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Subjective and Physiologic Reactions of Flight Phobics during VR Exposure and Treatment Outcome: What Adds Motion Simulation?

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Abstract: Background/problem: *The efficacy of VR exposure for the treatment of fear of flying was confirmed in more than 8 controlled clinical trials. Important goals of future studies are the evaluation of underlying treatment processes and the identification of crucial treatment components, both in order to optimize the treatment. The present study was designed to examine the effect of motion simulation on subjective and physiological fear reactions as part of a VR exposure that also included visual and acoustic stimuli. Our hypotheses were that motion simulation results in stronger initial subjective and physiological fear reactions, and as a consequence is associated with stronger habituations of fear responses within VR flights and between VR flights. Furthermore, we assumed that motion simulation enhances treatment efficacy as measured in the fear of flying scale (FFS).*

Methods and tools: *Twenty fife participants with flight phobia received a virtual reality exposure treatment including written information about fear of flying and how to cope with it (information booklet), one hour of cognitive therapy, and VR exposure (four flights). However, VR exposure included for twelve participants motion simulation while thirteen participants received VR exposure without motion simulation.*

Virtual flights consisted out of a different flying phases (start, flying, turbulences, landing) and were simulated using a head mounted display (HMD), a head tracking device and a motion platform to simulate accelerations and provide proprioceptive stimuli.

Results: *Overall, subjective fear ratings as well as skin conductance responses confirmed substantial fear of both groups during VR exposure. However, these responses were substantially stronger and habituated slower in the VR motion group compared to the VR no-motion group. Nevertheless and in contrast to network theories – which suggest that stronger activation of fear networks should result in an enhanced treatment outcome - we found no differences between groups in treatment outcome. There was even no trend of a superior treatment outcome for the VR-motion compared to the VR-no-motion group.*

Conclusions and novelty: *The present study helps to better understand VR exposure treatment and gives hints for future research to evaluate the treatment process. Based on our results it may be speculated that treatment outcome is more related to the amount of habituation during exposure than to the strength of the initial fear response.*

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INTRODUCTION

Many studies confirm the efficacy of Virtual Reality (VR) exposure for the treatment of different psychiatric disorders, especially for specific phobia.[1,2,3] The efficacy of VR exposure for the treatment of fear of flying was confirmed in more than 8 controlled clinical trials.[4-7]

Important goals of future studies are the evaluation of underlying treatment processes and the identification of crucial treatment components, both in order to optimize the treatment. VR exposure is an especially valuable tool to achieve this since it allows on the one hand to control exposure settings and on the other hand to create a wide range of experimental manipulations.

For exposure therapy, a widely accepted theoretical assumption is that the fear network has to be activated before it can be changed. Foa and Kozak[9] further assumed that this activation has to be reflected in initial subjective as well as physiological fear responses. Following this initial activation, an effective exposure treatment should lead to a habituation of activation both within and between repeated exposures.[9] In line with this assumption, an association between strong initial heart rate reactions during exposure and superior treatment outcome was repeatedly found.[10]

Network theories also predict that effective VR treatments must be able to induce substantial fear reactions. In flight phobics, such substantial fear reactions have been observed in VRs incorporating visual, acoustic and motion simulation[4] or visual, acoustic and vibration simulation.[10] Variables that were discussed to moderate the amount of fear elicited by VR exposure are the presence in VR[11,12] or the feedback of physiological activation during VR.[7] An additional important variable modulating subjective and physiological fear reactions within VR exposure might be the applied simulation modalities.

The present study was designed to examine the effect of motion simulation on subjective and physiological fear reactions as part of a VR exposure that also included visual and acoustic stimuli. We considered this important since motion simulation, on the one hand, might be important to trigger fear during virtual flights but, on the other hand, is rather expensive to add because it needs additional hardware (motion chair). Our hypotheses were that motion simulation results in stronger initial subjective and physiological fear reactions, and as a consequence is associated with stronger habituations of fear responses within VR flights and between VR flights. Based on earlier results[4] we specifically expected heart rate to habituate mostly between flights and skin conductance levels to habituate especially strong within flights. Furthermore, we assumed that motion simulation enhances treatment efficacy as measured in the fear of flying scale (FFS).

METHOD

Participants

Participants were recruited through newspaper articles. Respondents completed a mailed questionnaire package that included a socio-demographic and a medical history questionnaire, and several psychometric instruments which assessed fear of flying, trait anxiety, and psychopathology. For a detailed description of the selection procedure, the inclusion and exclusion criteria, the complete treatment program and characteristics of the participants see Mühlberger et al.[13] Written informed consent was obtained from all study participants.
The presented analyses are based on 25 participants with fear of flying with complete process data: All participants received all treatment components including written information about fear of flying and how to cope with it (information booklet), one hour of cognitive therapy (CT), and VR exposure (four flights). However, VR exposure included for twelve participants motion simulation (VR-motion group) while thirteen participants (VR-no-motion group) received VR exposure *without* motion simulation. For the presented evaluation of treatment outcome missing follow-up data of two participants of the no-motion group was completed by the group mean of all participants who did not fly during follow-up period.

Apparatus

Virtual Reality (VR): The VR environment included visual, acoustic, and partly motion simulations of a commercial flight. VR flights lasted 18 min and included all important flight phases (i.e., take-off, ascending, reaching flight altitude, two phases of air turbulence, descending, and landing).

The visual cues were presented by a head-mounted display (HMD; *V6*, Virtual Research Corporation). The head position was monitored with an electro-magnetic tracking device (*Fast Track*, Polhemus Corporation) in order to adapt the field of view to head movements. A Reality Engine II Computer (Silicon Graphics Corporation) with two processing units provided real-time texture mapping and implemented the real-time rendering of the environment with respect to the head position. A high amount of details and a frame-rate of at least 12 frames per second were achieved by renouncing stereoscopic rendering.

The three-dimensional environment consisted of the inside of an airplane (Boeing 737) and the view through an airplane window (somewhat enlarged compared to reality). The participant's position was a passenger compartment at the left window row in the middle of the plane. The seat at the right of the participant was taken by a virtual passenger. The participant was able to look out of the plane through the window to the left. The outside environment changed dependent on the flight phase (e. g., parking position, runway, airport-tower, several airport-buildings at take-off or landing, fields or clouds while flying).

Sounds were presented by an Indigo Computer (Silicon Graphics Corporation) via earphone integrated in the HMD. The audio cues were original airplane sounds and flight announcements, both recorded and stored as digital audio files.

A motion base with 6 degrees of freedom (Symtech Corporation) was used to manipulate the body position and to simulate motions. Simulations of speed accelerations, speed deceleration (during take-off or landing), and air turbulence (during the flight) were implemented. The motion data mirrored a flight that was performed by a real pilot in a professional flight simulator. A special program ("Wash-out") developed by the Fraunhofer-Institute for Graphical Data Processing (IGD) in Darmstadt was used to transform the data for motion base use and to ensure an optimal and realistic perception of speed acceleration or speed deceleration.

Relevant psychometric measures (for a complete list see Mühlberger et al., 2003).

Subjective Units of Discomfort (SUDs)[14] ranging from 0 (no discomfort) to 100 (panic-like discomfort) were used to assess fear responses. Participants were trained to use this scale, and ratings were requested at eight assessment points per flight (before the start, directly after the start, during quite flight, during two phases of turbulences, once again during quite flight, after landing and reaching the final parking position) via earphone instruction.

The Fear of Flying Scale (FFS[15]) consists of 21 items describing situations representative for air travel (e.g., "The plane accelerates down the runway and lifts off the ground"). The fear elicited by the described situations has to be rated on 5-point scales (not a all (0) to very much (4)). A mean score was calculated. Cronbach's a and 3 month retest reliability of the original FFS were .94 and .86, respectively.[15] We confirmed these indices for our German translation in two studies:[13] Cronbach's a were .90 (N=120) and .98 (N=257); 3 month retest reliabilities were .83 (N= 37) and .87 (N=43).

PROCEDURE

For the evaluation of treatment outcome participants completed the FFS before and after the VR exposure treatment and 6 month later. For a detailed description of the complete treatment and the details of the outcome assessment see Mühlberger et al.[13]

Participants of both VR groups were accompanied to the VR simulator after the same cognitive preparation. The VR devices were then explained. Participants sat down on a cushioned seat mounted on a motion platform and the HMD was put on. Before starting the VR flights, participants were instructed not to suppress their fear during the VR flights, but to experience the fear and its reduction with ongoing exposure. Participants completed four successive VR flights of 18 min duration each; the VR-motion group with motion (including vibration) simulation, the VR-non-motion group without motion (and without vibration) simulation. A break of 5 to 10 minutes separated the second from the third flight.

Physiological data acquisition and data reduction

Electrocardiogram (ECG) and skin conductance level (SCL) were registered continuously with a sampling rate of 384 Hz with a Vitaport I system (Becker Inc.). Skin conductance was recorded from two electrodes placed on the medial phalanges of the second and third finger of the non-dominant hand. The ECG was converted online to heart rate (HR) by an integrated R-wave detection algorithm. Phases of 60 s duration corresponding to SUD ratings were extracted and means for each phase and each flight were calculated. Then, differences to the pre-flights baseline measures were computed. Physiological signals were pre-analyzed offline with the BrainVision Analyser Software of BrainProducts Inc.

Statistical data analysis

SUD, HR and skin conductance were analyzed with mixed ANOVAs with the between factor Motion Group (with or without) and the within factors Flight (one to four) and Phase (8 assessment points). Treatment outcome was analyzed with mixed ANOVA with the between factor Motion Group (with or without) and the within factor Time (pre, post, follow-up). If appropriate, Greenhouse-Geisser corrections of degrees of freedom (df) were applied. Significant effects were followed up with specific ANOVAs or planed contrasts.

RESULTS

Treatment process

Fear reports (SUDs): Figure 1 depicts the mean fear reports (SUDs) assessed during the four VR exposure flights separated for the groups with (VR motion) and without motion simulation (VR no-motion). Strongest fear reports were observed during the turbulence phases of the first VR flight with a mean SUD above 40 in the VR motion group. A decrease of fear within VR exposure flights and across repeated VR flights is clearly visible.

The overall analysis revealed significant main effects of Flight ($F_{(3, 69)}$=24.7, p<.001, η^2=0.52), Phase ($F_{(7,161)}$=12.0, p<.001, η^2=0.34), and Motion Group ($F_{(1, 23)}$=5.5, p=.028, η^2=0.19), and a significant Motion Group by Phase ($F_{(7, 161)}$= 4.6, p=.005, η^2=0.17) interaction. Contrasts revealed a significant habituation from flight to flight ($F_{(1,23)}$= 10.1; 32.5; 32.1, p=.004; <.001; <.001, η^2=0.31; 0.59; 0.58). The main effect of Phase can be traced back to enhanced fear during the start ($F_{(1,32)}$ =17.3, p<.001, η^2=0.43) and the first flight phase ($F_{(1,23)}$=17.3, p<.001, η^2= 0.17), and reduced fear after landing ($F_{(1,23)}$=17.4, p<.001, η^2=0.43), compared to the fear before the start of the flight. The motion group displayed overall enhanced fear responses, which were – as the interaction Motion Group by Phase indicated – stronger as the non-motion group responses' during the first flight phase ($F_{(1,23)}$ =5.9, p=.024, η^2=0.20) and both turbulence phases ($F_{(1,23)}$=4.1; p=.055, η^2=0.15; and $F_{(1,23)}$=6.5, p=.018, η^2=0.22).

Heart rate: The analysis returned significant main effects of Flight ($F_{(3, 63)}$=9.2, p=.001, η^2=0.30) and Phase ($F_{(3, 63)}$=3.3, p=.023, η^2=0.13), and significant Phase by Motion Group ($F_{(7, 147)}$=4.3, p=.006, η^2=0.17) and Flight by Phase ($F_{(21, 441)}$=6.2, p<.001, η^2=0.23) interactions. Further analyses within groups returned no significant effects for the VR no-motion group. For the VR Motion group, the main effects Flight ($F_{(3, 30)}$=8.9, p=.005, η^2=0.47) and Phase ($F_{(7, 70)}$=5.4, p=.006, η^2=0.35) and the interaction Flight by Phase ($F_{(21, 210)}$=5.1, p<.001, η^2=0.34) were significant. These effects are based on the strong initial heart rate reaction during the start phase of flight one, a smaller one during flight two (see Figure 2), and no further reactions during flight tree and four (not depicted).

Skin conductance level: The analysis yielded a significant main effect of Phase ($F_{(7,154)}$=4.8, p=.007, η^2=0.18) and significant Flight by Motion Group ($F_{(3,66)}$=5.9, p=.005, η^2=0.21) and Phase by Flight by Motion Group ($F_{(21,462)}$=4.5, p=.005, η^2=0.17) interactions. A separate ANOVA for the VR motion group revealed a significant main effect of Flight ($F_{(3,30)}$=5.5, p=.017, η^2=0.36). Contrasts returned significant habituations between the second and the third flight ($F_{(1,10)}$=5.9, p=.035, η^2=0.37) and between the third and the fourth flight ($F_{(1,10)}$

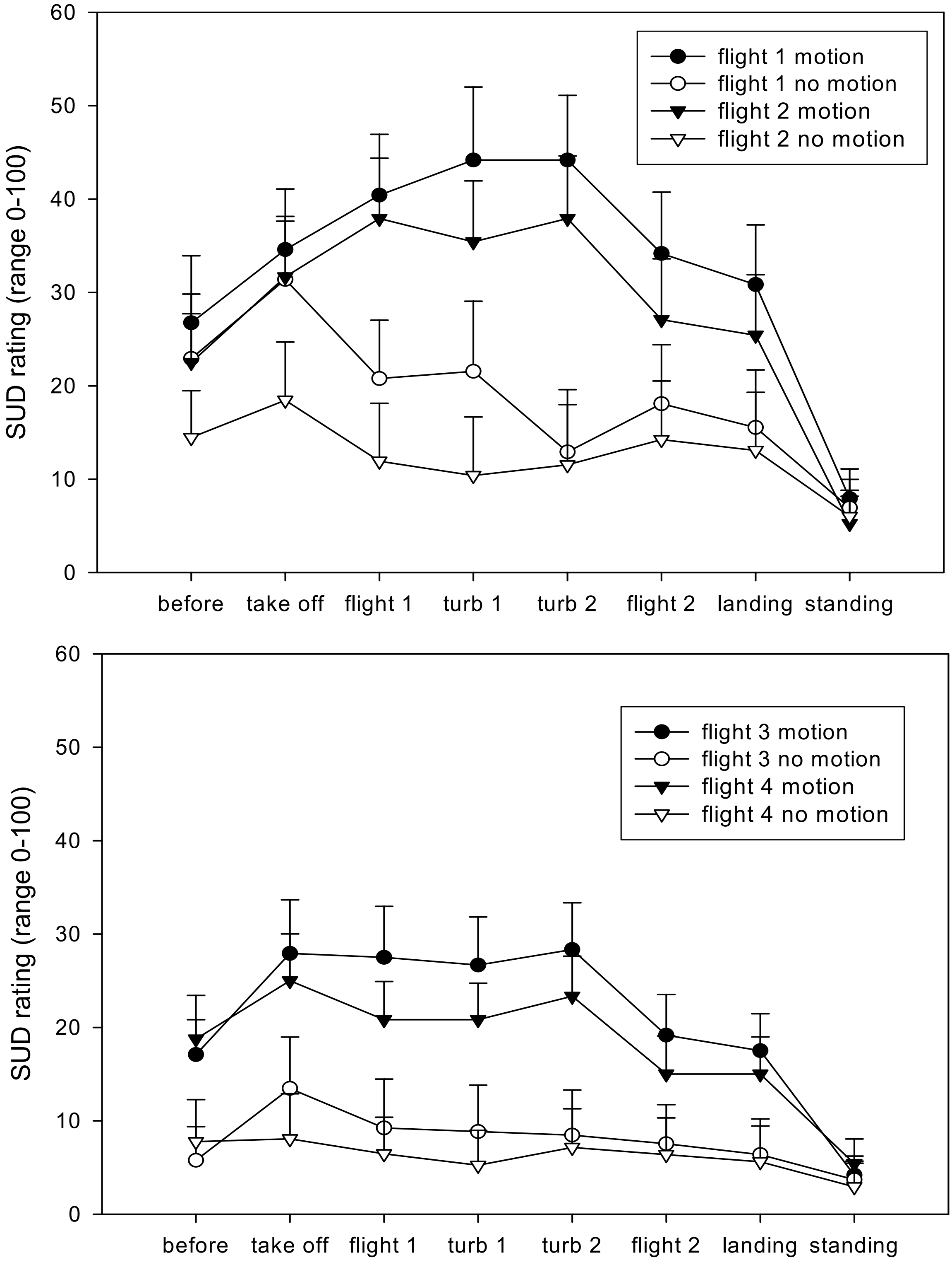

Figure 1. SUD ratings for the first two (top) and the last two (bottom) VR flights of the Motion (N=12) and the No-motion (N=13) groups. Flights have eight phases including two phases with turbulences (turb)

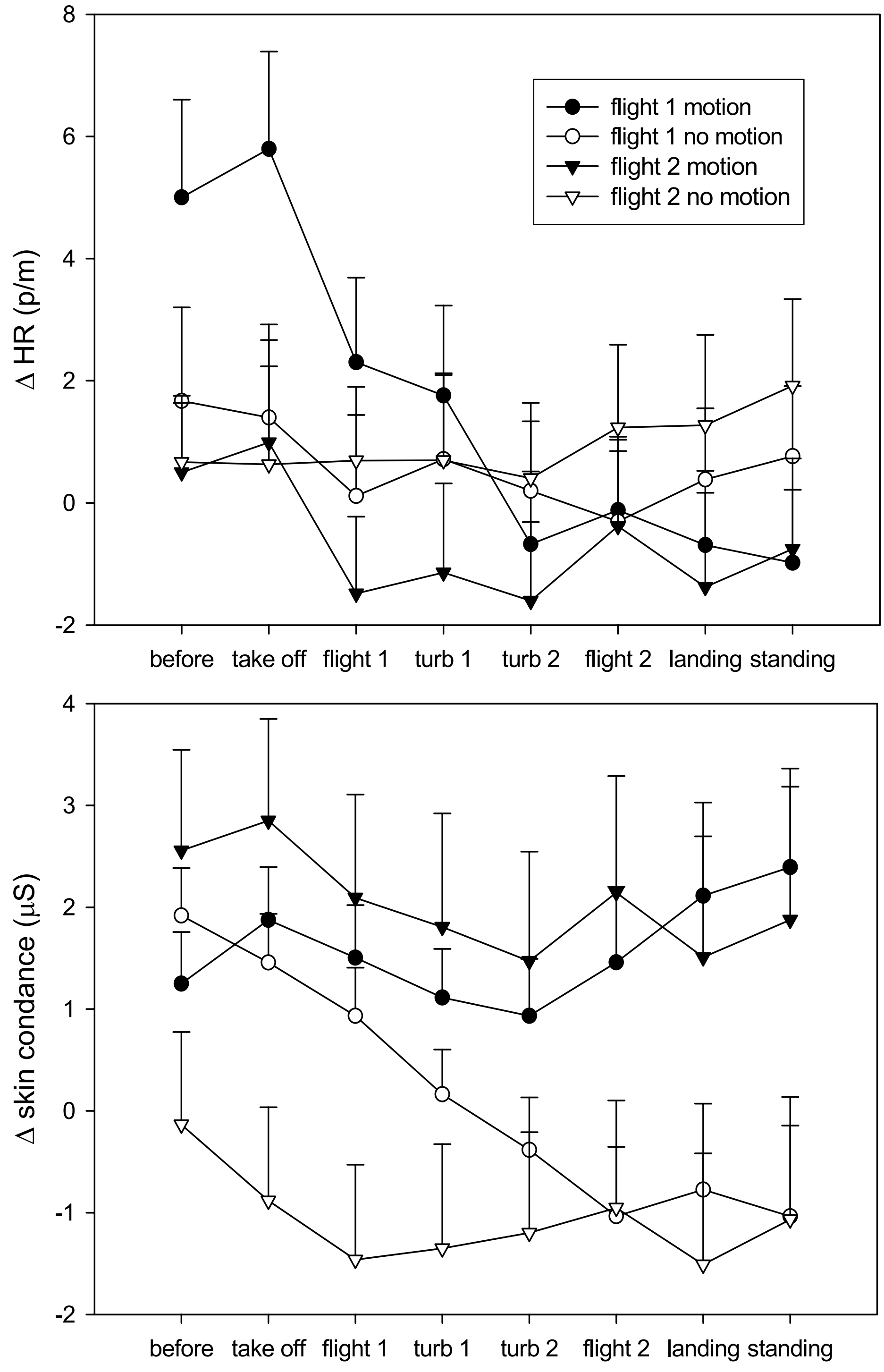

Figure 2. HR responses (top) during the first two VR flights of the Motion and the No-motion groups (N_{motion} =11, $N_{no\ motion}$ = 12) and skin conductance level responses (bottom) during the first two VR flights of the Motion and the No-motion groups N_{motion} =11, $N_{no\ motion}$ = 13); Flights have eight phases including two phases with turbulences (turb).

=8.6, p=.015, η^2=0.46) (not depicted). The ANOVA for the VR no-motion group resulted in a significant main effect of Phase ($F_{(7,84)}$=3.6, p=.041; η^2=0.23) and a significant Phase by Flight ($F_{(21,252)}$=4.0, p=.028; η^2=0.25) interaction. As depicted in Figure 2, skin conductance level of the VR no-motion group habituated strongly during the first flight and remained constant during the second flight.

Treatment outcome (FFS)

Within the VR-motion group, the mean FFS score dropped from 2.7 pre treatment (sd = 0.4) to 1.9 post treatment (sd = 0.4) and 2.1 six months later (sd = 0.7). The corresponding scores for the VR-no-motion group were 2.5 at pre treatment, (sd = 0.5), 1.7 post treatment (sd = 0.8) and 1.7 at follow-up (sd = 0. 9). Significant Time main effects ($F_{(2,46)}$=18.6, p<.001, η^2=0.45) revealed an overall treatment efficacy. The Motion Group by Time interaction was not significant ($F_{(2,46)}$=0.5, p=.489, η^2 =0.02). Contrasts revealed that fear of flying was effectively reduced from pre to post treatment ($F_{(1,23)}$=39.7, p<.001, η^2 =0.63) and from pre-treatment to follow-up ($F_{(1,23)}$=21.6, p<.001, η^2=0.49).

DISCUSSION

Results support prior investigations that found substantial subjective fear reactions of flight phobics during virtual reality (VR) flights. However, the VR with motion simulation induced substantially stronger subjective fear over all flights and all flight phases than the VR without motion simulation. Especially pronounced differences between the motion and the no-motion groups were found during the first flight before and during phases with intensive motion simulation, namely the phases with simulation of air turbulences. SUD ratings decreased immediately after the start phase in the group without motion simulation, while fear remained enhanced in the VR motion group until the phases with turbulences were completed.

Both treatment groups displayed a habituation of subjective fear responses from flight to flight. However, the expected association between strong initial fear reactions and strong habituation effects was not confirmed. Both groups did not differ in the strength of habituation. As a consequence, fear responses at the end of the exposure of the VR-motion group were still higher than the responses of the VR-no-motion group, although both groups had widely diminished subjective fear responses.

Fear associated heart rate responses could only be detected in the VR-motion group. Significant HR accelerations were observed during the first flight's take off phase and – to a weaker extend – during the second flight's take off. During later flights, HR was habituated, and further significant reactions did not occur. The VR group without motion simulation showed no significant HR reactions at all.

Skin conductance level of the VR motion group remained enhanced during the first and second flights and habituated only afterwards. In contrast, the VR no-motion group displayed enhanced SCL responses only during the take off phase of the first flight; SCL responses were habituated during later flight phases and later flights.

Overall, subjective fear ratings as well as skin conductance responses confirmed substantial fear of both groups during VR exposure. However, these responses were substantially stronger and habituated slower in the VR motion group compared to the VR no-motion group. Nevertheless and in contrast to network theories – which suggest that stronger activation of fear networks should result in an enhanced treatment outcome - we found no differences between groups in treatment outcome. There was even no trend of a superior treatment outcome for the VR-motion compared to the VR-no-motion group. Both groups also showed comparable habituation effects, although the habituation within the VR-motion group took place at a higher level (subjective fear) or had a later onset (skin conductance).
Although these results are limited due to the small sample sizes, the present study helps to better understand VR exposure treatment and gives hints for future research to evaluate the treatment process. Based on our results it may be speculated that treatment outcome is more related to the amount of habituation during exposure than to the strength of the initial fear response. Furthermore, since activation and

habituation are highly related in exposure therapies,[16] the manipulation of distinct stimuli properties within VR exposure seems to be a valuable tool to clarify the active components of exposure treatments.

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