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Improving Anorexia Nervosa Treatment with Virtual Reality Body Exposure and Attentional Bias Modification: A Single Case Study

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Abstract: This case study explores the potential of integrating attentional bias modification training (ABMT) with mirror exposure therapy (MET), utilizing virtual reality and eye-tracking, for a 14-year-old girl diagnosed with anorexia nervosa (AN). The ABMT-MET intervention was used alongside a standard treatment program called Home Treatment (HoT), which combines cognitive behavioral therapy with family-based therapy. Though the patient began HoT with a 3-week inpatient phase, the ABMT-MET intervention specifically took place during the subsequent Home Treatment sessions. The experimental treatment, comprising five consecutive weekly sessions, was bookended by pre- and post-assessment sessions and included a six-month follow-up. During the sessions, the patient engaged in systematic and hierarchical exposure to a virtual representation of her silhouette, with gradual adjustments made to the avatar's body mass index (BMI) toward a healthier range. ABMT sessions, conducted before each MET session, aimed to redistribute the patient's focus evenly across her body, successfully neutralizing her initial attentional bias toward non-weight-related body parts. The patient demonstrated consistent decreases in anxiety and fear of weight gain, effectively progressing through the BMI hierarchy in the virtual setting. Post-treatment assessments indicated significant enhancements in body dissatisfaction, drive for thinness, body-checking behaviors, and body appreciation, with these gains preserved at the six-month follow-up, although the attentional bias returned to pre-treatment levels. Though the single-case design limits definitive conclusions, these findings suggest ABMT-MET may be a promising adjunct therapy for AN, requiring further research for confirmation.

Keywords: anorexia nervosa; attentional bias modification training; mirror exposure therapy; virtual reality; eye-tracking

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1. Introduction

Anorexia nervosa (AN) represents a severe eating disorder characterized by significant mental health challenges and pronounced health risks. It is notably the leading cause of mortality among mental illnesses in Western societies, as highlighted by Van Eeden et al. [1].

This fact underscores the urgency of addressing AN as a critical public health priority, particularly in children and adolescents. The disorder typically emerges during these formative years, with early onset cases, such as those in teenagers, often presenting unique challenges and requiring tailored therapeutic interventions. The treatment and management of AN in this young demographic are essential, not only for immediate health improvement but also for preventing the long-term physical and psychological consequences associated with the disorder. In vivo exposure techniques like mirror exposure therapy (MET) are often integrated into cognitive behavioral therapy (CBT) to reduce symptoms of eating disorders such as AN and alleviate body dissatisfaction, as noted in studies by Griffen et al. [2], Key et al. [3], Hildebrandt et al. [4], and Jansen et al. [5]. By incorporating advanced technologies such as virtual reality (VR), exposure treatments have been refined to more directly address body-related symptoms and the pervasive fear of weight gain, a predominant issue in AN [6]. This innovative approach overcomes the limitations inherent in imaginal exposure methods, which include difficulties in sustaining visualization and the tendency of patients to avoid confronting the most distressing stimuli, such as visualizing themselves with a higher body mass index (BMI) [7]. By implementing a structured and hierarchical exposure to a virtual representation of the patient's silhouette and progressively adjusting the avatar's BMI across sessions towards a healthier range, VR-based MET has been shown to effectively diminish weight gain fears and improve body image disturbances [6]. However, it has been found that the efficacy of MET can be compromised by the presence of attentional biases (ABs). Individuals diagnosed with AN often exhibit a body-related AB [8], which is also associated with body dissatisfaction [9]. This bias manifests as an excessive focus or avoidance of attention on self-perceived unattractive and weight-related body parts (such as the legs, hips, or stomach) compared to other areas [10–13]. Since MET involves patients systematically observing their reflections while expressing emotions and thoughts about their body, individuals with AN who excessively concentrate on certain body parts while neglecting others might disrupt the exposure-based task. This disruption could potentially diminish therapeutic benefits and influence treatment outcomes [8,14–16]. The limitation of MET, primarily addressing top-down processes in managing body image disturbances, might arise due to neglecting automatic and unconscious mechanisms such as AB.

Therefore, addressing body-related AB becomes a clinically important task to enhance the effectiveness of MET [17]. Attentional bias modification training (ABMT) has shown effectiveness in altering selective attention toward body image [17]. The most widely used ABMT methods involve tasks such as the modified visual-probe task, where participants must respond to a prompt (e.g., a dot or letter) that appears at a location different from where a recent threat cue (e.g., an image related to weight gain) was shown [18,19]. Additionally, participants are encouraged to actively search for positive cues within an array of negative or threat cues [20,21]. In previous studies, the successful implementation of ABMT utilized a combination of VR and eye-tracking (ET), achieving a balanced focus between weight-related and non-weight-related body parts in both healthy individuals [22,23] and individuals with AN [24], thereby ensuring equal attention distribution across the entire body. In response to these challenges, this study proposes an innovative approach: integrating ABMT into MET using VR and ET technology. The integration of ET with VR enables precise control over attentional patterns, addressing biased focus and offering robust measurements of sensory processing, surpassing traditional reaction time-based assessments [25]. This approach improves patient engagement and immersion, providing a more realistic representation of real-life scenarios, e.g., looking at one's own body in the mirror [26,27], and offering a more ecologically valid experimental setting. Additionally, VR's embodiment-based procedures foster a sense of ownership over a virtual body (e.g., [28–30]), potentially targeting core body-related fears in AN, such as the fear of gaining weight.

This study aims to initially validate the efficacy of integrating ABMT into body exposure therapy using VR- and ET-enhanced MET as an adjunct treatment to the standard

treatment for a single patient diagnosed with AN, as classified by the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5) [31]. During the study, the patient was receiving Home Treatment (HoT), an evidence-based program for adolescents with AN that combines cognitive behavioral therapy (CBT) with family-based therapy (FBT) [32]. Expected outcomes include reductions in fear of gaining weight, body dissatisfaction, and achieving a balanced attentional focus. Improvements are also anticipated in reaching a healthy BMI, reduced body anxiety, fewer body-checking behaviors, and increased body appreciation. Moreover, the study aims to also assess whether the observed improvements are maintained at the six-month follow-up.

Case Formulation

Patient A is a 14-year-old female adolescent diagnosed with restrictive-type AN according to the DSM-5 at the Eating Disorders Unit of Hospital Sant Joan de Déu in Barcelona. Due to a severe restrictive intake of both solids and liquids, the patient was referred to the Eating Disorders Unit by a healthcare outpatient service center, after she had lost 40% of her body weight in the previous ten months, with a maximum BMI value of 22.67 kg/m^2 (percentile, 75%). In the preceding ten months, the patient began exhibiting significant food-restrictive behaviors, progressively reducing her intake or eliminating some foods perceived as unhealthy, while favoring fruits and vegetables. The patient did not display typical purgative or self-harming behaviors. However, she engaged in compensatory intense physical activity, exercising daily at home, waking up every night, and performing routines such as abdominal crunches. She consistently remained on her feet and regularly climbed stairs at home. Upon admission, her BMI was 13.79 (percentile, 1%), indicative of severe malnutrition. She initiated a home-based program for eating disorder management at the unit (HoT), which serves as an intermediary between inpatient and outpatient care and demonstrates efficacy in promoting successful outcomes [32]. Its three-phase structure prioritizes medical stabilization, weight recovery, and family empowerment through inpatient pediatrics in the initial phase of 3 weeks. In the subsequent 4 weeks, HoT involves interdisciplinary sessions, five sessions a week, combining in-person and remote strategies to generalize AN management. The final phase, lasting 3 weeks, focuses on patient autonomy and community integration, guiding outcomes for transition or continued care, with two sessions per week. HoT emphasizes family involvement, psychoeducation, emotional regulation, and social skills development, incorporating CBT and FBT which stands out as the first-choice therapy for adolescents with AN [33–35]. Patient A started this experimental therapy at the beginning of the second phase and completed it at the end of the third phase. Upon admission, she exhibited poor insight into her illness, along with low self-esteem, a high level of body image disturbances, the expression of concerns about her physical appearance, particularly for certain weight-related body areas (e.g., the thighs and stomach), and ruminations regarding food intake, with occasional anxiety episodes induced by food intake or comparisons with others. Following the conclusion of both the experimental study and the final phase of Home Treatment, the patient transitioned to follow-up care through an outpatient mental health community service, which provided individual psychotherapy sessions every 2 weeks. She was in her third year of secondary school and lived with her biological family. According to her medical records, her age at menarche was 11 years, and she started amenorrhea six months before entering the Eating Disorders Unit. Additionally, she received pharmacological treatment based on a single daily dose of Fluoxetine (10 mg) and Lorazepam (2.5 mg). Patient A was highly ready to recover and complete the entire VR treatment.

2. Materials and Methods

2.1. Measures

Pre-assessment, post-assessment, and six-month follow-up measures.

The following measures were assessed before starting the experimental treatment (ABMT and MET), at the end of the experimental treatment, and after a six-month follow-up period.

1. Body-related AB was quantified using the patient's visual fixation, defined as the act of sustaining one's gaze on a specific location for a minimum duration of 100 ms [36]. This measure was applied to specific Areas of Interest (AOIs) based on the Physical Appearance State and Trait Anxiety Scale (PASTAS) [37]. The AOIs were categorized as follows:
   - Weight-related body parts: thighs, buttocks, hips, stomach, legs, and waist.
   - Non-weight-related body parts: neck, chest, shoulders, arms, and feet.

   The head was excluded from the AOIs, because it was obscured by a head-mounted display (HMD) and hat.

   Visual fixation was determined using two measures [8,38,39]:
   - Number of fixations on AOIs: the total number of fixations on each specified AOI group.
   - Complete fixation time on AOIs: the cumulative duration of fixations on each specified AOI group, measured in milliseconds.
2. Body dissatisfaction and drive for thinness were assessed using the Spanish versions of the subscales from the Eating Disorder Inventory-3 (EDI-3) [40], as translated and validated by Elosua et al. [41].
   - Body dissatisfaction (EDI-BD): This subscale is comprised of 10 items, with scores ranging from 0 to 40. Higher scores indicate greater dissatisfaction with one's body.
   - Drive for thinness (EDI-DT): This subscale consists of 7 items, with scores ranging from 0 to 28. Higher scores indicate a stronger desire to be thin.

   The Spanish version of this instrument exhibits a Cronbach's alpha ranging from 0.74 to 0.96.
3. Anxiety Toward Weight-related Body Parts: Assessed using the Weight Scale of the PASTAS, with a total score range of 0 to 32. Higher scores indicate increased anxiety toward weight-related body parts. The scale demonstrates good internal reliability, with a Cronbach's alpha ranging from 0.82 to 0.92. It also shows good test–retest reliability (r = 0.87) and convergent validity indices for the W scale (r = 0.74 with EDI-BD, r = 0.62 with EDI-DT) [40].
4. Body-Checking Behaviors: Measured using the 23-item Body-Checking Questionnaire (BCQ) [42], which includes three subscales and has a total score ranging from 23 to 115. Higher scores indicate more frequent body-checking behaviors. The BCQ is noted for its good test–retest reliability (r = 0.94).
5. Body Appreciation: Employed using the 12-item Spanish version of the Body Appreciation Scale for adolescents (BAS) [43], translated and validated by Lobera and Ríos [44], with scores ranging from 13 to 65. Higher scores reflect greater body appreciation. The Spanish version demonstrates adequate internal consistency (Cronbach's $\alpha = 0.908$) and construct validity.

Ongoing assessments at each session.

1. BMI: Calculated by dividing the patient's weight (in kilograms) by the square of their height (in meters).
2. Visual analog scales (VAS) ranging from 0 (not at all) to 100 (completely) were used to assess the following measures:

- Full-body ownership illusion (FBOI): The degree to which the patient felt the virtual body was her own.
- Fear of weight gain (FGW): The extent to which the patient feared gaining weight while embodied in the virtual body.
- Anxiety: The level of anxiety the patient experienced while having the virtual body.

Other measures.

At the post-treatment session, the System Usability Scale (SUS) [45], a 10-item questionnaire, was administered to assess the perceived usability of the VR and ET system, with scores ranging from 0 to 100. A score up to 70 indicates good usability.

The timeline of the assessment for this study is presented in Figure 1.

PRE-TREATMENT ASSESSMENT SESSION	ABMT + MET SESSIONS	POST-TREATMENT ASSESSMENT SESSION	FOLLOW-UP AT 6 MONTHS SESSION
1. Informed consent 2. Photography procedure to create the virtual body 3. AN measures • BMI • Body Dissatisfaction • Drive for Thinness • Anxiety Toward Weight-related Body Parts • Body Checking Behaviours • Body Appreciation 4. FBOI procedures within the VR environment 5. VASs within the VR environment • FBOI • Anxiety • Fear of gaining weight 6. Body-Related AB assessment within the VR environment	1. BMI 2. FBOI procedures within the VR environment 3. VASs within the VR environment • FBOI • Anxiety • Fear of gaining weight 4. ABMT within the VR environment 5. MET within the VR environment 6. Anxiety-VAS measured every 120 seconds during MET within the VR environment 7. VR-relaxing environment for the last five minutes of each session	1. AN measures • BMI • Body Dissatisfaction • Drive for Thinness • Anxiety Toward Weight-related Body Parts • Body Checking Behaviours • Body Appreciation 2. FBOI procedures within the VR environment 3. VASs within the VR environment • FBOI • Anxiety • Fear of gaining weight 4. Body-Related AB assessment within the VR environment 5. System Usability Scale	1. AN measures • BMI • Body Dissatisfaction • Drive for Thinness • Anxiety Toward Weight-related Body Parts • Body Checking Behaviours • Body Appreciation 2. FBOI procedures within the VR environment 3. VASs within the VR environment • FBOI • Anxiety • Fear of gaining weight 4. Body-Related AB assessment within the VR environment

Figure 1. Experimental design of the study. Note. AN = anorexia nervosa; BMI = body mass index; FBOI = full-body ownership illusion; VR = virtual reality; VAS = visual analog scale; AB = attentional bias; ABMT = attentional bias modification training; MET = mirror exposure therapy.

2.2. Instruments: Software and Hardware

The VR environment was designed and developed using Unity 3D 5.6.1 (Unity Technologies, San Francisco, CA, USA). It featured a virtual room with a large mirror on the wall, placed 1.5 virtual meters in front of the patient. Two boxes were positioned on the floor near the avatar's feet, serving as neutral stimuli (see Figure 2). The patient could observe herself in the third-person perspective, reflected in the mirror, even during movement. The avatar was created using Blender v. 2.78 and dressed in a simple top, jeans (whose color could be changed to match the participants' clothing), and black trainers. A grey hat was used to cover the hair, minimizing the impact of hairstyle variations. The VR system included an HTC Vive Pro Eye (HTC Corporation, Taoyuan, Taiwan) HMD with a built-in Tobii eye tracker (Tobii Technology, Stockholm, Sweden), two VR controllers held by the patient, and two additional body trackers attached to the patient's feet. Additionally, two HTC-VIVE base stations were positioned two meters above the ground, diagonally at opposite corners of the room, to create a minimum play area of 2 m $\times$ 1.5 m. This setup formed the full-body tracking system to capture the patient's entire range of body movements.

Figure 2. Patient's perspective of the virtual environment.

2.3. Procedure

The ethics committees of Hospital Sant Joan de Déu in Barcelona approved this study. Before treatment, written informed consent was obtained from both the patient and her parents. The patient was informed about the procedure, the confidentiality of her data, and her right to withdraw from the study at any time. The study consisted of eight sessions in total. Five of these sessions were focused specifically on the VR intervention. The entire course of treatment spanned seven consecutive weekly sessions, which included the initial assessments and final evaluations. A follow-up assessment was conducted six months later. All sessions were administered by a female psychologist (see Table 1).

Table 1. Description of each session.

Session	Type of Experimental Session	Standard Intervention
Session I	Pre-treatment assessment session	Phase 1 of HoT
Session II	1° VR session	Phase 2 of HoT
Session III	2° VR session	Phase 2 of HoT
Session IV	3° VR session	Phase 2 of HoT
Session V	4° VR session	Phase 3 of HoT
Session VI	5° VR session	Phase 3 of HoT
Session VII	Post-treatment assessment session	Phase 3 of HoT
Session VIII	Follow-up assessment session	Outpatient mental health service

The experimental design is detailed in the following information, as illustrated in Figure 1.

The pre-treatment assessment session, lasting approximately one hour, involved several preparatory steps. Initially, a personalized avatar was created using frontal and lateral photographs of the patient. The avatar's silhouette was manually aligned with the patient's physical measurements. Simultaneously, the patient completed the pre-treatment questionnaires. Following these initial steps, the patient was immersed in the virtual environment, and the ET device integrated into the HMD was calibrated. The FBOI was then induced through visuo-motor and visuo-tactile stimulation techniques lasting five minutes (for further details, see [46]). Subsequently, measurements were taken of the patient's current body anxiety, fear of gaining weight, and sense of FBOI using a VAS. To assess body-related AB, the patient observed herself in the virtual mirror for 30 s, following the method described in Jansen et al. [14] and Roefs et al. [47], and her eye movements were monitored by the ET device. To ensure the patient maintained focus on her reflection and to minimize distractions, the researcher monitored the ET data in real time. This allowed the researcher to detect whether the patient's gaze strayed from the mirror image for extended periods, such as looking at the wall or door. In such cases, the researcher would gently remind the patient to refocus on her reflection in the virtual mirror. As a cover story, the patient was informed that this was part of a sensor calibration process to prevent any bias from knowing the true objective, which was disclosed only after the completion of the study to avoid influencing the patient's gaze patterns.

Clinical sessions: ABMT + MET. Each clinical session, lasting approximately an hour, included ABMT followed by MET within the virtual environment. The exposure began with the patient's virtual body at her real BMI and progressed to avatars with incrementally increased BMI in subsequent sessions, culminating in a target healthy BMI. This target BMI was calculated based on the patient's age, sex, and pre-disorder BMI, following the growth charts by the World Health Organization [48]. Each session began with the calibration of the ET device and the induction of FBOI, followed by assessments of anxiety, fear of gaining weight, and FBOI using a VAS.

ABMT: This component was adapted from the AB induction procedure proposed by Smeets et al. [49]. It involved the visual selection of geometric figures that matched specific body areas on the avatar. Participants focused on the body part highlighted by these figures for 4 s as they were progressively illuminated, aiming to balance attention

between weight-related and non-weight-related body parts. In 45% of the trials, figures appeared on weight-related parts, 45% on non-weight-related parts, and 10% on neutral stimuli. The discrimination tasks within these trials alternated between focusing on the shape or color of the figures. The patient engaged in this search-and-stare task for 150 figures over 10–15 min, with a 1 min break between two series. The duration of this task was based on previous research indicating this length was sufficient to significantly reduce AB [22].

MET: During the MET component, the patient focused on different parts of the virtual body, starting from the shoulders down to the feet, and verbally expressed thoughts and feelings about each part. Anxiety levels were measured every 120 s with VAS. Each subsequent session started with an avatar displaying a progressively higher BMI, following a hierarchical order, provided that the patient's body anxiety had decreased by 40% or that the anxiety level remained at or below 40% compared to the last session. If there was no such reduction, the same BMI avatar from the previous session was reused. Additionally, if the patient's weight had increased since the last session, the avatar was adjusted to reflect her current weight.

After completing ABMT and MET, AB was measured. Each session concluded with a 5 min debrief in a calming virtual environment (such as waterfalls, forests, or beaches) to help alleviate any anxiety or discomfort resulting from the exposure tasks.

Post-treatment and follow-up assessment session. In the post-treatment and the six-month follow-up sessions, the patient was immersed in the virtual environment where the FBOI procedure was conducted. Following this, assessments of anxiety, fear of gaining weight, and FBOI were conducted using a VAS. AB was also evaluated. After completing these activities, the patient removed the VR equipment and filled out the post-treatment and follow-up assessment questionnaires to evaluate changes and progress since the initial treatment.

2.4. Data Analysis

Open Gaze and Mouse Analyzer (OGAMA) software (version 5.1) was used to convert raw ET data into appropriate quantitative data. These data were then processed by calculating the difference between focus on weight-related and non-weight-related body parts. A positive result indicated a greater focus on weight-related parts, whereas a negative result suggested a focus on non-weight-related parts. A result near zero indicated a balanced attention between the two.

For the post-treatment and follow-up assessments, reliable changes were calculated only for measures with available clinical and community means and standard deviations, specifically for EDI-DT, EDI-BD, PASTAS, BAS, and BCQ [37,41,42,44]. The analysis followed the Jacobson and Truax [50] criteria, using the Leeds Reliable Change indicator calculator in Excel [51] for single case assessments. The Reliable Change Index (RCI), which compares baseline and follow-up measurements, takes into account individual variability in scores over time and the standard error of measurement (SEM). The SEM helps quantify the expected variability in scores due to measurement errors alone. The RCI is calculated by dividing the difference between baseline and follow-up scores by the SEM. If the RCI exceeds 1.96, for a 95% confidence interval, it indicates that the change was statistically significant and not merely due to measurement error.

3. Results

The patient consistently achieved a reduction in anxiety levels by at least 40% or maintained levels equal to or less than 40% of the initial measurement throughout the sessions. Alongside these improvements in anxiety, the avatar's BMI progressively increased by 0.9 kg/m^2 each session. This gradual increase allowed the patient to progress through the entire hierarchy of avatar BMI values, ultimately reaching the target BMI of 18.36 (representing the 25th percentile), as established by the treating physicians. For a detailed representation of the incremental changes in the avatar's BMI, refer to Table 2.

Table 2. The body mass index (BMI) values of the avatar in the five virtual reality sessions and the BMI values of the patient during these sessions.

Session	BMI Increase	Avatar's BMI	Patient's Actual BMI
Pre-treatment session	No increase	14.40	14.40
1° VR session	No increase	14.79	14.79
2° VR session	Increase of 0.9 point	15.68	14.79
3° VR session	Increase of 0.9 point	16.57	14.83
4° VR session	Increase of 0.9 point	17.46	14.79
5° VR session	Increase of 0.9 point	18.36	14.95
Post-treatment session	No increase	15.02	15.02
Follow-up session	No increase	18.79	18.79

Throughout the five treatment sessions, the actual BMI consistently ranged from 14.79 to 14.95. In the post-treatment session, an increase in BMI was observed, reaching 15.02. This upward trend continued in the follow-up session, where the patient successfully achieved the target healthy BMI of 18.79, slightly surpassing the 25th percentile BMI of 18.36 initially set by the clinicians overseeing the treatment. As depicted in Figure 3, the patient initially exhibited a high level of fear of gaining weight, which markedly decreased by the end of the treatment, achieving very low values at both the post-treatment assessment and the follow-up. Anxiety levels, initially medium to high during the first two sessions, progressively decreased from the third session onward, reaching very low levels by the post-treatment assessment, and they were completely eradicated by the follow-up. Levels of FBOI were moderate initially but gradually increased, reaching a high level at both the post-treatment assessment and the follow-up.

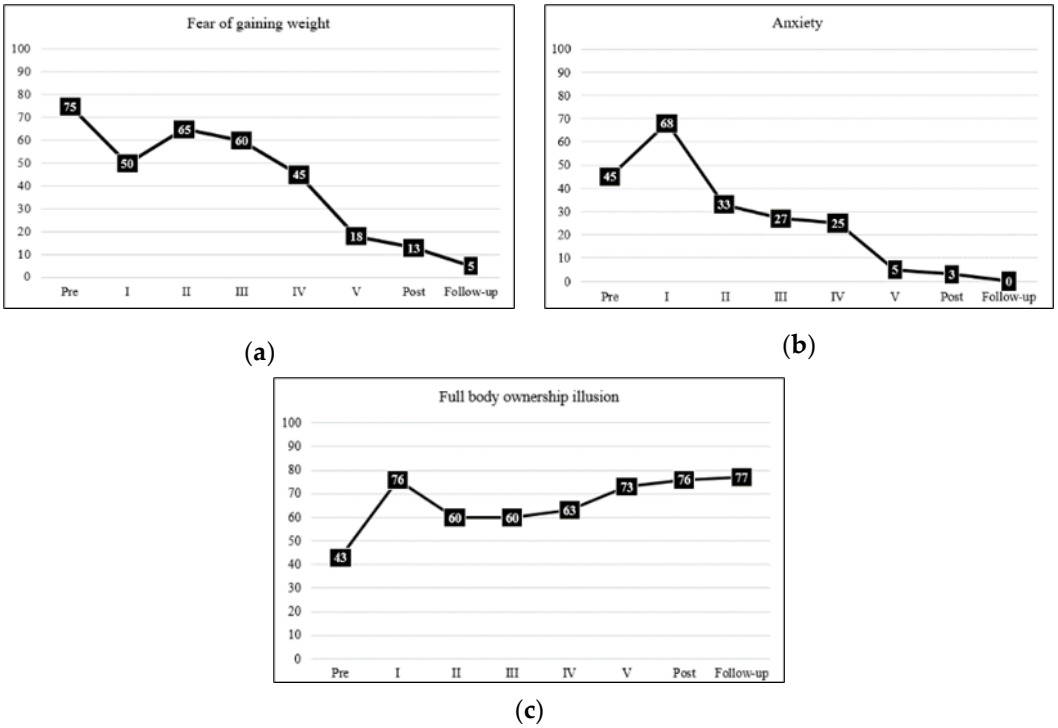

Figure 3. (**a**–**c**). Scores from the VAS measuring fear of weight gain (**a**), anxiety (**b**), and FBOI (**c**) across eight sessions. 'Pre' refers to the pre-treatment assessment session; 'I' to 'V' denotes the first through fifth treatment sessions, respectively; 'Post' indicates the post-treatment assessment session; and 'Follow-up' refers to the follow-up assessment session.

The patient showed a statistically reliable reduction in body dissatisfaction, drive for thinness, body anxiety, and body-checking behavior following treatment. These improvements were further enhanced after a six-month follow-up, maintaining a significant and reliable reduction. Additionally, there was a considerable and reliable improvement in measures of body appreciation, which continued to increase after 6 months. Regarding AB, initial scores for complete fixation time measures during pre-treatment assessment indicated the patient's avoidance of weight-related body parts. Following the intervention, the difference in complete fixation time between weight-related and non-weight-related areas of interest approached zero, indicating more balanced attention between these two types of body parts. After six months, there was a slight increase in the negative complete fixation time value, suggesting a partial resurgence of attentional avoidance of weight-related body parts, albeit less pronounced than in the pre-treatment session. Similar patterns were observed in the number of fixations, reflecting the patient's attentional avoidance of weight-related body parts during the pre-treatment assessment. There was a decrease after the intervention in the difference in the number of fixations between weight-related and non-weight-related areas of interest, indicating more balanced attention between these two types of body parts. However, in the follow-up assessment after six months, the negative value of the number of fixations increased again, indicating a reemergence of the attentional avoidance of weight-related body parts. See Table 3 for detailed results on all measures.

Table 3. Pre-treatment, post-treatment, and follow-up assessment scores from the administered questionnaires, and attentional bias measures.

Measures	Pre-Assessment Time	Post-Assessment Time	Follow-Up Time
EDI-Body dissatisfaction	28	14 *	5 *
EDI-Drive for thinness	20	3 *	0 *
PASTAS-Weight-related body parts anxiety	19	5 *	0 *
BCQ-Body-checking behaviours	82	46 *	26 *
BAS-Body appreciation	33	48 *	63 *
CFT-Attentional bias	−13,333	−899	−6992
NF-Attentional bias	−27	−5	−35

Note: Eating Disorder Inventory (EDI-3), Physical Appearance State and Trait Anxiety Scale (PASTAS), complete fixation time (CFT), number of fixations (NF). * Significant Reliable Change Index (RCI): if the RCI is 1.96 or greater, the difference is statistically significant.

The SUS value assessed at the post-treatment assessment session was notably high, registering at 70.

4. Discussion

This single case study suggests that ABMT integrated into VR-based MET may be a promising adjunct to standard evidence-based treatment for AN. The incorporation of ABMT successfully targeted AB associated with AN. Before treatment, the patient exhibited an AB towards non-weight-related body parts, aligning with studies indicating avoidance of unsatisfactory or unattractive self-body parts in AN patients [13] and women with high body dissatisfaction in the general population [52]. After treatment, the patient exhibited a balanced attentional focus between weight-related and non-weight-related body parts, indicating a reduction in the AB for both complete fixation time and number of fixations. These findings are in line with another study [24], which also demonstrated a successful reduction in AB towards the body parts following ABMT intervention in AN patients, leading to a more balanced attention pattern towards the body.

Following treatment, the patient notably reduced fear of weight gain and anxiety, successfully navigating the BMI hierarchy. The observed decrease in these AN symptoms aligns with previous studies emphasizing the beneficial effects of imaginal exposure therapy [7] and MET [6] on fear of weight gain and anxiety in AN patients. These outcomes correspond with habituation principles: exposure to changing body images likely aided

the patient in adapting to evolving perceptions, lessening fear of weight gain. The combined AB reduction and systematic VR exposure addressed traditional MET limitations. The patient's ability to redirect attention to the entire body may have accelerated anxiety and fear reduction related to perceived weight changes. Consequently, anxiety towards weight-related body parts significantly diminished post-treatment. These findings align with previous research emphasizing the anxiety-reducing effects of exposure therapies, particularly in VR contexts [53].

The patient demonstrated a reduction in both body dissatisfaction and thinness drive after treatment. This observed improvement aligns with findings from a study examining the effects of ABMT alone on patients with AN, which have demonstrated reductions in body dissatisfaction [24]. Prior research has established a connection between AB and body dissatisfaction in individuals with AN and women with elevated levels of body dissatisfaction [24,54]. Moreover, these results align with findings from studies using exposure-based interventions, such as MET, which have been successful in reducing body dissatisfaction and drive for thinness [3–5]. This highlights the comprehensive impact of the integrated approach on enhancing body image perceptions. The study revealed a significant reduction in body-checking behaviors, a common feature among individuals with AN. The inclusion of AB modification in the treatment likely contributed to balancing attentional focus, reducing fixation on specific body parts, and consequently mitigating body-checking tendencies. The integration of immersive experiences, controlled exposure, and ABMT likely facilitated the creation of a therapeutic environment, enabling the patient to confront and manage anxiety associated with specific aspects of her body perception effectively. This, in turn, led to a positive transformation in her overall body image appreciation.

The gradual increase in FBOI throughout the VR-based intervention is a noteworthy aspect of the study, indicating a heightened identification with the virtual avatar's body. This high FBOI likely played a crucial role in facilitating habituation, aiding the patient in adapting to the virtual body's changes and reducing fear of gaining weight and the overall anxiety response associated with body-related concerns. As other studies have shown, the integration of FBOI into the therapeutic process enhances the overall effectiveness of VR exposure, providing a more immersive and impactful treatment environment [55,56].

The patient's initially low pre-treatment BMI slightly increased by the end of treatment, yet it did not reach the defined healthy threshold of 18.36. Furthermore, during the follow-up assessment, the BMI surpassed the healthy threshold, achieving a value of 18.79. An interesting observation was the larger increase in BMI from pre-treatment to session 1 (0.39 kg/m^2) compared to the increase between session 1 and post-treatment (0.26 kg/m^2), with most of the BMI increase occurring between post-treatment and follow-up (3.77 kg/m^2). This pattern aligns partially with a study by Herpertz-Dahlmann et al. [32], where the highest weight gain occurred between admission and the beginning of HoT (2.09 kg/m^2), with continued weight gain during HoT (1.31 kg/m^2) but minimal increase between HoT end and 1-year follow-up (0.06 kg/m^2). Factors that could explain this initial pattern include initial motivation and participation in high-intensity treatment programs, with total hospitalization standing out, where recovery speed is usually faster due to the controlled and more supportive environment it offers. The observed weight stability during the experimental treatment, despite a decrease in fear of weight gain, can be attributed to the complex interplay of psychological and physiological factors, with changes in habits and metabolism not being immediately apparent. Though the VR-ABMT intervention may have contributed to the follow-up improvement in BMI, the limitations of the single-case design prevent definitive conclusions about its isolated effects. The continuation of standard treatment that the patient was receiving, as well as the holistic impact of therapy sessions, home interventions, and family involvement on the patient's overall well-being likely played a role. Controlled studies are essential to conclusively establish whether adding this combination of ABMT and MET to standard treatments like HoT can improve outcomes compared to standard treatment alone.

At the six-month follow-up evaluation, most of the improvements in the clinical measures observed at the post-treatment evaluation were sustained. However, the limitations of a single-case design and the patient's continued participation in outpatient treatment preclude definitive attribution of these sustained improvements solely to the experimental intervention. Interestingly, the patient's AB for attending to non-weight-related body parts returned to pre-treatment levels at follow-up, despite this period showing the greatest increase in BMI. This dissociation suggests that factors beyond the reduction in AB achieved during the intervention may have contributed to the BMI change.

From the outset of the treatment, the patient exhibited remarkable motivation. By the end of the sessions, the patient expressed an overall positive experience with the intervention. She noted a progressive increase in relaxation and comfort throughout the sessions, enhancing her overall user experience. The patient found the sessions not only enjoyable but also highly effective in mitigating anxiety and fear related to weight gain. Specifically, she observed a beneficial shift in her focus on her body. Feedback on the session duration and the attention bias modification training was also positive, with the patient experiencing no fatigue or boredom, indicating effective pacing and engagement of the intervention. She particularly praised the immersive and engaging nature of the virtual environment and appreciated the ability to customize her avatar's appearance, which further enhanced her experience. However, she suggested improvements for increased realism, such as dynamically adapting the avatar's clothing to match her real-time attire, which could heighten the sense of immersion and personalization. This positive reception forms a solid foundation for successful therapy. Patients who view VR and ET interventions favorably are more likely to feel comfortable and secure using such technologies. This comfort translates into active engagement and openness to the therapeutic process. Consequently, patients are more likely to remain engaged, maximizing the therapeutic benefits. Furthermore, an intuitive and user-friendly VR system that integrates seamlessly into the therapeutic environment is important for ensuring full immersion into the virtual world, which is essential for eliciting genuine emotional responses.

This case report shows that ABMT can be effectively combined with VR-based MET, with the patient reporting a positive reception of the intervention. This suggests promising potential for treating AN and body image-related disorders. However, further controlled trials are necessary due to the limitations inherent in single-patient studies. These should include comparisons of ABMT-MET as an adjunct to standard treatment against standard treatment alone, to validate these findings.

In conclusion, the positive therapeutic outcomes observed in this study for an adolescent patient with AN highlight the potential of integrating ABMT with body exposure when used in addition to a standard treatment program to improve the effectiveness of interventions.

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