Psychotherapy and Psychosomatics

Innovations

Psychother Psychosom 2023;92:170–179
DOI: 10.1159/000530932

Received: December 19, 2022
Accepted: April 27, 2023
Published online: May 30, 2023

Virtual Reality Exposure to a Healthy Weight Body Is a Promising Adjunct Treatment for Anorexia Nervosa

Simone C. Behrens[a, b, c] Joachim Tesch[b] Philine J.B. Sun[a]
Sebastian Starke[d] Michael Black[b] Hannah Schneider[a] Jacopo Pruccoli[a, e, f]
Stephan Zipfel[a, c] Katrin E. Giel[a, c]

[a]Psychosomatic Medicine and Psychotherapy, Medical University Hospital, Tübingen, Germany; [b]Max Planck Institute for Intelligent Systems, Tübingen, Germany; [c]Centre of Excellence for Eating Disorders (KOMET), Tübingen, Germany; [d]Meta Reality Labs, London, UK; [e]IRCCS Istituto delle Scienze Neurologiche di Bologna, Pediatric Neuropsychiatry Unit, Center for Eating Disorders, Bologna, Italy; [f]Department of Medical and Surgical Sciences, University of Bologna, Bologna, Italy

Keywords

Anorexia nervosa · Anxiety · Cognitive-behavioral psychotherapy · Eating disorders · Psychological stress · Psychotherapy research · Virtual reality

Abstract

Introduction/Objective: Treatment results of anorexia nervosa (AN) are modest, with fear of weight gain being a strong predictor of treatment outcome and relapse. Here, we present a virtual reality (VR) setup for exposure to healthy weight and evaluate its potential as an adjunct treatment for AN. ***Methods:*** In two studies, we investigate VR experience and clinical effects of VR exposure to higher weight in 20 women with high weight concern or shape concern and in 20 women with AN. ***Results:*** In study 1, 90% of participants (18/20) reported symptoms of high arousal but verbalized low to medium levels of fear. Study 2 demonstrated that VR exposure to healthy weight induced high arousal in patients with AN and yielded a trend that four sessions of exposure improved fear of weight gain. Explorative analyses revealed three clusters of individual reactions to exposure, which need further exploration. ***Conclusions:*** VR exposure is a well-accepted and powerful tool for evoking fear of weight gain in patients with AN. We observed a statistical trend that repeated virtual exposure to healthy weight improved fear of weight gain with large effect sizes. Further studies are needed to determine the mechanisms and differential effects.

Introduction

Anorexia nervosa (AN) is a severe mental disorder that often exhibits a long-standing course and high rates of morbidity and mortality [1–3]. Key symptoms of the disorder are significant underweight, fear of weight gain, and body image disturbance [4]. Currently, weight gain is a prioritized treatment goal [5]. However, body image disturbance and fear of weight gain are strong predictors for weight outcome in treatment and for

karger@karger.com
www.karger.com/pps

Karger
OPEN ACCESS

Correspondence to:
Simone C. Behrens, simone.behrens@med.uni-tuebingen.de

relapse after weight restoration [6, 7]. Thus, body image disturbance and fear of weight gain are promising targets for improving therapy within a mechanism-based approach [8]. Their contribution to the maintenance of AN can be conceptualized as a maladaptive circle with avoidance as an intuitive yet reinforcing reaction to fear, similar to anxiety disorders [9, 10]. Current guidelines [5, 11] endorse cognitive-behavioral therapy, specialist supportive clinical management, Maudsley AN treatment for adults, and focal dynamic therapy. These approaches address fear as a motivational barrier and avoidance behaviors (e.g., restriction, physical activity, rumination, or purging) as isolated symptoms rather than as integral elements of a maladaptive cycle.

Previous research has suggested that just like pathologic fears, fear of weight gain is mostly driven by expected consequences of weight gain such as loss of control or social reactions, and less by the stimuli such as scales or food that patients often report as triggers [9, 12, 13]. According to current evidence on mechanisms of fear treatment [14], efficient exposure to weight gain would enable patients to check whether their expected negative consequences actually hold. Existing interventions for fear of weight gain and body image, however, aim to improve patient's perception and cognitions about their current body rather than the expected healthy, normal weight body [15, 16]. Virtual reality (VR) provides the unique opportunity to expose patients to a healthy body while at the same time counteracting avoidance through its multisensory, immersive nature [17].

As VR tools for psychotherapy have progressed, there have been calls to link clinical considerations with technical implementation from the outset, including the choice of hardware and specific software characteristics [17, 18]. Studies using VR for therapeutic applications in eating disorders have recently increased (for reviews, see [19, 20]), but existing setups for virtual body exposure are either technically rough but accessible (e.g., [21, 22]) or complex and bound to the developing laboratory (e.g., [23, 24]). Other differences include strategies to induce body ownership [25] and therapeutic rationales [19, 26, 27]. Importantly, research focus on existing setups for body image therapy has mostly been on the feasibility and potential clinical utility of virtual body exposure [19] and less on identifying technical features for successful implementation and optimizing therapeutic procedures. This study adds on to previous research by presenting a portable VR body exposure setup along with user experience data on technical features and on the therapeutic procedure of pure exposure to healthy weight as an adjunct treatment for AN. The VR setup uses a state-of-the-art parametric body model [28, 29] along with real-time animation for the induction of ownership [25] and can be used flexibly to match individual therapeutic needs. Study 1 investigated a subclinical sample of 20 women with high weight or shape concern to characterize the setup in terms of user experience and to test whether the setup actually induces fear of weight gain. Study 2 was conducted in a sample of 20 patients with AN who underwent four 30-min sessions of pure virtual exposure to healthy weight. Changes in fear of weight gain, body image dissatisfaction, and arousal within the sessions and between the first and last session were assessed. Further, typical courses of self-reported arousal within the sessions were explored and user experience of the setup and procedure was assessed to generate hypotheses on helpful therapeutic ingredients of virtual body exposure.

Materials and Methods

Sample

The recruitment and study procedures were conducted in accordance with the ethical guidelines from the Declaration of Helsinki and were approved by the Ethics Committee of the Medical Faculty Tübingen (No. 580/2019BO2 and 760/2018BO1). Exposure sessions were supervised by a licensed psychological psychotherapist. All participants provided written informed consent prior to their participation.

For study 1, $N = 20$ participants with healthy weight and high weight or shape concern according to the German version of the Eating-Disorder-Examination Questionnaire (EDE-Q, [30]) were recruited. Inclusion criteria were age between 18 and 44 years, German language proficiency, body mass index between 19 and 25 kg/m^2, negative screening for an eating disorder (EDE-Q total score <2,3, [31]), positive screening for significant weight or shape concern (EDE-Q shape concern or weight concern ≥1,2, i.e., percentile >70 in women ≤44 years [31]), self-report of no mental health diagnosis or pregnancy within the last 2 years. Participants were recruited via mailing lists.

For study 2, $N = 24$ patients who were in treatment for AN were recruited. Inclusion criteria were a confirmed diagnosis of AN and ongoing inpatient or outpatient treatment, no current pregnancy or lactation, absence of physical conditions that might interfere with use of VR (e.g., neurological diseases, uncorrected vision), absence of severe comorbid mental health diagnoses such as psychotic disorders, active substance abuse or addiction, or bipolar disorder. Participants were recruited through their therapists, and AN diagnosis according to DSM-5 was independently confirmed by the experimenter using the Eating Disorder Examination Interview [32]. Four patients dropped out of the study because of scheduling issues ($n = 2$) and violation of inclusion criteria ($n = 1$ unconfirmed diagnosis of typical AN, $n = 1$ substance use disorder), so data from $n = 20$ participants were analyzed.

VR Setup

For the VR setup (Fig. 1), a Valve Index headset and controllers along with three VIVE trackers that were attached to the upper arms and hips of the participant were used. Rendering was done on

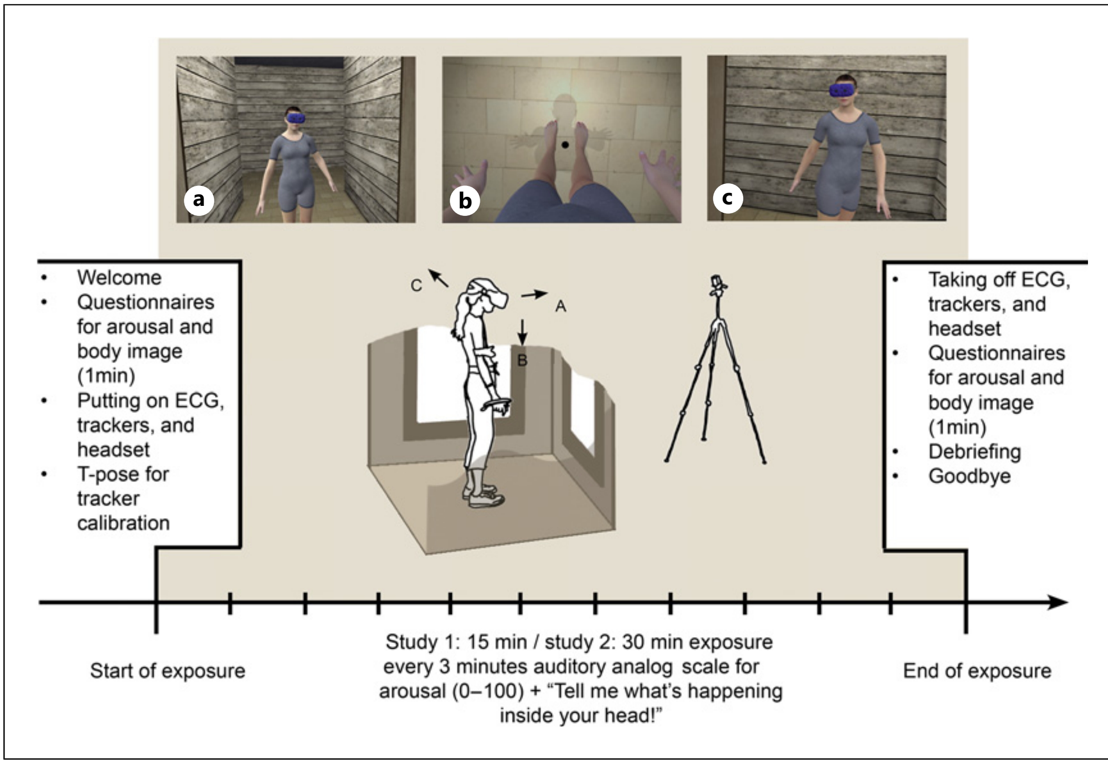

Fig. 1. Procedure and setup of exposure sessions. Torso, arms, and head were animated so that participants could see their avatar in the front or side mirror as well as from a first-person perspective. While height corresponded to participants' actual size, weight was determined individually to match a body mass index of +30% (study 1) or a body mass index between 19 and 25 kg/m^2 (study 2).

a Lenovo Legion Y740 15ICHg laptop with NVIDIA RTX2070 GPU. One SteamVR base station was positioned in front of the participant. The VR environment was set up in the Unity game engine with the SteamVR plugin for tracking integration. A floor calibration routine at the beginning of each run was used to ensure accurate height measurement. To calibrate trackers, participants performed a T-pose. Tracker calibration was conducted at the beginning of the session and whenever technical issues with animation occurred during the session.

The virtual environment shows two virtual full-body stereoscopic mirrors in a u-shaped changing cabin with real-time body shadows on the ground plane for additional realism. The participant was represented in VR by an avatar standing in the middle of the cabin, viewed in mirrors in front and to the left of the participant and from a first-person perspective. Position of head, arms, head as well as torso rotation was tracked through the hand controllers, headset, and trackers. The avatar was animated in the respective body parts at a stable rate of 90 Hz, so that the participant could move the avatar's arms, head, and upper body through moving his/her own physical body. The setup was designed to work for both male and female body shapes. To standardize their appearance to a white-skinned, European look, both avatars were rendered with similar textures, showing white skin, neutral gray tops and gray pants as clothing. The textures were matched for color and brightness. The avatar's face was covered by a 3D model of a headset.

The personalized avatar was generated at run-time based on specified height and weight by using the Virtual Caliper tool [29], which creates an accurate, rigged human body based on the Skinned Multi-Person Linear Model (SMPL; 28) from anthropometric measurements. Height and weight of the avatar were entered manually, yielding a prediction of an average body shape for the height and weight. Body animation was tested with Azure Kinect Body Tracking Hardware (Microsoft), Final IK (RootMotion, commercial full-body IK solver), and Ultimate IK (Sebastian Starke, https://github.com/sebastianstarke/AI4Animation/tree/master/AI4Animation/SIGGRAPH_Asia_2019). Finally, the Ultimate IK full-body IK solver was used because it yielded the fewest artifacts at no additional latency. However, compared to standard configuration, additional limb constraints were needed in conjunction with tracked orientation of the upper arms and position of the hands to avoid artifacts in shoulder and elbow regions.

Procedure

Study 1 was conducted within a single session of approximately 45 min. It comprised a brief psychoeducational session on the concept of exposure with a focus on the need for refraining from any avoidance behavior as a strategy to reduce arousal during the exposure and a 15-min session of VR exposure to 30% weight gain. To pilot measures for effects of the virtual exposure, analog scales assessing fear, body dissatisfaction, and fear of weight gain as well as heart rate were assessed at baseline, during VR exposure, and after VR exposure. VR experience was assessed in a post-questionnaire based on procedures described in previous studies [33–35].

Study 2 comprised five sessions. The first session took about 90 min and was a diagnostic and educational session. Eating disorder diagnosis was confirmed and additional demographic and illness-related information as well as self-reported measures of self-esteem (Rosenberg SES, [36], body image [37], cognitions on body checking [38, 39], and body checking habits [40, 41] were assessed). In the educational part of the session, the experimenter informed the participant about the procedure in the exposure sessions, handed out information materials about maladaptive cycles of fear of weight gain and avoidance behavior, along with information on how exposure could be used to break this cycle (see online suppl. material, patient manual; for all online suppl. material, see https://doi.org/10.1159/000530932) and discussed how exposure could help break this cycle for the specific patient. We opted for pure exposure instead of any guided procedure to account for the individual character of eating disorder fears [14, 42] and thus need for developing individually adapted appropriate coping strategies. Furthermore, previous studies on mirror exposure reported that pure exposure induces broader effects compared to guided procedures [43–45]. Patients were informed that they would be exposed to an average body shape, i.e., a long-term realistic body rather than one that they might have immediately after weight gain [46–48], and planned exposure weights were jointly agreed (see online suppl. materials, experimenter manual). The number of exposure sessions was set to four and chosen based on current practice for exposure reported in the literature [14, 49]. Exposure sessions took about 50 min each (see Fig. 1). During exposure, heart rate was continuously recorded. Before and after exposure, participants completed visual analog scales on arousal, body dissatisfaction, and fear of weight gain as well as figure rating scales for their current and ideal body weight. At the first and last exposure session, salivary samples were collected before and after the exposure.

Exposure sessions were conducted following an experimenter manual (see online suppl. materials) and only differed in regards to the exposure weight, which was continuously adapted in consultation with the participant. In each session, participants were welcomed, completed baseline assessments of arousal, body dissatisfaction, and fear of weight gain, and were supported in putting on the electrocardiogram device, arm and pelvis trackers, controllers, and headset. Then VR exposure was conducted for 30 min. Participants were exposed to a weight corresponding to at least 19 kg/m^2, which could be gradually increased over sessions to up to 25 kg/m^2. To maximize potential outcomes on body image and fear of weight gain, the exact exposure weight was determined based on individual considerations to approach either a healthy premorbid weight or to match individual challenges (e.g., a "round" number or slightly above the individual no-go). During exposure, the experimenter asked every 3 min for currently perceived arousal (not fear, as in study 1) on a scale from 0 to 100 and prompted the participant to verbalize her thoughts. Following a manualized procedure (see online suppl. materials), the experimenter paraphrased the thoughts and, if appropriate, gave further hints on technical opportunities (e.g., pointed to the second mirror), with the aim to support the participant in focusing on the exposure. In case of obvious avoidance, this impression was shared in the paraphrases. After exposure 1–3, participants were given the opportunity to reflect on their experiences and the next exposure weight was jointly agreed. After the last exposure session, participants were handed the same debriefing questionnaire asking for VR experience and feedback on the study as in study 1 and a brief semi-structured interview was conducted for more informal feedback.

Outcomes

Arousal

To account for frequently observed problems of patients with AN in verbalizing their emotions [50], arousal before, during, and immediately after exposure was assessed with both physiological measures and self-report. For self-report, patients were asked to quantify their currently perceived arousal on visual analog scale before and after each exposure as well as every 3 min during exposures on a scale from 0 to 100. As a physiological measure, heart rate variability was assessed through low-frequency power (LF), high-frequency power (HF), and root mean square successive difference (RMSSD) for the 3-min bins during exposure as well as the overall exposure sessions.

For the first and fourth exposure session in study 2, salivary cortisol was assessed using Salivette (Sarstedt®, Nümbrecht, Germany). Special care was taken to ensure that both sessions took place at the same time of the day. Samples were taken by moistening a cotton roll 1 h before exposure as well as immediately after exposure and 15 min after exposure, reflecting arousal before, at the beginning of the exposure, and in the middle of exposure. Samples were placed into a Salivette device and frozen at −80°C until the end of the data collection. Samples underwent centrifugation and cortisol values were determined by averaging the results from two runs of the luminescence immunoassay method.

Body Dissatisfaction

To assess changes in body dissatisfaction, figure rating scales from Mölbert, Thaler [51] suited for normal to overweight (study 1) and underweight to normal weight (study 2) as well as visual analog scales ranging from 0 to 100 that asked for global body dissatisfaction were used. Before and after each exposure, participants were asked to indicate their perceived current and ideal body, as well as their overall body dissatisfaction.

Fear of Weight Gain

Changes in fear of weight gain were assessed using visual analog scales ranging from 0 to 100, which participants completed before and after each exposure.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics 28. For study 1, two-tailed paired samples *t*-tests were used to compare arousal, body dissatisfaction, and fear of weight gain before and after exposure. Courses in self-reported fear during exposure were plotted and analyzed descriptively. Feedback on VR experience was summarized descriptively to enable comparison with previous VR studies, where possible.

For study 2, two-tailed repeated-measures ANOVAs with factors within session (pre/post) and exposure session (1/4) were ran to compare fear of weight gain, body image dissatisfaction, and self-reported arousal within and between the sessions. For salivary cortisol, the same analysis was conducted using immediately after and 15 min after values, thereby reflecting initial changes during exposure. For heart rate variability, heart rate variability (HF, LF, and RMSDD) was compared between the first and fourth exposure session. Individual courses of self-reported arousal were plotted and patients were clustered based on their arousal courses independently by two authors (S.C.B. and P.S.). Both raters identified three clusters and spontaneous rater agreement in assigning patients to clusters was high (90%). Disagreements could be resolved in joint discussion by defining clusters more precisely. Feedback on VR experience was analyzed as in study 1.

Results

Study 1

All participants were female and their age ranged from 19 to 44 years (M = 26.36, SD = 6.54). EDE-Q total score was M = 1.46 (SD 0.46), EDE-Q weight concern was M = 1.61 (SD = 1.05), and EDE-Q shape concern was M = 2.21 (SD = 0.70), corresponding to percentiles between 80 and 85 in the German norm sample [31]. On the visual analog scales, participants reported stable levels of arousal, body dissatisfaction, and fear of weight gain before and after exposure. Changes in these self-reported measures were not significant and effect sizes were null or small (all $p > 0.15$, $d < 0.15$). Self-reported fear of weight gain during exposure showed no clear courses and the same applied for heart rate variability parameters (RMSDD, SDNN, AVNN, each calculated over 15-min exposure). In the post-questionnaire, however, 95% of participants (19/20) reported fear symptoms during the session. 65% of participants (13/20) reported cognitive symptoms, and 50% of participants (10/20) reported physiological symptoms such as sweating or faster heart rate. Similarity of the avatar with the own body was rated M = 3.85 (SD = 1.46) on a 1–7 scale, ownership was rated M = 5.25 (SD = 1.43) on a 1–10 scale, thereby exceeding previous results from studies using non-individualized and non-animated avatars with synchronous visuo-tactile stimulation [35] and in the same range as a setup using fully individualized animated avatars [23].

Study 2

Descriptive information about the sample is provided in Table 1. All participants were female. 35% of participants (7/20) reported comorbid disorders, among them recurrent severe depression (30%; 6/20), obsessive-compulsive disorders (15%; 3/20), and post-traumatic arousal disorder (15%; 3/20). 65% of participants (13/20) had received their first diagnosis of AN within less than 3 years, 10% (2/20) between 3 and 6.9 years ago, and 25% (5/20) more than 7 years ago. 50% of participants (10/20) reported active measures for weight control.

On the visual analog scales, the ANOVA yielded a significant main effect suggesting reduction in fear of weight gain within session 1 and 4 ($F(19) = 8.51, p < 0.01, \eta^2 = 0.31$) and a large but nonsignificant main effect suggesting reduction in fear of weight gain between session 1 and 4 from M = 71 (SD = 24) to M = 54 (SD = 34) ($F(1) = 3.01, p < 0.10, \eta^2 = 0.14$). ANOVAs for body dissatisfaction and ideal body indicated in the figure rating scales yielded trends for medium to large within-session effects (body dissatisfaction: ($F(19) = 1.57, p < 0.23, \eta^2 = 0.08$; ideal body: ($F(19) = 3.71, p < 0.07, \eta^2 = 0.16$) but no significant change across sessions (all $p > 0.45$). Self-reported arousal before and after the exposure did not change significantly either within or across sessions (all $p > 0.80$). No significant change, moreover, was documented for saliva cortisol levels ($p > 0.72$). When considering HRV parameters (RMSSD, HF, and LF, each calculated over 30-min exposure), none of them significantly changed between sessions. Nonetheless, RMSSD and HF yielded trends for a decrease (RMSSD: ($F(1) = 2.44, p < 0.14, \eta^2 = 0.11$; HF: ($F(1) = 2.55, p < 0.13, \eta^2 = 0.12$), suggesting a trend toward higher arousal in exposure session 4 compared to session 1.

Self-reported arousal courses during exposure yielded three clusters of individually stable courses (see Fig. 2). 45% of patients (9/20) showed a reduction in arousal within and across sessions (cluster 1), 20% of patients (4/20) showed generally low arousal levels (cluster 2), and 35% of patients (7/20) showed rising or continuously high arousal levels within the sessions (cluster 3). Patients in cluster 1 reported active efforts to overcome avoidance as strategy during exposure (focus on nice body parts, explicit focus on problematic body parts, convincing themselves of the importance of gaining weight and its pros, trying other people's perspective on the body). Cluster 2 reported strategies oscillating between active

Table 1. Descriptive information about the patient sample from study 2

	N	Mean	SD	Range
Age, years	20	30.1	11.9	18–58
BMI, kg/m^2	20	16.0	1.3	12.7–17.9
Lowest BMI, kg/m^2	20	14.1	1.9	10.9–16.6
Premorbid BMI, kg/m^2	16[A]	18.1	2.7	14.1–22.9
EDE Total Score (0–6)	20	3.2	1.2	0.3–5
EDE Restrictive Eating (0–6)	20	2.7	1.4	0.2–5.8
EDE Eating Concern (0–6)	20	3.4	1.2	0.4–4.8
EDE Weight Concern (0–6)	20	3.6	1.6	0.0–6
EDE Shape Concern (0–6)	20	3.6	1.6	0.6–6
FKB-20 Perception of Body Dynamics (10–50)	18	25.2	6.4	12.0–35
FKB-20 Body Dissatisfaction (10–50)	19	37.0	8.2	26.0–50
Rosenberg Self-Esteem (0–3)	17	1.2	0.7	0.1–2.4
BCCS	17	3.3	1.4	1.2–7.2
BCQ	16	2.8	0.9	1.5–4.5

BMI, Body Mass Index; EDE, Eating Disorder Examination Interview; FKB-20, Body Image Questionnaire [37]; Rosenberg Self-Esteem, Rosenberg self-esteem scale [36]; BCCS, Body Checking Cognitions Scale [38, 39]; BCQ, Body Checking Questionnaire [40, 41]. [A]Four patients could not indicate any premorbid weight due to their illness course. Other missing data were due to incomplete answers.

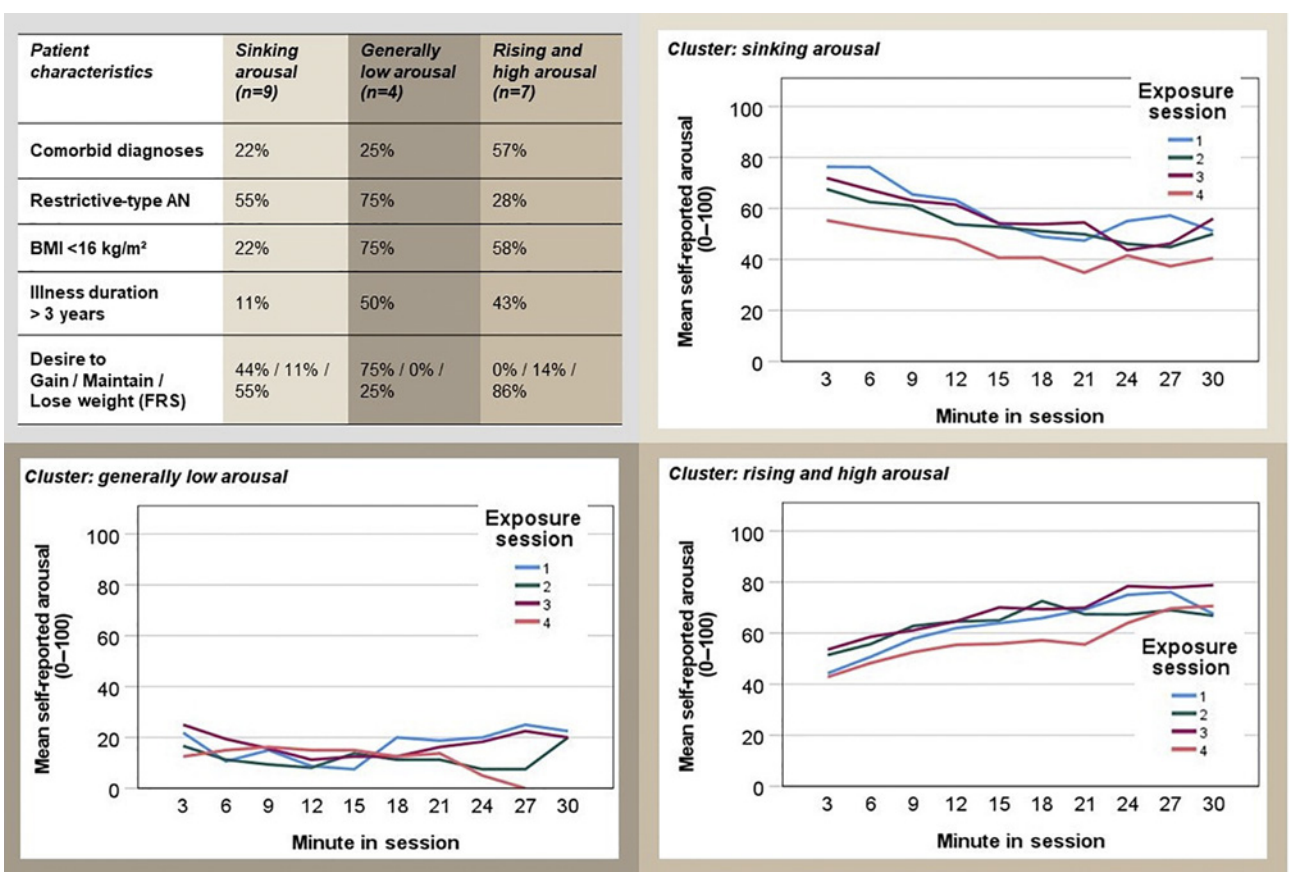

Fig. 2. Average courses of self-reported arousal (0–100) during exposure in the three identified clusters and patient characteristics in the respective clusters. FRS, Figure Rating Scales [51].

avoidance (looking away) and seeing the healthy weight body as a recovered version of themselves. In cluster 3, explorative analysis of verbal comments during exposure suggested focus on subjectively ugly body regions and avoidance as strategy in coping with higher body weight, which was paraphrased by the experimenter according to the protocol. In terms of fear of weight gain, cluster 3 reported less improvement than the other clusters. In all clusters, ownership was reported between 5 and 5.8.

In the debriefing questionnaire and interview, 85% of patients (17/20) reported fear symptoms during exposure such as bad memories, mind racing, panic, sweat, tears, faster heart rate, nausea, vertigo, or flatter breathing. While most patients (95%; 18/19) would recommend VR exposure to other patients, one commented that it had actually increased her fear of weight gain and the recommended ideal time for participation varied greatly between "as early as possible" and "late in therapy." Similarity with the own body was rated M = 3.79 (SD = 1.51) on a 1–7 scale; ownership was rated M = 5.18 (SD = 1.82) on a 1–10 scale.

Discussion

The present study presents a VR setup that exposes the participant to a body of higher weight along with pilot data from a subclinical sample and a sample of patients with AN who used the setup in a pure exposure procedure. The results suggest that VR exposure to higher weight is a powerful tool in evoking fear of weight gain, e.g., supported by a statistical trend for a large effect of improving fear of weight gain after four 30-min sessions of pure exposure to healthy weight. The observed reduction corresponded to an average reduction from extreme fear of weight gain (>70 on a 0–100 scale) to a fear level that can be handled (54 on a 0–100 scale), but reactions to exposure differed greatly between participants. Patient reactions were heterogeneous, and there are many possible variations to the setup and the therapeutic procedure that might help better address this heterogeneity. Further studies will be needed to replicate and better characterize the different response patterns in terms of emotion regulation strategies and to optimize the setup and therapeutic strategies.

While study 1 investigated a subclinical sample, study 2 provides data from patients with AN who suffer from severe symptoms of varying duration. The patient sample included 7 patients (35%) with severe comorbid diagnoses that are known to decrease chances for good treatment response [52] and 13 patients (65%) with an illness duration of less than 3 years, which has been reported a negative predictor of improvement in drive for thinness during hospitalization [53]. Indeed, typical courses with sinking arousal [7] and reduced fear of weight gain occurred mostly in patients with short illness duration. Independent of the individual arousal course, 95% of participants (18/19) reported positive feedback on the procedure. The explorative analysis of verbal comments suggests that differences in emotion regulation strategies [54] and attentional focus [55] might have driven the differences in reactions. Hence, the standardized procedure used in this study might help some patients in practicing functional coping strategies on weight gain while it supports others in elaborating an individual understanding of their body dissatisfaction.

Participants in both study 1 and study 2 reported intensive arousal reactions already before the actual exposure started and across all exposure sessions, which was also reflected in physiological measures. Participants from study 1 did not show any change in self-reported and physiological arousal, which was probably due to the short exposure sequence of only 15 min. In study 2, the overall constant physiological arousal contradicts the self-report of low or sinking arousal during the sessions reported by more than half of the patient sample. This result needs further examination to be fully understood. Possible explanations are the gradual weight increase over sessions, a generally high level of strain, and individually different processes during exposure, e.g., reduction of avoidance behavior over sessions in 1 patient versus increase of difficulty over sessions in another patient. Further, it should be noted that individuals with AN may display blunted/reduced cortisol and sympathetic nervous system responses to stress exposure [56], which might have biased arousal assessments.

Even though effects were not statistically significant, study 2 yielded large effect sizes for improvement in fear of weight gain, which is in line with other preliminary findings on VR exposure to higher weight [21, 57]. There was no lasting effect on body dissatisfaction. This could be due to the sparse assessment using visual analog scales. While visual analog scales are generally an established item format and widely established for unidimensional constructs such as arousal [58], they are non-validated measures for fear of weight gain and body dissatisfaction. Specifically, for body dissatisfaction, which is a multidimensional construct [59], this assessment method has limitations. Effects on fear of weight gain and body dissatisfaction were larger within sessions than across sessions. These observations suggest that multiple sessions of exposure to healthy weight are needed to generate lasting effects. However, based on our study protocol, it was not possible to determine the ideal number of sessions needed. Moreover, controlled and sufficiently powered study designs are needed to disentangle the observed effects from baseline effects of ongoing treatments.

Overall, the technical evaluation of the setup yielded good usability, low to medium similarity ratings with the own body, and medium levels of ownership over the virtual body. These values reach previous results from studies using synchronous visuo-tactile stimulation [33, 35] and animated, fully individualized avatars [23]. This suggests that roughly individualized bodies (accurate height, skin tone, and sex) can be used for virtual body exposure, when ownership is induced through visual-motor congruency [25]. Further research incorporating systematic modifications to the technical setup and/or therapeutic procedure could improve the understanding of AN core symptoms and support the generation of therapeutic algorithms and procedures. For example, technical or instructional elements could target specific consequences of weight gain (social judgment, personal consequences) [13] or support the adoption of a healthy attention allocation [55]. Incremental use of such procedures in routine care should then be tested in randomized controlled trials.

Acknowledgments

The authors thank Astrid Günther and Nina Gottschewsky for their support in running exposure sessions for study 2 as well as Sandra Becker and Florian Junne for their advice and support in establishing study 2. We further thank Nazar Mazurak for support in analyzing heart rate variability data.

Statement of Ethics

The recruitment and study procedures were conducted in accordance with the ethical guidelines from the Declaration of Helsinki (https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/). All participants provided written informed consent prior to their participation. The study protocols were reviewed and approved by the Ethics Committee of the University of Tübingen, approval number 580/2019BO2 and 760/2018BO1.

Conflict of Interest Statement

S.C.B. collaborates with VirtuallyThere GmbH, which commercializes 360° videos for exposure therapy, in providing educational resources for use of virtual reality technology in psychotherapy. M.J.B. has received research gift funds from Adobe, Intel, Nvidia, Meta/Facebook, and Amazon. M.J.B. has financial interests in Amazon, Datagen Technologies, and Meshcapade GmbH. While M.J.B. is a part-time employee of Meshcapade, his research was performed solely at, and funded solely by, the Max Planck Society. S.S. works with Meta Reality Labs, which invents and develops tools for augmented and virtual reality. However, his contributions for this study are not related to any of his work there.

Funding Sources

S.C.B. was funded through intramural funding from the Medical Faculty of the University of Tübingen, Grant No. 2535-0-0 and 2724-0-0. The funder had no role in the preparation of data or the manuscript.

Author Contributions

S.C.B., M.J.B., S.Z., and K.E.G. conceptualized the study; S.C.B., J.T., S.S., and M.J.B. designed the VR setup; S.C.B., P.S., and H.S. acquired the data; S.C.B., P.S., J.P., and H.S. conducted data analysis and interpreted the data; S.C.B. drafted the manuscript; S.C.B. and P.S. prepared the figures; and all authors critically revised the manuscript, agreed to its final version, and approved to be accountable for all aspects of this work.

Data Availability Statement

Due to a current guideline of the University Hospital Tübingen data protection team, data are considered as sensitive and cannot be publicly provided. Interested authors are invited to contact the corresponding author to find individual solutions for data sharing.

References

1 Zipfel S, Giel KE, Bulik CM, Hay P, Schmidt U. Anorexia nervosa: aetiology, assessment, and treatment. Lancet Psychiatr. 2015;2(12):1099–111.
2 Arcelus J, Mitchell AJ, Wales J, Nielsen S. Mortality rates in patients with anorexia nervosa and other eating disorders. A meta-analysis of 36 studies. Arch Gen Psychiatry. 2011;68(7):724–31.
3 van Hoeken D, Hoek HW. Review of the burden of eating disorders: mortality, disability, costs, quality of life, and family burden. Curr Opin Psychiatry. 2020;33(6):521–7.
4 DSM-5. Arlington, VA: American Psychiatric Association; 2013.
5 National Institute for Health and Care Excellence. Eating disorders: recognition and treatment; 2017.
6 Junne F, Wild B, Resmark G, Giel KE, Teufel M, Martus P, et al. The importance of body image disturbances for the outcome of outpatient psychotherapy in patients with anorexia nervosa: results of the ANTOP-study. Eur Eat Disord Rev. 2019;27(1):49–58.
7 Berends T, Boonstra N, van Elburg A. Relapse in anorexia nervosa: a systematic review and meta-analysis. Curr Opin Psychiatry. 2018;31(6):445–55.
8 Glashouwer KA, Brockmeyer T, Cardi V, Jansen A, Murray SB, Blechert J, et al. Time to make a change: a call for more experimental research on key mechanisms in anorexia nervosa. Eur Eat Disord Rev. 2020;28(4):361–7.

9 Murray SB, Strober M, Craske MG, Griffiths S, Levinson CA, Strigo IA. Fear as a translational mechanism in the psychopathology of anorexia nervosa. Neurosci Biobehav Rev. 2018;95:383–95.
10 Maier S, Schneider K, Stark C, Zeeck A, Tebartz van Elst L, Holovics L, et al. Fear network unresponsiveness in women with anorexia nervosa. Psychother Psychosom. 2019;88(4):238–40.
11 Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften (AWMF). S3-Leitlinie Diagnostik und Behandlung der Essstörungen. AWMF online; 2020. Vol 051/026 Klasse S3.
12 Murray SB, Loeb KL, Le Grange D. Dissecting the core fear in anorexia nervosa: can we optimize treatment mechanisms? JAMA Psychiatry. 2016;73(9):891–2.
13 Brown ML, Levinson CA. Core eating disorder fears: prevalence and differences in eating disorder fears across eating disorder diagnoses. Int J Eat Disord. 2022;55(7):956–65.
14 Craske MG, Treanor M, Conway CC, Zbozinek T, Vervliet B. Maximizing exposure therapy: an inhibitory learning approach. Behav Res Ther. 2014;58:10–23.
15 Alleva JM, Sheeran P, Webb TL, Martijn C, Miles E. A meta-analytic review of stand-alone interventions to improve body image. PLoS One. 2015;10(9):e0139177.
16 Ziser K, Mölbert SC, Stuber F, Giel KE, Zipfel S, Junne F. Effectiveness of body image directed interventions in patients with anorexia nervosa: a systematic review. Int J Eat Disord. 2018;51(10):1121–7.
17 Behrens SC, Streuber S, Keizer A, Giel KE. How immersive virtual reality can become a key tool to advance research and psychotherapy of eating and weight disorders. Front Psychiatry. 2022;13:1011620.
18 Wienrich C, Döllinger N, Hein R. Behavioral framework of immersive Technologies (BehaveFIT): how and why virtual reality can support behavioral change processes. Front Virtual Real. 2021;2.
19 Magrini M, Curzio O, Tampucci M, Donzelli G, Cori L, Imiotti MC, et al. Anorexia nervosa, body image perception and virtual reality therapeutic applications: state of the art and operational proposal. Int J Environ Res Public Health. 2022;19(5):2533.
20 Turbyne C, Goedhart A, de Koning P, Schirmbeck F, Denys D. Systematic review and meta-analysis of virtual reality in mental healthcare: effects of full body illusions on body image disturbance. Front Virtual Real. 2021;2.
21 Porras-Garcia B, Ferrer-Garcia M, Serrano-Troncoso E, Carulla-Roig M, Soto-Usera P, Miquel-Nabau H, et al. AN-VR-BE. A randomized controlled trial for reducing fear of gaining weight and other eating disorder symptoms in anorexia nervosa through virtual reality-based body exposure. J Clin Med. 2021;10(4):682.
22 Serino S, Pedroli E, Keizer A, Triberti S, Dakanalis A, Pallavicini F, et al. Virtual reality body swapping: a tool for modifying the allocentric memory of the body. Cyberpsychol Behav Soc Netw. 2016;19(2):127–33.
23 Döllinger N, Wolf E, Mal D, Wenninger S, Botsch M, Latoschik ME, et al. Resize me! Exploring the user experience of embodied realistic modulatable avatars for body image intervention in virtual reality. Front Virtual Real. 2022;3.
24 Mölbert SC, Thaler A, Mohler BJ, Streuber S, Romero J, Black MJ, et al. Assessing body image in anorexia nervosa using biometric self-avatars in virtual reality: attitudinal components rather than visual body size estimation are distorted. Psychol Med. 2018;48(4):642–53.
25 Mottelson A, et al. A systematic review and meta-analysis of the effectiveness of body ownership illusions in virtual reality. ACM Transactions on Computer-Human Interaction; 2023.
26 Riva G, Malighetti C, Serino S. Virtual reality in the treatment of eating disorders. Clin Psychol Psychother. 2021;28(3):477–88.
27 Irvine KR, Irvine AR, Maalin N, McCarty K, Cornelissen KK, Tovée MJ, et al. Using immersive virtual reality to modify body image. Body Image. 2020;33:232–43.
28 Loper M, Mahmood N, Romero J, Pons-Moll G, Black MJ. SMPL: a skinned multi-person linear model. ACM Trans Graph. 2015;34(6):1–16.
29 Pujades S, Mohler B, Thaler A, Tesch J, Mahmood N, Hesse N, et al. The virtual caliper: rapid creation of metrically accurate avatars from 3D measurements. IEEE Trans Vis Comput Graph. 2019;25(5):1887–97.
30 Hilbert A, Tuschen-Caffier B, Karwautz A, Niederhofer H, Munsch S. Eating disorder examination-questionnaire. Diagnostica. 2007;53(3):144–54.
31 Hilbert A, de Zwaan M, Braehler E. How frequent are eating disturbances in the population? Norms of the eating disorder examination-questionnaire. PLoS One. 2012;7(1):e29125.
32 Hilbert A, Tuschen-Caffier B, Ohms M. Eating Disorder Examination: deutschsprachige Version des strukturierten Essstörungsinterviews. Diagnostica. 2004;50(2):98–106.
33 Piryankova IV, Wong HY, Linkenauger SA, Stinson C, Longo MR, Bülthoff HH, et al. Owning an overweight or underweight body: distinguishing the physical, experienced and virtual body. PLoS One. 2014;9(8):e103428.
34 Karnath HO, Mölbert SC, Klaner AK, Tesch J, Giel KE, Wong HY, et al. Visual perception of one's own body under vestibular stimulation using biometric self-avatars in virtual reality. PLoS One. 2019;14(3):e0213944.
35 Keizer A, van Elburg A, Helms R, Dijkerman HC. A virtual reality full body illusion improves body image disturbance in anorexia nervosa. Plos One. 2016;11(10):e0163921.
36 von Collani G, Herzberg PY. Eine revidierte Fassung der deutschsprachigen Skala zum Selbstwertgefühl von Rosenberg. Z Differ Diagn Psychol. 2003;24(1):3–7.
37 Clement U, Löwe B. Body image questionnaire (BIQ-20), manual with questionnaire and assessment tools. Göttingen: Hogrefe; 1996.
38 Mountford V, Haase A, Waller G. Body checking in the eating disorders: associations between cognitions and behaviors. Int J Eat Disord. 2006;39(8):708–15.
39 Neubauer K, Bender C, Tuschen-Caffier B, Svaldi J, Blechert J. Erfassung dysfunktionaler kognitionen zum body checking. Zeitschrift für Klinische Psychologie und Psychotherapie. 2010;39(4):251–60.
40 Reas DL, Whisenhunt BL, Netemeyer R, Williamson DA. Development of the body checking questionnaire: a self-report measure of body checking behaviors. Int J Eat Disord. 2002;31(3):324–33.
41 Vocks S, Moswald C, Legenbauer T. Psychometrische Überprüfung einer deutschsprachigen Fassung des Body Checking Questionnaire (BCQ). Zeitschrift für Klinische Psychologie und Psychotherapie. 2008;37(2):131–40.
42 Levinson CA, Vanzhula IA, Christian C. Development and validation of the eating disorder fear questionnaire and interview: preliminary investigation of eating disorder fears. Eat Behav. 2019;35:101320.
43 Diaz-Ferrer S, Rodríguez-Ruiz S, Ortega-Roldán B, Mata-Martín JL, Carmen Fernández-Santaella M. Psychophysiological changes during pure vs guided mirror exposure therapies in women with high body dissatisfaction: what are they learning about their bodies? Eur Eat Disord Rev. 2017;25(6):562–9.
44 Diaz-Ferrer S, Rodríguez-Ruiz S, Ortega-Roldán B, Moreno-Domínguez S, Fernández-Santaella MC. Testing the efficacy of pure versus guided mirror exposure in women with bulimia nervosa: a combination of neuroendocrine and psychological indices. J Behav Ther Exp Psychiatry. 2015;48:1–8.
45 Moreno-Dominguez S, Rodríguez-Ruiz S, Fernández-Santaella MC, Jansen A, Tuschen-Caffier B. Pure versus guided mirror exposure to reduce body dissatisfaction: a preliminary study with university women. Body Image. 2012;9(2):285–8.
46 Murray HB, Tabri N, Thomas JJ, Herzog DB, Franko DL, Eddy KT. Will I get fat? 22-year weight trajectories of individuals with eating disorders. Int J Eat Disord. 2017;50(7):739–47.
47 El Ghoch M, Calugi S, Lamburghini S, Dalle Grave R. Anorexia nervosa and body fat distribution: a systematic review. Nutrients. 2014;6(9):3895–912.

48 Hubel C, Yilmaz Z, Schaumberg KE, Breithaupt L, Hunjan A, Horne E, et al. Body composition in anorexia nervosa: meta-analysis and meta-regression of cross-sectional and longitudinal studies. Int J Eat Disord. 2019;52(11):1205–23.
49 Koskina A, Campbell IC, Schmidt U. Exposure therapy in eating disorders revisited. Neurosci Biobehav Rev. 2013;37(2):193–208.
50 Westwood H, Kerr-Gaffney J, Stahl D, Tchanturia K. Alexithymia in eating disorders: systematic review and meta-analyses of studies using the Toronto Alexithymia Scale. J Psychosom Res. 2017;99:66–81.
51 Mölbert SC, Thaler A, Streuber S, Black MJ, Karnath HO, Zipfel S, et al. Investigating body image disturbance in anorexia nervosa using novel biometric figure rating scales: a pilot study. Eur Eat Disord Rev. 2017;25(6):607–12.
52 Schlegl S, Quadflieg N, Löwe B, Cuntz U, Voderholzer U. Specialized inpatient treatment of adult anorexia nervosa: effectiveness and clinical significance of changes. BMC Psychiatry. 2014;14(258):258.
53 Marzola E, Martini M, Brustolin A, Abbate-Daga G. Inpatients with severe-enduring anorexia nervosa: understanding the "enduringness" specifier. Eur Psychiatry. 2021;64(1):e44–10.
54 Puttevils L, Vanderhasselt MA, Horczak P, Vervaet M. Differences in the use of emotion regulation strategies between anorexia and bulimia nervosa: a systematic review and meta-analysis. Compr Psychiatry. 2021;109:152262.
55 Tuschen-Caffier B, Bender C, Caffier D, Klenner K, Braks K, Svaldi J. Selective visual attention during mirror exposure in anorexia and bulimia nervosa. PLoS One. 2015;10(12):e0145886.
56 Het S, Vocks S, Wolf JM, Hammelstein P, Herpertz S, Wolf OT. Blunted neuroendocrine stress reactivity in young women with eating disorders. J Psychosom Res. 2015;78(3):260–7.
57 Levinson CA, Christian C, Ram SS, Vanzhula I, Brosof LC, Michelson LP, et al. Eating disorder symptoms and core eating disorder fears decrease during online imaginal exposure therapy for eating disorders. J Affect Disord. 2020;276:585–91.
58 Wewers ME, Lowe NK. A critical review of visual analogue scales in the measurement of clinical phenomena. Res Nurs Health. 1990;13(4):227–36.
59 Cash TF. Body image: past, present, and future. Body Image. 2004;1(1):1–5.