to leave the therapist's office (Bouchard et al., 2012). VRET has been found effective for the treatment of anxiety disorders (Carl et al., 2019; Fodor et al., 2018), but the mechanisms underlying its

efficacy are not well understood (Diemer et al., 2016).
The present thesis aimed to elaborate on the mechanisms underlying VRET, with a focus on two major questions: first, how virtual environments elicit fear responses, and second, whether treatment efficacy can be increased by incorporating techniques derived from two different theoretical models of exposure therapy. To this end, five studies in VR were conducted.

5.1 Fear in Virtual Reality

The studies for the first research question—how virtual environments elicit fear responses—followed the model of fear in VR I established in the introductory section (see Figure 4). According to the model, fear (measured on a subjective, physiological, and behavioral level) in virtual height situations is a function of trait height-fearfulness and presence, the sense of 'being there' in the virtual environment. Furthermore, presence is thought to be dependent upon immersion, the characteristics of the VR system, and the fear response. In the following, I will go through the hypotheses put forward in the introductory section of the thesis and propose a revised model of fear in VR based on the findings of the present studies.

(1) Virtual height environments elicit fear responses in height-fearful individuals. These fear responses can be measured on different levels, i.e., on a subjective, physiological, and behavioral level.

(2) The strength of fear responses in virtual height environments is dependent upon the trait level of height-fearfulness.

Study 1 demonstrated that fear responses on both a subjective and behavioral level were dependent upon the level of trait height-fearfulness. Compared to the low height-fearful participants, the high height-fearful participants reported higher fear, dangerousness of the situation, and dizziness, and displayed behavioral avoidance when asked to approach the railing at the tower's top platform. Study 2 extended these findings by showing that fear responses were also evident on a physiological level (although much more pronounced on skin conductance than on HR). Furthermore, by using a different VR system (an HMD instead of a CAVE), Study 2 confirmed the findings of the first study by showing that VR's capabilities to trigger fear responses are independent of the used VR system (a finding that was further confirmed by Experiment 2 in Study 4, that used yet another VR system). Study 3, finally, corroborated these findings by showing that the fear responses were specific, i.e., were dependent upon both the level of trait height-fearfulness (using it as a linear predictor) and the height level (using random presentation of the height levels). Also, as a new virtual environment was used compared to the previous studies, Study 3 showed that elicitation of fear responses was not dependent on a specific virtual environment. This finding was further validated by Study 4, which used two more virtual environments. Furthermore, Study 3 also

replicated the finding from Study 2 that physiological reactivity was much more pronounced on skin conductance than on HR, and this finding was further replicated in both experiments of Study 4.

Several conclusions can be drawn from these results. The findings indicate that VR is a valid tool to trigger fear responses (on a subjective, physiological, and behavioral level). Importantly, this was neither dependent on a specific VR system (as three different systems were used) nor on a specific virtual environment (as four different virtual environments were used). Following theoretical models of exposure therapy, VR thus satisfies necessary premises for being a valid medium to conduct exposure therapy. According to the EPT, a requirement for successful exposure is that the fear network is activated (Foa & Kozak, 1986). An index for this activation is IFA, the initial fear response towards a feared stimulus or situation. The studies in the present thesis show that, indeed, VR triggers such (initial) fear responses, suggesting that the fear network sensu EPT was activated. According to the inhibitory learning model, a CS must be present during exposure and trigger US expectancies (e.g., "I will fall off") (Craske et al., 2008, 2014). Following this framework, the fear responses towards virtual heights in the studies of the present thesis can be interpreted as CRs, allowing the conclusion that virtual heights can serve as CSs (or more precisely, as generalization stimuli, GS, as the fear was probably not acquired in VR). What remains an open research question, however, is to what extent VR stimuli trigger US expectancies. As Scheveneels (2019) points out, VR stimuli will probably not trigger the same US expectancies as real stimuli (as, for example, getting physically hurt by falling off is not possible in VR). Following the inhibitory learning approach of exposure therapy, not being able to violate certain US expectancies should result in less successful treatment outcome (Scheveneels, 2019). However, inconsistent with this assumption, meta-analyses showed that VRET was not less effective than exposure *in vivo* (Carl et al., 2019; Morina et al., 2015; Opriş et al., 2012; Powers & Emmelkamp, 2008). Scheveneels (2019) suggests two possible explanations for this paradox: first, high levels of presence may actually trigger US expectancies such as "I could fall off", and second, VRET may work by violating US expectancies regarding one's own reactions (e.g., "I'm gonna have a heart attack"). Future studies should investigate what kind of US expectancies are triggered in VRET, further illuminating the mechanisms underlying VRET.

Several manipulations with regards to the content of the virtual environments affected fear responses in the present thesis. These were height level (especially in Study 3), tactile wind simulation (Study 1), and sound (the creaking sound of the wooden plank in Study 4 Experiment 1). This confirms one potential advantage of VRET over exposure *in vivo*, namely that VR allows precise control over the phobic stimuli and how much fear they trigger (Bouchard et al., 2012). According to the EPT, increased IFA indicates stronger activation of the fear network (Foa & Kozak, 1986), which is a requirement for successful exposure. For patients who display only weak fear responses when confronted with a phobic stimulus, manipulating the fear relevance of the stimulus in the virtual environment (e.g., by increasing

the height) could be used to stronger activate the fear network. The other way around, Foa and Kozak (1986) argue that too high arousal (possibly caused by extreme fear responses) during exposure could interfere with treatment outcome (see also Foa et al., 2006). In this case, manipulation of fear levels in VR could be used to attenuate high arousal. Following an inhibitory learning approach, if patients display only very weak fear responses when confronted with a phobic stimulus, it could indicate that US expectancies were not activated by the virtual environment. According to the model, this would prevent the violation of these expectancies and lead to poor treatment outcome. Manipulations of phobic stimuli in VR could, in this case, be used to increase US expectancies. Furthermore, manipulations of fear levels and US expectancies could in the future be used to experimentally test predictions of both the EPT (e.g., IFA indicates positive treatment outcome) and the inhibitory learning model (e.g., stronger expectancy violation leads to more favorable treatment outcome). Previous studies on the effects of IFA on treatment outcome have typically only been correlational. Using VR, studies could aim to induce weak vs. moderate vs. strong IFA and investigate effects on treatment outcome. In a similar design, inducing weak vs. moderate vs. strong US expectancies could be used to test the effects of expectancy violation on treatment outcome (see also 5.2).

The findings that physiological responses towards the virtual heights were stronger for skin conductance than for HR in Studies 2, 3, and 4 confirm findings of previous VR studies (see Diemer et al., 2014, for a review). As a reason for this, Diemer et al. (2014) hypothesize that HR responses may be more complex than electrodermal responses. Lang and Bradley (2010) argue that skin conductance rises with increasing threat imminence, whereas HR shows a decline to distal threats and increases only if the threat is imminent. Studies 2 and 3 support the assumption about skin conductance. In both studies, varying height levels were presented to participants, and skin conductance increased with altitude (which may be interpreted as threat imminence in the present case). For HR, Study 3 visually showed a pattern of initial deceleration and subsequent acceleration in line with the assumption by Lang and Bradley (2010), when averaging across trials and participants (with stronger acceleration with increased height, see Appendix H). This result was, however, not supported by statistical tests. Comparing the measures of skin conductance and HR in the present thesis, HR seems to have greater variability, suggesting a lower signal-to-noise ratio which calls for a larger number of measurements than used in the present studies. An additional argument for the complexity of HR in fear situations comes from findings which show that HR is not only an indicator of fear, but that heartbeats conversely also affect fear processing (Garfinkel & Critchley, 2016). In sum, the present studies indicate that skin conductance may be more suitable as a physiological index of fear compared to HR, at least in studies with few trials.

(3) Besides trait height-fearfulness, the strength of fear responses in virtual height environments is also dependent upon presence, the sense of 'being there' in the virtual

environment. Vice versa, fear responses also influence the level of experienced presence.

Regarding the correlational relationship between presence and fear, the studies in the current dissertation replicated the findings from a recent meta-analysis (Ling et al., 2014). Except for Study 3, all studies showed that stronger fear ratings did go along with higher presence. Furthermore, Study 1 replicated the finding that the correlation between presence and fear was higher in more height-fearful participants. Studies 1, 2, and 4 replicated the finding that correlations were higher for one-item measures than for questionnaires. In Study 3, correlation coefficients pointed to the expected (positive) direction but were not significant. This null finding of Study 3 (in which only a questionnaire at the end of the experiment was used to measure presence and no online presence rating) could be due to the very short scene presentations and the breaks caused by fixation crosses between trials.
As there have only been few studies on the causal relationship between both measures, Study 4 thought to elaborate on this by manipulating both presence and fear experimentally. Experiment 2 of Study 4 showed that presence ratings increased with higher fear (fear → presence, i.e., higher presence ratings in the height situation compared with control situations), replicating previous findings (Alsina-Jurnet & Gutiérrez-Maldonado, 2010; Bouchard et al., 2008; Peperkorn et al., 2016). Conversely, the manipulation of presence did not lead to differences in fear responding, i.e., increases in presence by having a higher visual and auditory realism did not increase fear responses. This finding suggests that targeting content-related aspects of a virtual environment (e.g., the height of a situation, wind stimuli) may be more important when aiming for strong fear responses than high levels of presence (e.g., by increasing the visual realism). Although the causal presence → fear relationship could not be shown via experimental manipulation, an exploratory analysis of Experiment 2 of Study 4 indicated that persons who had high initial presence levels (in a safe situation) were also those persons who had the highest fear levels (in the height situation). This finding suggests that presence could be a mediator of an effect of *immersive user characteristics*—which lead to high *baseline* presence—on fear responses. Such immersive user characteristics could, for example, be absorption, immersive tendencies, perspective-taking, and mental imagination (Kober & Neuper, 2013). In this context, one could assume that such user characteristics do not only influence fear responding, but could also be of relevance to treatment outcome. To corroborate the findings of the present thesis, further studies with *a priori* hypotheses about the links between immersive user characteristics, presence, and fear need to be conducted.

(4) Presence can further be manipulated via immersion, the objective characteristics of the VR system.

Previous research has shown that presence can be manipulated via immersion (Cummings & Bailenson, 2016; Youngblut, 2007, see also the model by Diemer et al., 2015; Diemer & Zwanzger, 2019). Three experiments in the current dissertation aimed to elaborate on these

findings by evaluating a tactile wind simulation in Study 1 and manipulations of visual and auditory realism in Study 4. In Study 1, adding tactile wind simulation to the virtual height environment did not increase presence (neither in presence ratings nor on a questionnaire). In Experiment 1 of Study 4, manipulation of visual realism and auditory content did also not affect presence (again neither in presence ratings nor on a questionnaire). Using a stronger manipulation of visual realism and auditory content, the manipulation was successful in Experiment 2 of Study 4 for one-item presence ratings (small to moderate effect) but not for the presence questionnaire.

The results of Study 4 replicate the finding of a recent meta-analysis that visual realism does not have a particularly strong effect on presence (Cummings & Bailenson, 2016). This implicates that virtual environments for use in exposure do not necessarily have to be photo-realistic representations of phobic situations in order to induce a sense of presence. Instead, the phobic stimuli need to be included and trigger fear to be adequate for exposure. This assumption is supported by the finding that there is no effect of publication year (assuming that virtual environments are more advanced in more recent years) on treatment outcome in a recent meta-analysis of VRET (Carl et al., 2019). Future studies that want to achieve sufficiently large differences in levels of presence between groups should probably use manipulations different than visual realism to affect presence, or manipulate immersion at multiple levels. The results of a meta-analysis suggest that tracking, field of view, and stereoscopy may be more relevant options (Cummings & Bailenson, 2016).

In consequence of the results of the first four studies, I propose a revised model of fear in VR (see Figure 24). The model describes fear responses towards VR heights (on a subjective, physiological, and behavioral level) to be a function of trait height-fearfulness, fear-related content of the virtual environment, and (at least to some degree) on presence. Presence is assumed to be a function of immersion, immersive user characteristics, and fear. A similar model was proposed by Diemer and Zwanzger (2019).

5.2 Mechanisms Underlying Exposure Therapy Efficacy

The second research question—whether VRET implementations following two different theoretical models of exposure therapy produce different outcomes—was examined in the last study of the dissertation. To this end, two implementations of exposure therapy were compared. The first implementation followed the EPT, assuming that fear reduction during exposure is crucial for positive treatment outcome. In this condition, patients were asked to focus on their fear responses and the decline of fear (habituation) during exposures. The second implementation was based on the inhibitory learning model, assuming that expectancy violation is the primary mechanism underlying exposure therapy efficacy. In this condition, patients were asked to focus on the non-occurrence of feared outcomes during exposure.

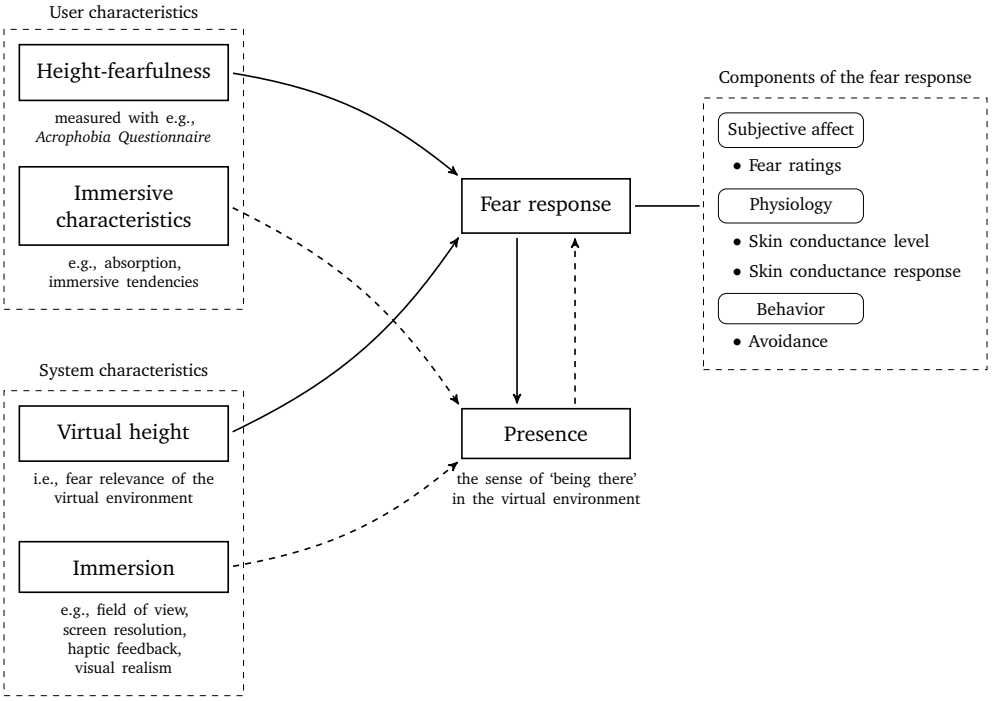


Figure 24: A revised model for the study of fear in virtual height situations. The fear response towards a virtual height is hypothesized to be dependent on the trait height-fearfulness, fear relevance of the virtual height situation, and on the sense of presence in the virtual environment. Furthermore, presence is thought to be dependent upon immersion, fear, and immersive user characteristics. Solid arrows indicate strong experimental support from the current studies, dashed arrows indicate less strong experimental support or exploratory results.

(5) Exposure treatment following the expectancy violation approach of the inhibitory learning model outperforms exposure treatment following a habituation-based approach.

At large, the results support recent meta-analyses to the extent that VRET is an effective treatment for fear of heights (Carl et al., 2019; Fodor et al., 2018). Comparing the two different implementations of VRET, however, outcome between the habituation-based and expectancy-violation-based condition did not differ. In the following, I will discuss possible reasons for this null finding, resulting implications, as well as suggestions for further research.

5.2.1 The Inhibitory Learning Model Revisited

In the following, I will critically examine the inhibitory learning model by investigating why its proposed strategies possibly do not exhibit large effects on treatment outcome. Craske et al. (2012) assume that the mechanism underlying exposure therapy is inhibitory learning: "[m]ore recent theories of exposure therapy that draw from extinction research highlight the importance of inhibitory regulation, or the formation of safety learning, as the primary underlying mechanism" (Craske et al., 2012, p. 323), and that "there is tremendous clinical value to optimizing inhibitory learning during exposure therapy in order to [...] enhance

treatment efficacy" (Craske et al., 2012, p. 323). However, the literature research in the introductory section of the dissertation (see 2.3.2 and Figure 3), as well as the review by Weisman and Rodebaugh (2018) reveal only little empirical evidence for the clinical value of the specific strategies of the inhibitory learning model (see also Scheveneels, 2019). Several possible reasons for these findings should be discussed. Craske et al. (2018) assume that findings in fear extinction research can be translated back and forth on four levels: (1) conditioned fears in animals, (2) conditioned fears in healthy humans, (3) conditioned and existing fears in clinical analogue samples, and (4) conditioned and existing fears in clinical samples (see the 'extended translational model of fear extinction', Craske et al., 2018, p. 7). Furthermore, it is assumed that fear acquisition is "centered on the amygdala, prefrontal cortex (PFC) and hippocampus" (Young & Craske, 2018, p. 84; see also Craske et al., 2017), and that fear conditioning and fear extinction research are adequate tools to investigate neurobiological mechanisms in these structures across species. However, recent meta-analyses of fMRI studies showed that activation patterns of human fear conditioning and extinction studies do not overlap with those suggested from animal research (Fullana et al., 2018a, 2018b, 2016; Morriss, Hoare, & van Reekum, 2018). Of note is especially the lack of consistent amygdala activation (Fullana et al., 2018b, 2016). As one possible reason, Fullana et al. (2018a) suggest that human fear conditioning experiments might rather induce states of mild anticipatory anxiety instead of strongly probing the amygdala defense-survival circuit function. As an example, in a study with a differential fear conditioning paradigm, a CS+ was paired with an electric shock (45 presentations, 21 of these were reinforced) which resulted in an absolute negative valence of about 0.25 on a scale from -2 to 2 (higher is more negative) (Sperl, Panitz, Hermann, & Mueller, 2016, Figure 2). If such mild anxious states are functionally different from states in which an individual prepares for imminent threat, then treatment strategies derived from findings of human fear conditioning studies might not be easily transferable to clinical populations. Other examples that highlight the complexity of translating findings between the different levels proposed by the Craske et al. (2018) translational model (e.g., extinction of conditioned fears in animals → extinction of conditioned fears in humans) include challenges in providing evidence for memory reconsolidation in humans (Elsey, Van Ast, & Kindt, 2018) and difficulties in demonstrating positive effects of transcutaneous vagus nerve stimulation on extinction retention in humans (Burger et al., 2017, 2016; Genheimer, Andreatta, Asan, & Pauli, 2017). A further possible explanation for the failure to translate treatment strategies derived from fear conditioning studies to exposure therapy in anxiety disorders are possible differences in how clinical fears vs. conditioned fears are stored in memory (Walsh et al., 2018). According to Walsh et al. (2018), "[t]he learning history of naturally acquired maladaptive memories is usually unknown [...], although it is assumed that in general, these memories are formed through multiple, intermittent reinforcements (Pavlovian and instrumental) in a variety of contexts and over a prolonged period. This is generally radically different from the

situation for experimentally acquired memories" (Walsh et al., 2018, p. 2508). Although fear conditioning and fear extinction have received positive support regarding their external validity for the acquisition and treatment of pathological fears (e.g., Pittig, Treanor, et al., 2018; Scheveneels, Boddez, Vervliet, & Hermans, 2016), there still seems an urgent need for the corroboration of external validity, especially for the predictive validity of fear extinction research (Scheveneels et al., 2016).

A further reason explaining the lack of positive results of inhibitory learning strategies in clinical studies is that fear extinction and inhibitory learning are not the only routes to fear reduction and positive treatment outcome (Craske et al., 2018; Scheveneels et al., 2016). Possible other processes are, for example, US habituation (Furlong, Richardson, & McNally, 2016; Haesen & Vervliet, 2015; Storsve, McNally, & Richardson, 2010, 2012), counter-conditioning (Jones, 1924a; Kang, Vervliet, Engelhard, van Dis, & Hagenaars, 2018; Newall, Watson, Grant, & Richardson, 2017; Wolpe, 1968), and avoidance extinction (Dymond, 2019; LeDoux, Moscarello, Sears, & Campese, 2017; Pittig, Treanor, et al., 2018; Treanor & Barry, 2017). It is not yet known what influence any one of these mechanisms plays in real-life exposure treatments.

In a broader sense, focusing merely on a dysfunctional CS–US association as the basis of anxiety disorders and the formation of a functional CS–noUS association as the primary mechanism underlying their treatment (e.g., Tolin, 2019) could be described as a form of explanatory reductionism of mental disorders (see also Insel & Cuthbert, 2015, for an explanatory reductionist view on mental disorders). Explanatory reductionism has been criticized by advocates of network models of mental disorders, arguing that mental disorders should be regarded as complex dynamic systems (Borsboom, 2017) rather than rooted in an underlying biological cause (Borsboom, Cramer, & Kalis, 2019). The point to be made is that if anxiety disorders are more complex than dysfunctional neurocircuitry representing CS–US associations, then inhibitory learning strategies likely produce not so tremendous effects on symptomatology as hoped. Network models of mental disorders offer a starting point to capture the complexity of mental disorders, disclosing further targets for treatment. As an example, the implementation of a network model for panic disorder (Robinaugh et al., 2019) does not only include a CS–US association (arousal → perceived threat) but also regards the interaction with anxiety sensitivity (in this case termed 'arousal schema') as an integral part of panic disorder. Anxiety sensitivity (Reiss, Peterson, Gursky, & McNally, 1986; Schmidt, Short, Stanley, Allan, & Albanese, 2019) is by far not the only construct relevant to anxiety disorders that could emerge as a possible treatment target. Other constructs include neuroticism (Watson, 2019), disgust proneness (Knowles & Olatunji, 2019), intolerance of uncertainty (McEvoy, Carleton, Correa, Shankman, & Shihata, 2019), distress tolerance (Rappaport, Berenz, Lejuez, & Roberson-Nay, 2019), experiential avoidance (Goodman, Larrazabal, West, & Kashdan, 2019), and emotion regulation (Fernandez, Morrison, & Gross, 2019).

Taken together, research indicates that the manifestations of pathological fears and anxiety are highly complex. For this reason, the strategies proposed by the inhibitory learning model must not only be validated in fear conditioning studies but also in analogue and clinical samples. In the following, I will propose how one of the strategies, the expectancy violation mechanism, could be investigated (experimentally) in analogue and clinical studies. First, reliable and valid metrics to assess threat expectancies and expectancy violation in naturalistic pathological fears need to be established before these can be related to treatment outcome. In acrophobia, a starting point for such a measure could, for example, be the Heights Interpretation Questionnaire (Steinman & Teachman, 2011). Second, once such metrics are validated, threat expectancies could be measured before and after exposure sessions and be used to predict treatment outcome. In an experimental approach, expectancies during exposure treatment could be manipulated by using exposure material triggering low vs. high threat expectancies, and the differential outcome of both conditions could be compared.
The clinical implications of the current findings are that applying inhibitory learning strategies in clinical practice does not guarantee an improved outcome. Nonetheless, inhibitory learning strategies may be used as suggestions for how individual exposures could be designed on a patient-by-patient basis.

5.2.2 Differences and Similarities in Exposure Therapy Theories

A second thought regarding the null finding in the last study of the dissertation concerns the issue of whether the EPT and inhibitory learning model are as different as they are often described in the literature. On the one hand, focusing on the decline of fear responses during an exposure session (i.e., habituation) can also be interpreted as a form of non-deliberate expectancy violation (for example, of the expectancy to have escalating fear symptoms such as palpitations). On the other hand, expectancies sensu inhibitory learning model can also relate to one's own reactions, and violating such expectancies may involve a decline in fear responses. Therefore, the two implementations of exposure therapy in the present thesis can probably not be clearly separated from each other. Furthermore, although the EPT and the inhibitory learning model have typically been described as two opposing theories, a closer examination reveals more similarities between both theories with regards to the assumed process of treatment. Figure 25 A and B illustrate the process of exposure therapy according to both theories. First, both theories assume that, as a first step, the mental representation of the pathological fear has to be retrieved from memory ("fear structure" in the EPT, CS–US association in the inhibitory learning model). Where both theories can be distinguished is the index with which this 'activation' is measured, i.e., IFA in the EPT, and US expectancy in the inhibitory learning model. Second, both theories require the patient to gain experiences that contradict contents of the mental representation of the pathological fear. In the inhibitory learning model, this is expectancy violation through the absence of the US. In the EPT,

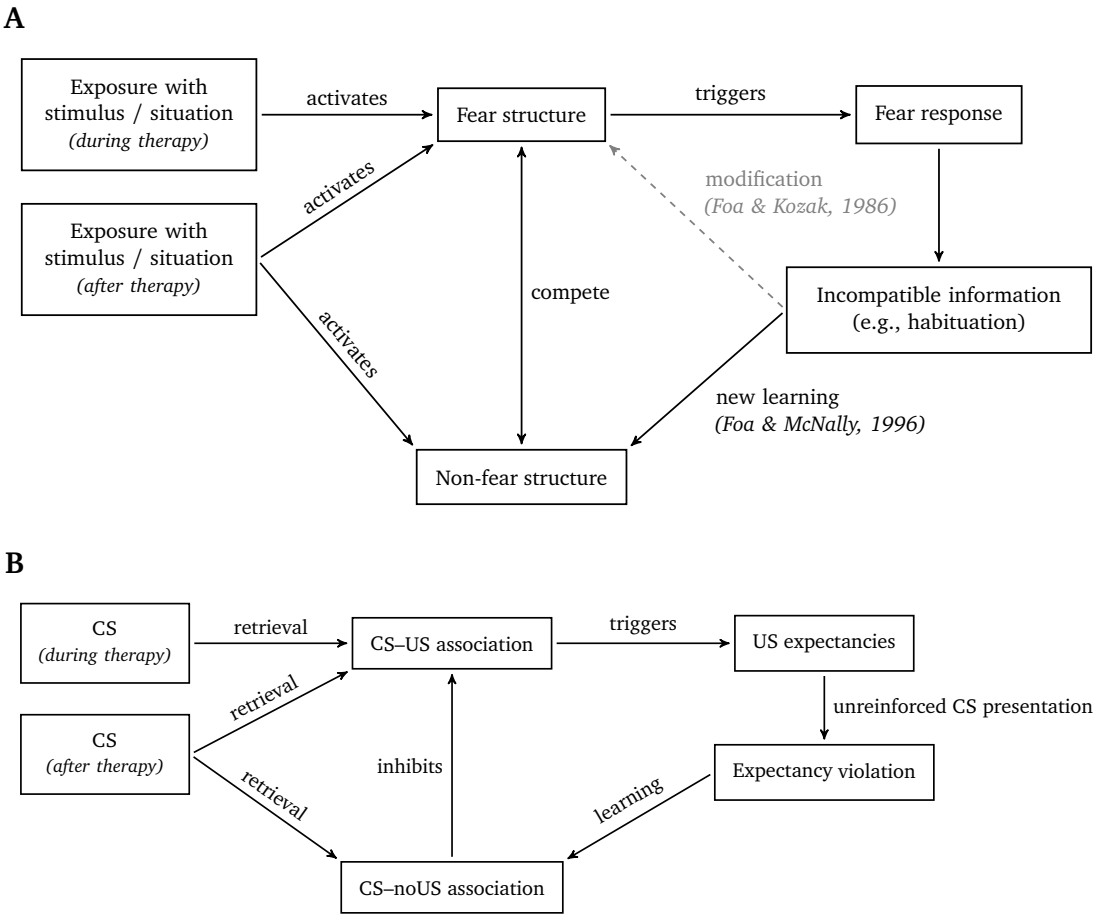


Figure 25: The process of exposure therapy described in terminology of the Emotional Processing Theory (A) and the inhibitory learning model (B).

this has been phrased in the broad term of "information that is sufficiently incompatible with the fear structure" (Foa & Kozak, 1986, p. 22). Where both theories again differ is the operationalization of this concept. In the inhibitory learning model, expectancy violation is the conscious experience that the feared outcome does not occur (which could be termed a form of behavioral cognitive restructuring). In the initial formulation of the EPT, information incompatible with the fear structure was operationalized as WSH, the extent to which fear declines within an exposure session (Foa & Kozak, 1986). In a more recent publication on the EPT, Foa et al. (2006) deemphasized the importance of WSH and put the focus on providing "corrective information about the nonthreat value of the stimuli, responses, and meaning elements [...]" (Foa et al., 2006, p. 9; see also Foa & McLean, 2016; Kaczkurkin & Foa, 2015). From this perspective, the habituation-based and expectancy-violation-based conditions in the present thesis might have produced similar outcomes as in both conditions, fear was 'activated,' and information incompatible with the pathological fear was acquired. Where both theories can be distinguished is that the inhibitory learning model takes a specific focus on how to improve the formation and retrieval of new non-threat associations. For this reason, the model proposes several strategies to enhance the formation and retrieval

of CS–noUS associations. However, as discussed above, there is not yet sufficient empirical evidence for the clinical value of these specific strategies. In sum, it is questionable whether the EPT and the inhibitory learning model should be regarded as two oppositional theories.

5.3 General Limitations

The studies in the present thesis sought to shed light on the mechanisms underlying VRET, but some limitations should be considered when interpreting the findings.

First, the present thesis investigated only persons with a fear of heights. In interpreting the findings, one should be cautious when generalizing the findings to other phobias and anxiety disorders. As an example, the meta-analysis on the relationship between presence and fear indicates that the strength of the correlation between both measures depends on the examined anxiety disorder (Ling et al., 2014). For social phobia, there was no significant correlation between presence and fear ($r = .001$), whereas, for acrophobia, there was a significant correlation ($r = .39$) (Ling et al., 2014). The relationship in acrophobia was replicated several times in the present thesis. For this reason, the model of fear in VR proposed in the current thesis relates to fear in virtual heights only and needs to be studied and evaluated in further phobias and anxiety disorders.

Second, except for the last study, only non-clinical analogue samples were investigated in the current studies. Lack of validation in clinically fearful samples might threaten the generalizability of the present findings. Therefore, although previous research indicates that findings from analogue samples can be generalized to clinical samples (Abramowitz et al., 2014; Flett, Vredenburg, & Krames, 1997; Vredenburg, Flett, & Krames, 1993), it is important to demonstrate that there are corresponding mechanisms at work in clinical and non-clinical analogue samples. Some of the analyses accounted for this problem by using height-fearfulness as a linear predictor (especially in Study 3), aiming to make predictions across different levels of trait height-fearfulness.

Third, VR might not have been the optimal choice as an exposure medium to compare a habituation-based vs. an expectancy-violation-based approach. The reason for this is that, compared to exposure *in vivo*, VRET might not allow the violation of certain US expectancies (e.g., falling off) (Scheveneels, 2019), thereby impeding treatment efficacy of the expectancy-violation approach. Although meta-analyses indicate that VRET is not less effective than exposure *in vivo* (Carl et al., 2019; Morina et al., 2015; Opriş et al., 2012; Powers & Emmelkamp, 2008), future studies should examine the effects of violating certain US expectancies on treatment outcome in more detail.

5.4 Outlook

Although VR has been used in the treatment of fears by clinical researchers for over two decades, its mainstream popularity has only gained momentum in recent years. The availability of affordable consumer VR hardware paves the way for accessible treatments in VR (Koller et al., 2018; Lindner et al., 2017), rendering VR as a central pillar in disseminating effective psychological treatments for mental disorders. The current thesis investigated mechanisms underlying fear in VR and identified several factors implicated in the experience of fear towards virtual heights. User characteristics, such as trait height-fearfulness and immersive characteristics, and system characteristics, such as the intensity of phobic stimuli, play an essential role in the emergence of fear in VR. Furthermore, the thesis investigated different theories of exposure therapy and identified several limitations within these theories. Predictions of both the EPT and the inhibitory learning model have fallen short of empirical evidence, and a differential efficacy between operationalizations based on these theories could not be established in the current thesis. Even more then ten years after Kazdin's (2007) seminal article, it still holds true that "we cannot provide an evidence-based explanation for how or why even our most well studied interventions produce change, that is, the mechanism(s) through which treatments operate" (Kazdin, 2007, p. 1). In part related to this problem is that not all patients respond to evidence-based psychological treatments. This becomes apparent in a meta-analysis on remission rates in CBT for anxiety disorders, where remission rates at follow-up were as low as 54% (Springer et al., 2018). Several research approaches plan to address these problems from different perspectives. Holmes et al. (2018) aim at increasing the understanding of mechanisms underlying psychological treatments by closing the gap between neuroscience and psychotherapy research. Hofmann and Hayes (2019) stress the need for a paradigm shift in psychotherapy research by focusing on underlying processes rather than rigidly adhering to a latent disease model of mental disorders. VR will likely play an important role in both of these approaches, given its high internal validity and potential for ecological validity (Parsons, 2015).

Chapter 6

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Appendix

Appendix A

Tabular representation of evidence for inhibitory learning strategies

Inhibitory learning strategy	Positive evidence	Category	Study
Expectancy violation	yes	clinical	Guzick et al. (2018)
		analogue	Deacon et al. (2013)
	no	clinical	Raes et al. (2011) Baker (2012) de Kleine et al. (2017) Blakey et al. (2019)
Deepened extinction	no	analogue	Lancaster (2017)
Mental rehearsal	mixed	clinical	Joos (2011)
Sleep	yes	clinical	Kleim et al. (2014)
		analogue	Pace-Schott et al. (2012)
	no	clinical	Pace-Schott et al. (2018)
External retrieval cues	yes	analogue	Shin and Newman (2018)
	no	analogue	Culver et al. (2011) Dibbets et al. (2013) Laborda et al. (2016)
Internal retrieval cues	yes	clinical	Elsesser et al. (2012)
		analogue	Mystkowski et al. (2006)
	no	analogue	Laborda et al. (2016)
Multiple contexts	yes	clinical	Shiban et al. (2013)
		analogue	Bandarian-Balooch et al. (2015)
	mixed	clinical	Shiban, Schelhorn, et al. (2015)
		analogue	Olatunji et al. (2017)
Scopolamine	mixed	clinical	Craske et al. (2019)
Stimulus variability	mixed	clinical	Shiban, Schelhorn, et al. (2015)
		analogue	Rowe and Craske (1998b)
	no	analogue	Lang and Craske (2000) Kircanski, Mortazavi, et al. (2012)
Variability in exposure timing	mixed	analogue	Tsao and Craske (2000)
	no	analogue	Rowe and Craske (1998b) Lang and Craske (2000)
Variability in exposure difficulty	mixed	analogue	Jacoby et al. (2019)
	no	analogue	Kircanski, Mortazavi, et al. (2012)

Inhibitory learning strategy	**Positive evidence**	**Category**	**Study**
Variability in fear levels	yes	clinical	Waters et al. (2015) Kircanski and Peris (2015)
	mixed	analogue	Culver et al. (2012) Kircanski, Mortazavi, et al. (2012)
	no	analogue	Jacoby et al. (2019)
Positive valence to feared stimuli	yes	analogue	Dour et al. (2016)
Affect labeling	mixed	analogue	Kircanski, Lieberman, and Craske (2012) Niles et al. (2015)
	no	analogue	Brown et al. (2018)
Reconsolidation	yes	analogue	Björkstrand et al. (2016)
	mixed	clinical	Maples-Keller et al. (2017)
		analogue	Telch et al. (2017)
	no	clinical	Shiban, Brütting, et al. (2015)
		analogue	Lancaster (2017)

Appendix B

Participant information for Study 1

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Probandeninformation

Untersuchung von Einflussfaktoren auf das Erleben von Höhe in virtueller Realität

Sehr geehrte Probandin, sehr geehrter Proband,

vielen Dank, dass Sie sich bereit erklärt haben an dieser wissenschaftlichen Untersuchung am Lehrstuhl für Psychologie I der Universität Würzburg teilzunehmen. Mit diesem Schreiben wollen wir Sie über die Art der Untersuchung, deren Ablauf und die verwendeten Methoden aufklären. **Ziel unserer Studie ist es, das Erleben von Höhe in virtueller Realität zu untersuchen.**

Die Teilnahme an der Untersuchung ist völlig freiwillig. Das bedeutet auch, dass Sie jederzeit ohne einen Nachteil für Sie die Untersuchung abbrechen können. Alle erhobenen Daten **werden durch einen Code pseudonymisiert und streng vertraulich nach geltenden Datenschutzrichtlinien behandelt.**

Vor und nach der Untersuchung möchten wir Sie bitten, einige Fragebögen auszufüllen. Diese beziehen sich auf einige allgemeine Angaben zu Ihrer Person, auf Ihre momentane Stimmung und auf Ihr Verhalten in verschiedenen Situationen. Der zeitliche Aufwand wird sich für Sie auf **ca. eine Stunde** beschränken.

Die eigentliche Untersuchung wird in virtueller Realität stattfinden, d.h. sie werden durch eine 3D-Brille von Computern erzeugte, auf Wände projizierte Bilder sehen. In unserem 3D-Multisensoriklabor sind alle Wände und der Fußboden Projektionsflächen. Sie werden also komplett in die virtuelle Welt versetzt. Sie können sich im virtuellen Raum frei bewegen.

Die Steuerung Ihrer Bewegung in der virtuellen Welt erfolgt zum einen durch reales Gehen. Wenn Sie einen Schritt nach vorne gehen, bewegen Sie sich auch virtuell nach vorn. Zum anderen können Sie auch mit Hilfe eines Gamepads, wie bei einer Spielkonsole, steuern und umherlaufen. In seltenen Fällen kann die virtuelle Realität Übelkeit oder Schwindel auslösen, ähnlich wie eine 3D-Kinofilm. **Falls dies passiert und Sie die Untersuchung abbrechen möchten, teilen Sie uns das bitte sofort mit.**

Während der Untersuchung stehen Sie über ein Mikrofon mit dem Versuchsleiter in Kontakt.

Die Untersuchung setzt sich aus drei Teilen zusammen. Im ersten Teil lernen Sie die virtuelle Umgebung und die Navigation kennen. Hierzu werden Sie in ein Labyrinth versetzt und Ihre Aufgabe wird es sein, eine blaue Kugel zu finden. Im zweiten Teil der Untersuchung werden Sie auf einen Aussichtsturm zulaufen und diesen besteigen. Im dritten Teil der Untersuchung werden Sie verschiedene Aufgaben auf dem Aussichtsturm bewältigen.

Wenn Sie noch Fragen haben, wenden Sie sich bitte nun an den Untersuchungsleiter.

Bitte erklären Sie nun mit Ihrer Unterschrift, dass Sie die Probandeninformation sorgfältig durchgelesen und verstanden haben, dass Sie sich mit dem beschriebenen Vorgehen einverstanden erklären und dass der Versuchsleiter ihre Fragen zu Ihrer Zufriedenheit beantwortet hat.

Appendix C

Informed consent for Studies 1–6

Julius-Maximilians-
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Einverständniserklärung

Untersuchung von Einflussfaktoren auf das Erleben von Höhe in virtueller Realität

Durch meine Unterschrift bestätige ich:

Die Probandeninformation habe ich sorgfältig durchgelesen und verstanden. Mit dem beschriebenen Vorgehen bin ich einverstanden. Der Versuchsleiter hat alle meine Fragen zu meiner vollen Zufriedenheit beantwortet.

Ich nehme freiwillig an der „Untersuchung von Einflussfaktoren auf das Erleben von Höhe in virtueller Realität“ teil und bin damit einverstanden, dass die erhobenen Daten in verschlüsselter Form, d. h. in unpersönlicher Form (ohne Namens- oder Initialnennung), aufgezeichnet, in Computern gespeichert und wissenschaftlich ausgewertet werden. Ich bin auch damit einverstanden, dass die Ergebnisse der Studie in Gruppen zusammengefasst wissenschaftlich veröffentlicht werden. Ich bin darüber aufgeklärt worden, dass ich jederzeit, auch nach der Erhebung, eine Vernichtung der von mir erhobenen Daten verlangen kann, solange eine Zuordnung zu meiner Person möglich ist. Eine Vernichtung der Codierungsschlüssel findet nach Abschluss der Studie, spätestens im Februar 2015, statt.

Ich bin darüber informiert worden, dass ich jederzeit ohne Angabe von Gründen und ohne einen Nachteil aus der Untersuchung ausscheiden kann. Alle erhobenen Daten werden durch einen Code pseudonymisiert und streng vertraulich nach geltenden Datenschutzrichtlinien behandelt.

_____
Name, Vorname

_____
Anschrift: Straße, PLZ, Ort, Datum

_____
Unterschrift Proband

_____
Unterschrift Versuchsleiter

Appendix D

Participant information for Study 2

Julius-Maximilians-
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Probandeninformation
Höhenangststudie

Sehr geehrte Probandin, sehr geehrter Proband,

vielen Dank, dass Sie sich bereit erklärt haben an dieser wissenschaftlichen Untersuchung am Lehrstuhl für Psychologie I der Universität Würzburg teilzunehmen. Mit diesem Schreiben wollen wir Sie über die Art der Untersuchung, deren Ablauf und die verwendeten Methoden aufklären. **Ziel unserer Studie ist es, die Wahrnehmung von Höhe in virtueller Realität zu untersuchen.**

Vor und nach der Untersuchung möchten wir Sie bitten, einige Fragebögen auszufüllen. Diese beziehen sich auf einige allgemeine Angaben zu Ihrer Person, auf Ihre momentane Stimmung, und auf Ihr Verhalten in verschiedenen Situationen. Der zeitliche Aufwand wird sich für Sie auf **ca. eineinhalb Stunde** beschränken.

Die Teilnahme an der Untersuchung ist völlig freiwillig. Das bedeutet auch, dass Sie jederzeit ohne einen Nachteil für Sie die Untersuchung abbrechen können. Alle erhobenen Daten **werden durch einen Code anonymisiert und streng vertraulich nach geltenden Datenschutzrichtlinien behandelt.**

Der Versuch wird in virtueller Realität stattfinden. Diese wird durch das Tragen einer VR-Brille erzeugt.

Die Steuerung Ihrer Bewegung in der virtuellen Welt erfolgt durch ein Gamepad. Damit können Sie wie bei einer Spielekonsole steuern und umherlaufen. Die Steuerung Ihrer Blickbewegung erfolgt dabei durch Ihre Kopfbewegung. In seltenen Fällen kann die virtuelle Realität Übelkeit oder Schwindel auslösen, ähnlich wie eine 3D-Kinofilm. **Falls dies passiert und Sie die Untersuchung abbrechen möchten, teilen Sie uns das bitte sofort mit.**

Die Untersuchung setzt sich aus zwei Teilen zusammen. Im ersten Teil lernen Sie die virtuelle Umgebung und die Navigation kennen. Hierzu werden Sie in ein Labyrinth versetzt und Ihre Aufgabe wird es sein eine blaue Kugel zu finden. Im zweiten Teil der Untersuchung

werden Sie auf einen Aussichtsturm zulaufen, diesen besteigen und dort verschiedene Aufgaben bewältigen.

Wenn Sie noch Fragen haben, wenden Sie sich bitte nun an den Untersuchungsleiter.

Bitte erklären Sie nun mit Ihrer Unterschrift, dass Sie die Probandeninformation sorgfältig durchgelesen und verstanden haben, dass Sie sich mit dem beschriebenen Vorgehen einverstanden erklären und dass der Versuchsleiter ihre Fragen zu Ihrer Zufriedenheit beantwortet hat.

Appendix E

Verbal focus instructions in Study 2

- “Konzentrieren Sie sich auf Ihre körperlichen Empfindungen.”
- “Spüren Sie Ihr Herz rasen.”
- “Nehmen Sie mögliche Angstgefühle wahr.”
- “Spüren Sie was die Höhe in Ihnen auslöst.”
- “Schauen Sie nach unten und nehmen Sie die Höhe wahr.”
- “Konzentrieren Sie sich ausschließlich auf die Höhenwahrnehmung.”

Appendix F

Participant information for Study 3

Julius-Maximilians-
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Probandeninformation
How high can you go?

Sehr geehrte Probandin, sehr geehrter Proband,

vielen Dank, dass Sie sich bereit erklärt haben an dieser wissenschaftlichen Untersuchung am Lehrstuhl für Psychologie I der Universität Würzburg teilzunehmen. Mit diesem Schreiben wollen wir Sie über die Art der Untersuchung, deren Ablauf und die verwendeten Methoden aufklären. **Ziel unserer Studie ist es, die Wahrnehmung von Höhe in virtueller Realität zu untersuchen.**

Vor und nach der Untersuchung möchten wir Sie bitten, einige Fragebögen auszufüllen. Diese beziehen sich auf einige allgemeine Angaben zu Ihrer Person, auf Ihre momentane Stimmung, und auf Ihr Verhalten in verschiedenen Situationen. Der zeitliche Aufwand wird sich für Sie auf **ca. eine Stunde** beschränken.

Die Teilnahme an der Untersuchung ist völlig freiwillig. Das bedeutet auch, dass Sie jederzeit ohne einen Nachteil für Sie die Untersuchung abbrechen können. Alle erhobenen Daten **werden durch einen Code anonymisiert und streng vertraulich nach geltenden Datenschutzrichtlinien behandelt.**

Der Versuch wird in virtueller Realität stattfinden. Diese wird durch das Tragen einer VR-Brille erzeugt. Während des Versuchs werden Ihre Herzrate und Hautleitfähigkeit gemessen.

Die Steuerung Ihrer Blickbewegung erfolgt durch Ihre Kopfbewegung. Sie können sich frei umsehen, indem Sie einfach wie gewohnt Ihren Kopf bewegen. Wichtig ist, dass Sie nur Ihren Kopf und Oberkörper bewegen, aber nicht ihre Beinstellung verändern. In seltenen Fällen kann die virtuelle Realität Übelkeit oder Schwindel auslösen, ähnlich wie eine 3D-Kinofilm. **Falls dies passiert und Sie die Untersuchung abbrechen möchten, teilen Sie uns das bitte sofort mit.**

Die Untersuchung setzt sich aus zwei Teilen zusammen. Im ersten Teil lernen Sie die virtuelle Realität kennen. Hierzu werden Sie in einen Raum versetzt und müssen blaue

Kugeln finden. Im zweiten Teil werden Sie in einer virtuellen Landschaft in verschiedene Höhen versetzt. Konzentrieren Sie sich hierbei bitte auf Ihre Höhenwahrnehmung.

Wenn Sie noch Fragen haben, wenden Sie sich bitte nun an den Untersuchungsleiter.

Bitte erklären Sie nun mit Ihrer Unterschrift, dass Sie die Probandeninformation sorgfältig durchgelesen und verstanden haben, dass Sie sich mit dem beschriebenen Vorgehen einverstanden erklären und dass der Versuchsleiter ihre Fragen zu Ihrer Zufriedenheit beantwortet hat.

Appendix G

Linear mixed models analysis syntax for Study 3

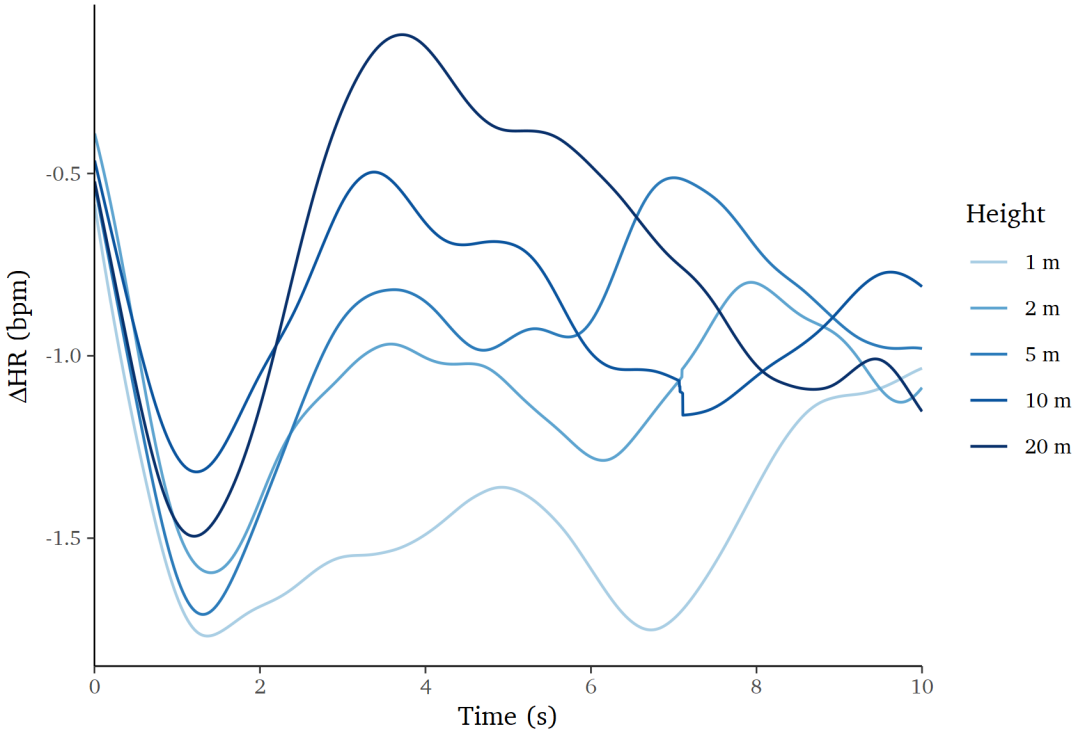
Linear mixed models of fear ratings

Model	lme4 syntax
(1) $Y_{si} = \beta_0 + S_{0s} + e_{si}$	`anx ~ 0 + (1 | id)`
(2) $Y_{si} = \beta_0 + S_{0s} + \beta_1 H_i + e_{si}$	`anx ~ height + (1 | id)`
(3) $Y_{si} = \beta_0 + S_{0s} + (\beta_1 + S_{1s})H_i + e_{si}$	`anx ~ height + (1 + height | id)`
(4) $Y_{si} = \beta_0 + S_{0s} + (\beta_1 + S_{1s})H_i + \beta_2 AQ_s + e_{si}$	`anx ~ height + aq_anx + (1 + height | id)`
(5) $Y_{si} = \beta_0 + S_{0s} + (\beta_1 + S_{1s})H_i + \beta_2 AQ_s + \beta_3(H_i \times AQ_s) + e_{si}$	`anx ~ height * aq_anx + (1 + height | id)`

Note: S_{0s} = random intercept, S_{1s} = random slope, H_i = height level, AQ_s = Acrophobia Questionnaire Anxiety Subscale score. s = subject index, i = height level index.

Appendix H

Aggregated heart rate data in Study 3



Appendix I

Participant information for Study 4 (Experiment 1)

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Probandeninformation
Höhenstudie in VR

Sehr geehrte Probandin, sehr geehrter Proband,

vielen Dank, dass Sie sich bereit erklärt haben an dieser wissenschaftlichen Untersuchung am Lehrstuhl für Psychologie I der Universität Würzburg teilzunehmen. Mit diesem Schreiben wollen wir Sie über die Art der Untersuchung, deren Ablauf und die verwendeten Methoden aufklären. **Ziel unserer Studie ist es, die Wahrnehmung von Höhe in virtueller Realität zu untersuchen.**

Vor und nach der Untersuchung möchten wir Sie bitten, einige Fragebögen auszufüllen. Diese beziehen sich auf einige allgemeine Angaben zu Ihrer Person, auf Ihre momentane Stimmung, und auf Ihr Verhalten in verschiedenen Situationen. Der zeitliche Aufwand wird sich für Sie auf **ca. eineinhalb Stunde** beschränken.

Die Teilnahme an der Untersuchung ist völlig freiwillig. Das bedeutet auch, dass Sie jederzeit ohne einen Nachteil für Sie die Untersuchung abbrechen können. Alle erhobenen Daten **werden durch einen Code anonymisiert und streng vertraulich nach geltenden Datenschutzrichtlinien behandelt.**

Der Versuch wird in virtueller Realität stattfinden. Diese wird durch das Tragen einer VR-Brille erzeugt.

Die Steuerung Ihrer Bewegung in der virtuellen Welt erfolgt durch ein Gamepad. Damit können Sie wie bei einer Spielekonsole steuern und umherlaufen. Die Steuerung Ihrer Blickbewegung erfolgt dabei durch Ihre Kopfbewegung. Sie können sich frei umsehen, indem Sie einfach wie gewohnt Ihren Kopf bewegen. Wichtig ist, dass Sie nur Ihren Kopf und Oberkörper bewegen, aber nicht ihre Beinstellung verändern. In seltenen Fällen kann die virtuelle Realität Übelkeit oder Schwindel auslösen, ähnlich wie eine 3D-Kinofilm. **Falls dies passiert und Sie die Untersuchung abbrechen möchten, teilen Sie uns das bitte sofort mit.**

Die Untersuchung setzt sich aus drei Teilen zusammen. Im ersten Teil lernen Sie die virtuelle Umgebung und die Navigation kennen. Hierzu werden Sie in ein Labyrinth versetzt und Ihre Aufgabe wird es sein, eine blaue Kugel zu finden. Im zweiten Teil der Untersuchung werden Sie durch eine Landschaft laufen und dort verschiedene Situationen erleben. Achten Sie hier bitte besonders auf die Wahrnehmung der Höhe. Während des Versuchs werden Sie mehrmals eine Instruktion erhalten, Ihr aktuelles Befinden einzuschätzen. Bitte teilen Sie ihre Einschätzung jeweils mündlich dem Versuchsleiter mit. Im dritten Teil der Untersuchung werden Sie noch einmal eine Situation aus dem vorherigen Teil aufsuchen.

Wenn Sie noch Fragen haben, wenden Sie sich bitte nun an den Untersuchungsleiter.

Bitte erklären Sie nun mit Ihrer Unterschrift, dass Sie die Probandeninformation sorgfältig durchgelesen und verstanden haben, dass Sie sich mit dem beschriebenen Vorgehen einverstanden erklären und dass der Versuchsleiter ihre Fragen zu Ihrer Zufriedenheit beantwortet hat.

Appendix J

Participant information for Study 4 (Experiment 2)

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Probandeninformation

Höhenstudie in VR

Sehr geehrte Probandin, sehr geehrter Proband,

vielen Dank, dass Sie sich bereit erklärt haben an dieser wissenschaftlichen Untersuchung am Lehrstuhl für Psychologie I der Universität Würzburg teilzunehmen. Mit diesem Schreiben wollen wir Sie über die Art der Untersuchung, deren Ablauf und die verwendeten Methoden aufklären. **Ziel unserer Studie ist es, die Wahrnehmung von Höhe in virtueller Realität zu untersuchen.**

Vor, zwischen den beiden Teilen der Untersuchung und danach möchten wir Sie bitten, einige Fragebögen auszufüllen. Diese beziehen sich auf einige allgemeine Angaben zu Ihrer Person, auf Ihre momentane Stimmung, und auf Ihr Verhalten in verschiedenen Situationen. Der zeitliche Aufwand wird sich für Sie auf **eine Stunde** beschränken.

Die Teilnahme an der Untersuchung ist völlig freiwillig. Das bedeutet auch, dass Sie jederzeit ohne einen Nachteil für Sie die Untersuchung abbrechen können. Alle erhobenen Daten **werden durch einen Code anonymisiert und streng vertraulich nach geltenden Datenschutzrichtlinien behandelt.**

Der Versuch wird in virtueller Realität stattfinden. Diese wird durch das Tragen einer VR-Brille erzeugt. Es werden für die Dauer des Versuchs EKG-Elektroden (am Schlüsselbein und unter den Rippen), sowie Hautleitfähigkeitselektroden (an der Hand) angebracht.

Die Steuerung Ihrer Blickbewegung in der virtuellen Umgebung erfolgt durch Ihre Kopfbewegung. Sie können sich frei umsehen, indem Sie einfach wie gewohnt Ihren Kopf bewegen. Wichtig ist, dass Sie nur Ihren Kopf und Oberkörper bewegen, aber nicht Ihre Fußstellung verändern.
In seltenen Fällen kann die virtuelle Realität Übelkeit oder Schwindel auslösen, ähnlich wie ein 3D-Kinofilm. **Falls dies passieren sollte und Sie die Untersuchung abbrechen möchten, teilen Sie uns das bitte sofort mit.**

Die Untersuchung setzt sich aus zwei Teilen zusammen. In beiden Teilen werden Sie sich an verschiedenen Orten in einer Landschaft befinden. Ihre Aufgabe dabei ist einfach, sich in der virtuellen Umgebung umzusehen. Achten Sie in Höhensituationen bitte besonders auf die Wahrnehmung der Höhe. Während des Versuchs werden Sie mehrmals eine Instruktion erhalten, Ihr aktuelles Befinden einzuschätzen. Bitte teilen Sie ihre Einschätzung jeweils mündlich dem Versuchsleiter mit.

Wenn Sie noch Fragen haben, wenden Sie sich bitte nun an den Untersuchungsleiter.

Bitte erklären Sie nun mit Ihrer Unterschrift, dass Sie die Probandeninformation sorgfältig durchgelesen und verstanden haben, dass Sie sich mit dem beschriebenen Vorgehen einverstanden erklären und dass der Versuchsleiter ihre Fragen zu Ihrer Zufriedenheit beantwortet hat.

Appendix K

Telephone screening for Study 5

Telefonscreening

VP-Code: Datum:

1. Alter:

☐☐ Jahre

Teilnahmevoraussetzung: Alter zwischen 18 und 65 Jahren

2. Geschlecht

☐ weiblich
☐ männlich

3. Liegt bei Ihnen eine Herzkreislauferkrankung vor?

☐ ja
☐ nein

Teilnahmevoraussetzung: nein

4. Leiden Sie unter einer sonstigen körperlichen Erkrankung?

☐ ja _____
welche?
☐ nein

Teilnahmevoraussetzung: keine Epilepsie

5. Konsummieren Sie illegale Drogen?

☐ ja
☐ nein

Teilnahmevoraussetzung: nein

6. Sind Sie schwanger?

☐ ja
☐ nein

Teilnahmevoraussetzung: nein

7. Auf einer Skala von 0-10, wie stark haben Sie Angst vor Höhensituationen?

keine Angst	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	extreme Angst
	0	1	2	3	4	5	6	7	8	9	10	

Teilnahmevoraussetzung: Rating zwischen 5 und 10

Telefonscreening

VP-Code: Datum:

8. Auf einer Skala von 0-10, wie sehr vermeiden Sie Höhensituationen?

keine Vermeidung	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	extreme Vermeidung
	0	1	2	3	4	5	6	7	8	9	10	

Teilnahmevoraussetzung: Rating zwischen 5 und 10

9. Auf einer Skala von 0-10, wie stark wird Ihnen bei 3D-Filmen schlecht?

keine Übelkeit	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	extreme Übelkeit
	0	1	2	3	4	5	6	7	8	9	10	

Teilnahmevoraussetzung: Rating zwischen 0 und 3

Appendix L

Participant information for Study 5

Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

Lehrstuhl für Psychologie I – Prof. Dr. Paul Pauli
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Marcusstraße 9-11
97070 Würzburg

Dipl.-Psych. Daniel Gromer
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Probandeninformation
Höhenangststudie

Sehr geehrte Probandin, sehr geehrter Proband,
vielen Dank, dass Sie sich bereit erklärt haben an dieser wissenschaftlichen Untersuchung am Lehrstuhl für Psychologie I der Universität Würzburg teilzunehmen. Mit diesem Schreiben wollen wir Sie über die Art der Untersuchung, deren Ablauf und die verwendeten Methoden aufklären.

1 Was sind Ziele der Untersuchung?

Ziel unserer Studie ist es, zugrunde liegende Wirkfaktoren eines Therapieverfahrens zur Behandlung von Höhenangst in virtueller Realität zu untersuchen.

2 Ablauf der Studie

2.1 Eingangsuntersuchung

Voraussetzung für die Teilnahme an der Studie ist eine umfassende diagnostische Abklärung, bei der geprüft wird, ob die zur Anwendung kommenden Behandlungsmaßnahmen für Sie angezeigt sind.

Diese Eingangsuntersuchung umfasst:

- ein ausführliches klinisches Interview zu Ihrem Krankheitsbild und der Krankheitsentwicklung
- Fragebögen
- einen Verhaltenstest, um die Schwere Ihrer Erkrankung festzustellen

2.2 Therapie

Bei dem eingesetzten Therapieverfahren handelt es sich um eine *Expositionstherapie*, ein Verfahren innerhalb der Kognitiven Verhaltenstherapie, welches bereits vielfach untersucht und in seiner Wirksamkeit bestätigt ist. Zentrales Element der Expositionstherapie ist das Aufsuchen der gefürchteten Situationen.
Die Therapie findet an zwei Sitzungen zu je ca. 1,5 Stunden im 3D-Multisensoriklabor der Universität Würzburg statt. Für die Behandlung werden Sie in eine virtuelle Welt versetzt, d. h. Sie werden durch eine 3D-Brille von Computern erzeugte, auf Wände projizierte Bilder sehen. In unserem 3D-Multisensoriklabor

sind alle Wände und der Fußboden Projektionsflächen. Sie werden also komplett in die virtuelle Welt versetzt. Sie können sich im virtuellen Raum frei bewegen.
Die Steuerung Ihrer Bewegung in der virtuellen Welt erfolgt zum einen durch reales gehen. Wenn Sie einen Schritt nach vorne gehen, bewegen Sie sich auch virtuell nach vorn. Zum anderen können Sie mit auch mit Hilfe eines Gamepads, wie bei einer Spielkonsole, steuern und umherlaufen. In seltenen Fällen kann die virtuelle Realität Übelkeit oder Schwindel auslösen, ähnlich wie ein 3D-Kinofilm. Falls dies passiert und Sie die Untersuchung abbrechen möchten, teilen Sie uns das bitte sofort mit. Während der Untersuchung stehen Sie über ein Mikrofon mit dem Versuchsleiter in Kontakt.
Zusätzlich werden während der Untersuchung physiologische Parameter aufgezeichnet. Hierzu werden Ihnen drei Elektroden am Oberkörper, zwei Elektroden an der rechten Hand, sowie ein Atemgurt angebracht.

2.3 Abschlussuntersuchung

Im Anschluss an die Therapie bitten wir Sie nochmals Fragebögen auszufüllen und einen Verhaltenstest durchzuführen um den Therapieerfolg und die Wirkfaktoren zu erfassen.

3 Was nutzt Ihnen die Studienteilnahme? Ist die Teilnahme freiwillig?

Die Studie bietet Ihnen die Möglichkeit, eine relativ kurze und wissenschaftlich gut fundierte Behandlung Ihrer Symptome zu erhalten. Mit Ihrer Teilnahme tragen Sie dazu bei, die Behandlung von Personen mit Phobien zukünftig weiter zu verbessern.
Die Studienteilnahme ist freiwillig. Es entstehen Ihnen keinerlei Nachteile in der Zukunft, wenn Sie sich gegen eine Studienteilnahme entscheiden. Darüber hinaus können Sie zu jedem Zeitpunkt, also auch während der Therapie, Ihr Einverständnis zur Studienteilnahme und den wissenschaftlichen Auswertungen widerrufen, ohne dass sich daraus Nachteile für Sie ergeben. Eine Angabe von Gründen ist dabei nicht notwendig.

4 Gibt es irgendwelche Risiken?

Die geschilderten Untersuchungsmaßnahmen und die Therapie sind mit keinerlei Risiken oder Belastungen verbunden, die über die einer normalen Psychotherapie hinaus gehen.

Appendix M

Treatment rationale for Study 5

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Informationen zur Expositionstherapie

Was ist Angst?

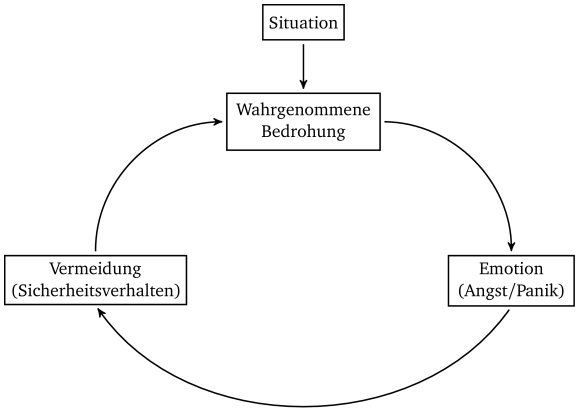
Angst ist eine unangenehme Emotion, die bei der Wahrnehmung einer Bedrohung ausgelöst wird. Angst wird auch als Alarmreaktion unseres Körpers beschrieben, welche ausgelöst wird, um uns vor Gefahr zu schützen. Dieser emotionale Zustand hat sowohl Auswirkungen auf den Körper als auch auf die Gedanken. Wenn man in einem Angstzustand ist, treten verschiedene körperliche Symptome auf, wie z. B. Muskelanspannung, Schwitzen, feuchte Hände, schneller Herzschlag, usw. Auf einer psychologischen Ebene ist Angst charakterisiert durch Anspannung, Beunruhigung und Befürchtungen. Angst ist eine normale Reaktion, sie erlaubt unserem Körper bereit zu sein auf eine potentielle Gefahr schnell zu reagieren (z. B. rennen um einem anfahrenden Auto auszuweichen).

Angst kann auf drei Ebenen beschrieben werden:

Gedanken: Wie wird die Situation interpretiert? (z. B. gefährlich, bedrohlich)

Emotionen: Emotionen sind die Angst- oder Panikreaktion selbst (z. B. schneller Herzschlag, Schwindel, weiche Knie)

Verhalten: Beispielsweise die Flucht aus der Situation (Vermeidung, auch Sicherheitsverhalten genannt). Wenn die Situation vermieden wird, ist es nicht möglich zu lernen, dass die Situation in Wirklichkeit nicht gefährlich ist.



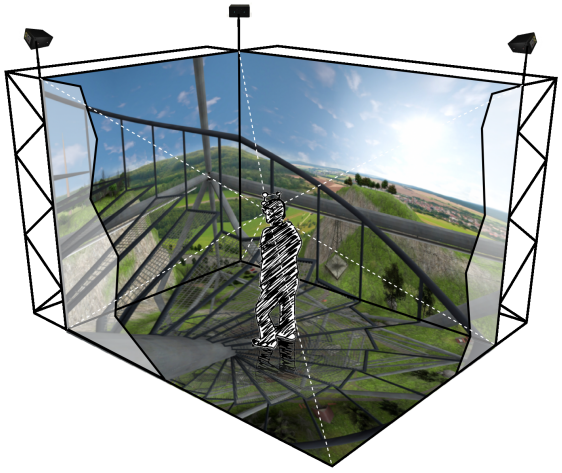
Teufelskreis der Angst

Ursachen der Angst

Es gibt verschiedene Ursachen die zur Entwicklung einer spezifischen Phobie, wie der Höhenangst, beitragen können. Bei einem Sturz von einer Leiter kann eine Person Angst vor Höhen entwickeln und diese von nun an meiden. In diesem Fall wird die Angst vor der Situation durch ein spezifisches Ereignis gelernt. Angst kann aber auch dann entstehen, wenn man beobachtet wie eine andere Person mit Angst auf eine Höhensituation reagiert.
Zudem sind Menschen evolutionär darauf vorbereitet vor gewissen Objekten und Situationen eher Angst zu haben als vor anderen. So fürchten sich beispielsweise deutlich mehr Personen vor Spinnen und Schlangen als vor Fahrzeugen, obwohl die Wahrscheinlichkeit von ersteren verletzt zu werden in der heutigen Zeit deutlich geringer ist als z. B. in einen Verkehrsunfall verwickelt zu werden. Höhenangst ist deshalb möglicherweise eine Angst, die man innehat und erst durch Erfahrungen verlernt werden muss. Personen mit Höhenangst haben evtl. nicht genügend korrektive Erfahrungen gesammelt, in welchen sie lernen konnten, das Höhensituationen nicht per se gefährlich sind.

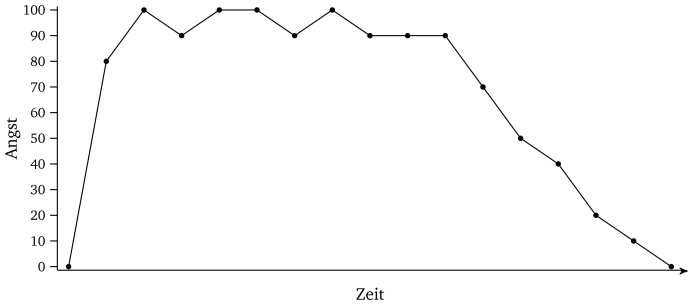
Therapie

Die empfohlene Behandlung für spezifische Phobien wie die Höhenangst ist die *Expositionstherapie*, ein Verfahren innerhalb der kognitiven Verhaltenstherapie. Die Expositionstherapie wurde bereits vielfach untersucht und ist in ihrer Wirksamkeit bestätigt. Sie ist ein Verfahren in dem sich eine Person angeleitet der Situation aussetzt, die sie fürchtet. Während der Exposition wird das automatische Vermeidungsverhalten verhindert und ermöglicht damit in der Situation korrektive Erfahrungen zu sammeln.



CAVE (Cave Automatic Virtual Environment)

Über die Zeit hinweg wird die Angst bei der Exposition mit der Situation abnehmen. Die Angst zeigt in der Regel den unten abgebildeten Verlauf. Durch die Abnahme der Angst in der Situation wird gelernt, dass die Situation nicht so gefährlich ist, wie man es zu Beginn eingeschätzt hat. Bei einem erneuten Aufsuchen der Situation wird die Angst in der Regel nicht mehr so stark ansteigen, wie noch beim ersten Mal.



Angstverlauf bei einer Exposition ohne Vermeidung

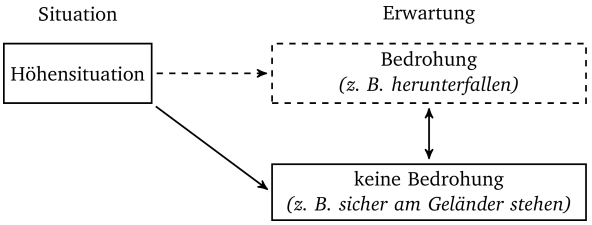
Was wird bei der Expositionstherapie gelernt?

Während der Expositionstherapie werden folgende Überzeugungen widerlegt:

- Überschätzung der Wahrscheinlichkeit, dass etwas Schlimmes eintritt (z. B. Sturz, Ohnmacht)
- Überschätzung der Verletzungen eines Sturzes
- Geringe Selbstwirksamkeit die Situation zu bewältigen
- Fehlerhafte Überzeugungen über das Erleben von Angst und Unsicherheit
- Überzeugungen, dass Sicherheitsverhalten nötig ist, um gefürchtete Konsequenzen zu verhindern

Während der Expositionstherapie werden Ängste nicht *verlernt*, sondern es findet ein neues Lernen statt. Es wird gelernt, dass die vorher als angstauslösend wahrgenommene Situation in Wirklichkeit sicher ist, bzw. das Risiko akzeptabel ist.

Während der Expositionstherapie werden die Erwartungen an die gefürchtete Situation getestet. Ziel der Therapie ist es zu lernen, dass die erwarteten Befürchtungen nicht eintreten.
Wenn die Befürchtung beispielsweise das Herunterfallen von einem Balkon ist, wenn man sich in der Nähe des Geländers aufhält, bietet die Expositionstherapie die Möglichkeit die Erfahrung zu machen, dass diese Befürchtung nicht eintritt. Durch die Therapie entstehen neue Erwartungen an die Situation, z. B. dass das Stehen am Geländer eines Balkons sicher ist.



Erwartungen an eine Höhensituation nach der Expositionstherapie

Was wird bei der Expositionstherapie gelernt?

Während der Expositionstherapie werden folgende Überzeugungen widerlegt:

- Überschätzung der Wahrscheinlichkeit, dass etwas Schlimmes eintritt (z. B. Sturz, Ohnmacht)
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Curriculum Vitae

Publication List

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Affidavit

I hereby confirm that my thesis entitled 'Mechanisms Underlying Virtual Reality Exposure Therapy for Specific Phobias' / 'Wirkmechanismen der Expositionstherapie in virtueller Realität bei spezifischen Phobien' is the result of my own work. I did not receive any help or support from commercial consultants. All sources and / or materials applied are listed and specified in the thesis.
Furthermore, I confirm that this thesis has not yet been submitted as part of another examination process neither in identical nor in similar form.

_____ _____

Place, Date Signature