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Virtual reality-based avatar intervention plus treatment as usual versus treatment as usual for anorexia nervosa and bulimia nervosa: a randomized clinical trial

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Article

Keywords:

Posted Date: June 4th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9856513/v1

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Additional Declarations:
There is **NO** Competing Interest.

All deidentified trial data are available through the Danish National Archives (Rigsarkivet), a public data repository, with no time restriction. Access requests can be submitted via: https://www.rigsarkivet.dkThe analysis code, including a data dictionary, is available at: https://osf.io/um638/overviewThe trial is registered at ClinicalTrials.gov (NCT06345040).

Title: Virtual reality-based avatar intervention plus treatment as usual versus treatment as usual for anorexia nervosa and bulimia nervosa: a randomized clinical trial

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Abstract

Interventions for eating disorders increasingly aim to target maintaining psychological mechanisms. One hypothesized mechanism is the internal “eating disorder voice.” In this randomized, parallel-group superiority trial, we evaluated a brief virtual reality (VR)-based psychotherapy enabling interaction with a therapist-operated avatar representing this voice, delivered as an adjunct to treatment as usual (TAU), in adults with anorexia nervosa or bulimia nervosa.

Ninety-six participants were randomized 1:1, stratified by TAU recruitment site, with concealed block size, to seven sessions of VR-based avatar intervention + TAU (n=48) or TAU (n=48). Outcomes were assessed at baseline, treatment cessation (12 weeks post baseline), and 24 weeks follow-up. The primary outcome was change in eating disorder symptoms, at treatment cessation measured with the Eating Disorder Examination Questionnaire. The primary analysis showed no statistically significant difference in treatment effect at treatment cessation (adjusted mean difference −0.28 points; 95% CI −0.67 to 0.11; Cohen’s $d = -0.33$; $P = 0.15$). However, the intervention showed significant improvement on several prespecified secondary outcomes related to the eating disorder voice and motivation for change, as well as exploratory measures of psychological recovery and quality of life. No serious adverse events related to the intervention were observed.

In conclusion, virtual reality-based avatar therapy did not reduce overall eating disorder symptom severity beyond treatment as usual but engaged hypothesized psychological mechanisms of change, supporting its potential role as an adjunctive intervention.

ClinicalTrials.gov registration: https://clinicaltrials.gov/study/NCT06345040?term=NCT06345040&rank=1, registration date: 14.03.2024. The study protocol was published in PLOS One (Hansen et al., 2025; https://doi.org/10.1371/journal.pone.0319875). The statistical analysis plan was preregistered on the Open Science Framework (https://osf.io/um638/overview). The study was funded by Independent Research Fund Denmark (reference 2096-00078B) and the Research Fund of the Mental Health Services, Capital Region of Denmark.

Background

Eating disorders are characterized by harmful eating behaviors and an overvaluation of weight and body shape in self-judgement [1]. They affect an estimated 7% of the global population[2] and are associated with serious physical and psychological complications, including an elevated risk of early mortality [3–5]. Beyond their clinical impact, eating disorders also impose a substantial economic burden through healthcare costs, reduced workforce participation, and productivity losses, exceeding those associated with anxiety and depressive disorders[6]. Psychological therapies are recommended as first-line interventions for eating disorders[7], but their effectiveness, particularly in anorexia nervosa, remains suboptimal. Relapse is common, with around 30% of adults who complete treatment experiencing recurrence within the first year[8,9], and dropout rates ranging from 20% to 70% have been reported [10,11]. Sustained recovery is often difficult to achieve, especially for individuals with anorexia nervosa [12], and substantial barriers to initiating treatment persist[13,14]. Together, these challenges highlight the need to improve treatment engagement and more directly target maintaining psychological mechanisms. Such mechanisms may also contribute to poor engagement and relapse, suggesting that interventions designed to address these processes could represent a promising strategy for improving outcomes.

Approximately 94% of individuals with an eating disorder, including anorexia nervosa and bulimia nervosa, report experiencing an internal "eating disorder voice," described as a self-critical inner commentary focused on weight, eating, and self-worth [15–17]. Although this voice may initially be perceived as helpful or protective, it often becomes increasingly controlling and critical over time, reinforcing maladaptive eating behaviours[16]. Qualitative studies suggest that this can be experienced as a division of the self, in which the eating disorder voice turns dominant and partly dissociated, often overriding personal values and contributing to a diminished sense of control[18,19]. A more dominant eating disorder voice has been associated with increased frequency of compensatory behaviors (e.g., fasting, vomiting, laxative misuse and excessive exercise) as well as longer illness duration[20]. Consistent with this, a subordinate position in relation to the eating disorder voice has been linked to symptom persistence and poorer treatment engagement[20].

Despite its clinical relevance, the eating disorder voice, and individuals' ongoing dialogue with it, are rarely addressed directly in therapeutic interventions. Most current approaches aim to reduce the disorder's influence on identity and behavior. However, targeting the eating disorder voice within a relational framework may strengthen patients' ability to reclaim a sense of control and develop a self-concept not defined by the disorder[19,21–23]. This approach is informed by research showing that the internal eating disorder voice shares a key relational feature with distressing auditory verbal hallucinations, namely the experience of a subordinate position in relation to the voice[19,21,22,24]. Accordingly, relational interventions developed for voice-hearing in psychosis (e.g. voice dialogue)[25] have been adapted to eating disorders, with preliminary qualitative work applying techniques such as chair work to facilitate dialogue with the eating disorder voice[19,22].

AVATAR therapy, a digital intervention originally developed for psychosis, uses computer-generated avatars to represent distressing internal voices and facilitate structured dialogue[26]. It has

demonstrated efficacy in reducing voice severity in three fully powered randomized clinical trials[27–29]. Early pilot adaptations of AVATAR therapy for anorexia nervosa have suggested acceptability, feasibility, and preliminary improvements in perceived power, increased self-compassion, and reduced emotional distress[11,30]. These adaptations, however, used a 2D desktop-based avatar interface rather than immersive virtual reality (VR)[11,30]. As greater immersion may enhance emotional engagement with salient therapeutic content[31], we developed and pilot tested a VR-based avatar intervention for eating disorders, which demonstrated feasibility and acceptability[32]. Building on these findings, the present study evaluated the intervention in a fully powered randomized clinical trial. To our knowledge, this is the first such trial to examine whether a relational, dialogue-based avatar intervention, delivered adjunctively to treatment as usual (TAU), can improve clinical and recovery-related outcomes in eating disorders. The primary hypothesis tested whether the intervention would lead to greater reductions in eating disorder symptoms at treatment cessation than treatment as usual alone.

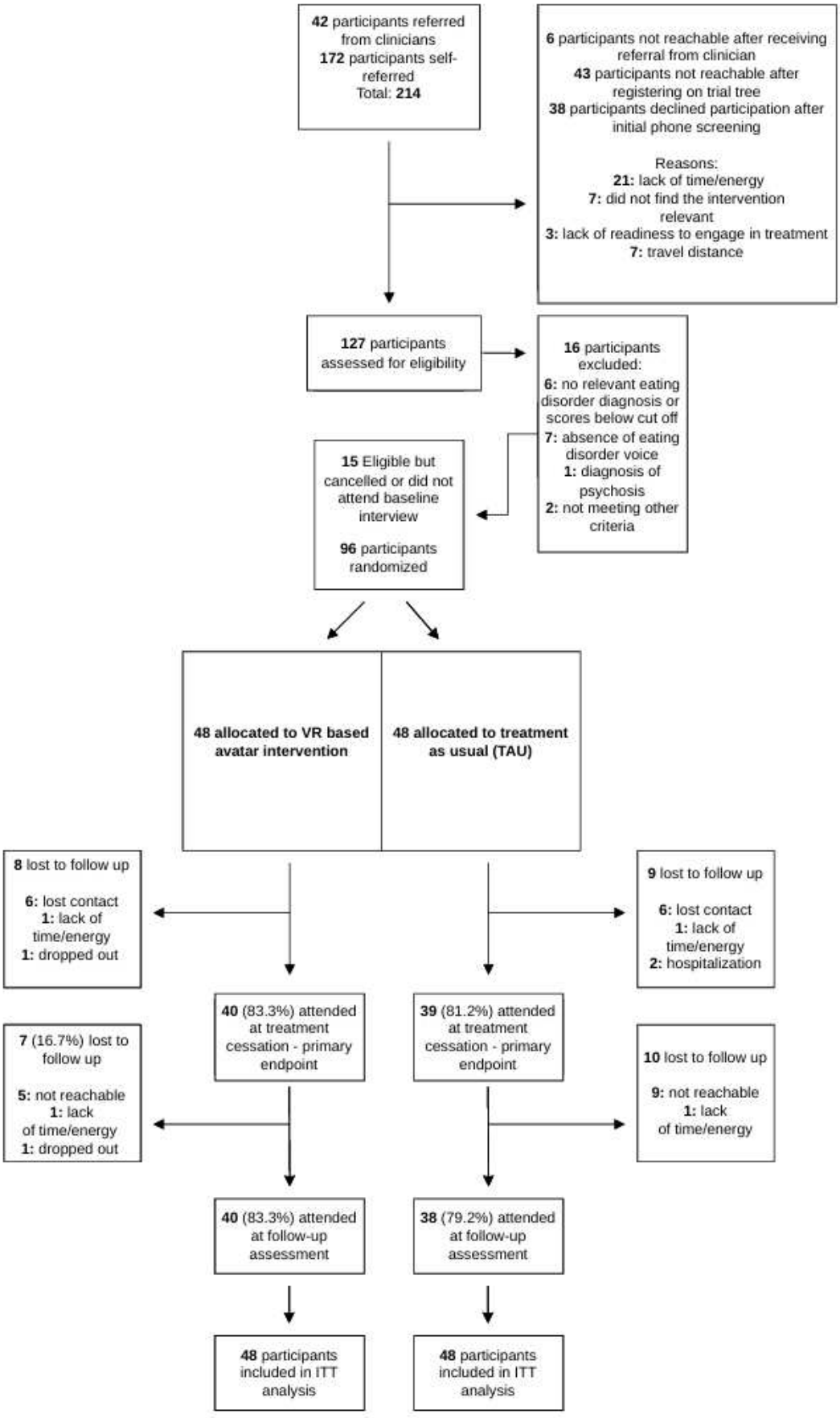
Results

Patient disposition

Between February 2024 and May 2025, 214 referrals were screened for eligibility. Of these, 42 participants were clinician-referred and 172 self-referred. Of the 214, 49 were not reachable and 38 declined participation after initial phone screening. Of the 127 participants assessed for eligibility, 16 were excluded; six did not meet diagnostic criteria or scored below the prespecified cut off of 2.77 on the global score of the Eating Disorder Examination questionnaire[33] (EDE-Q), and 10 did not meet other inclusion criteria. Fifteen eligible participants canceled or did not attend baseline assessment. The first participant was enrolled on February 26, 2024, and the last on June 20, 2025. Recruitment ended as planned once the prespecified target of 96 randomized participants was

achieved. A total of 96 participants provided informed consent and were randomized, with 48 allocated to the VR avatar intervention + treatment as usual (TAU) and 48 to TAU alone. All randomized participants were included in the intention-to-treat analyses (ITT) (Fig. 1).

Fig 1 Consort flow diagram of all participants assessed for the trial, randomized to VR avatar intervention + TAU and TAU, followed up to 3 months post treatment cessation.


42 participants referred from clinicians
172 participants self-referred
Total: 214
6 participants not reachable after receiving referral from clinician
43 participants not reachable after registering on trial tree
38 participants declined participation after initial phone screening
Reasons:
21: lack of time/energy
7: did not find the intervention relevant
3: lack of readiness to engage in treatment
7: travel distance
127 participants assessed for eligibility
16 participants excluded:
6: no relevant eating disorder diagnosis or scores below cut off
7: absence of eating disorder voice
1: diagnosis of psychosis
2: not meeting other criteria
15 Eligible but cancelled or did not attend baseline interview
96 participants randomized
48 allocated to VR based avatar intervention
48 allocated to treatment as usual (TAU)
8 lost to follow up
6: lost contact
1: lack of time/energy
1: dropped out
9 lost to follow up
6: lost contact
1: lack of time/energy
2: hospitalization
40 (83.3%) attended at treatment cessation - primary endpoint
39 (81.2%) attended at treatment cessation - primary endpoint
7 (16.7%) lost to follow up
5: not reachable
1: lack of time/energy
1: dropped out
10 lost to follow up
9: not reachable
1: lack of time/energy
40 (83.3%) attended at follow-up assessment
38 (79.2%) attended at follow-up assessment
48 participants included in ITT analysis
48 participants included in ITT analysis

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Baseline sociodemographic and clinical characteristics were generally comparable between groups, although psychiatric comorbidity (92.6% vs 82.4%) and psychotropic medication use (60.4% vs 39.6%), were slightly more frequent in the intervention group (Table 1).

Table 1 Clinical and sociodemographic characteristics of the ITT population across both trial arms at baseline

Variable	VR avatar	TAU	Total
Age, years (SD)	29.8 (8.2) *n*=48	28.1 (9.5) *n*=48	29.9 (8.9) *n*=96
Sex (%)			
Female	48 (100%) *n*=48	47 (97.9%) *n*=48	95 (99.0%) *n*=96
Male	0	1 (2.1%)	1 (1.0%)
Other	0	0	0 (0%)
Education			
Primary (in Denmark up to the age of 14)	5 (10.4%) *n*=48	7 (14.6%) *n*=48	12 (12.5%) *n*=96
Secondary	18 (37.5%)	19 (39.6%)	37 (38.5%)
Vocational education	2 (4.2%)	2 (4.2%)	4 (4.2%)
University degree (Bachelor or Graduate)	22 (45.8%)	19 (39.6%)	41 (42.7%)
Other (short higher education)	1 (2.1%)	1 (2.1%)	2 (2.1%)
Occupational status			
Employment (full time or part time	17 (35.5%) *n*=48	14 (29.1%) *n*=48	31 (32.3%) *n*=96
Student	22 (45.8%)	21 (43.8%)	43 (44.8%)
Unemployment	8 (16.7%)	8 (16.7%)	16 (16.7%)
Disability retirement (or retired)	1 (2.1%)	3 (6.2%)	4 (4.2%)
Housewife or husband	0	0	0 (0%)
Internship as unemployed/other	0	2 (4.2%)	2 (2.1%)
Diagnosis			
Anorexia nervosa	15 (31.2%) *n*=48	13 (27.1%) *n*=48	28 (29.2%) *n*=96
Anorexia nervosa Atypica	15 (31.2%)	13 (27.1%)	28 (29.2%)
Bulimia Nervosa	10 (20.8%)	12 (25%)	22 (22.9%)
Bulimia Nervosa Atypica	8 (16.7%)	9 (18.8%)	17 (17.7%)
Eating disorder, unspecified	0	1 (2.1%)	1 (1.0%)
[a]Eating disorder symptoms/EDE-Q global	4.1 (0.8) (95% CI 3.9–4.3) *n*=48	4.1 (0.8)) (95% CI 3.9 – 4.3) *n*=48	4.1 (0.8) *n*=96

BMI (SD) (range)	21.9 (5.5) (13.1 - 35.9) *n*=44	20.6 (3.4) (13.6 - 27.5) *n*=47	21.2 (4.5) *n*=91
Duration untreated eating disorder symptoms (DUED)	4.7 (5.4) *n*=48	4.8 (8.0) *n*=48	4.7 (6.8) *n*=96
Comorbid diagnosis			
yes	41 (92.6%) *n*=48	32 (82.4%) *n*=48	73 (76.0%) *n*=96
no	7 (7.4%)	16 (17.6%)	23 (24.0%)
Number of comorbid diagnosis			
0-1	19 (39.6%)	24 (50%)	(44.8%)
2 or more	29 (60.4%)	24 (50%)	(55.2%)
Type of comorbidity			
Depression	22 (23.4%) *n*=48	19 (20.9%) *n*=48	41 (42.7%) *n*=96
Anxiety	19 (20.2%)	21 (23.1%)	40 (41.7%)
OCD	3 (3.2%)	3 (3.3%)	6 (6.5%)
PTSD	7 (7.4%)	8 (8.8%)	15 (15.6%)
Bipolar disorder	1 (1.1%)	1 (1.1%)	2 (2.1%)
ADHD/ADD	14 (14.9%)	8 (8.8%)	22 (22.9%)
Autism spectrum disorder	6 (6.4%)	4 (4.4%)	10 (10.4%)
Personality disorder	8 (8.5%)	5 (5.5%)	13 (13.5%)
Schizotypal disorder	2 (2.1%)	1 (1.1%)	3 (3.1%)
Substance use disorder	5 (5.3%)	2 (2.2%)	7 (7.3%)
Psychotropic medication			
no	19 (39.6%) *n*=48	29 (60.4%) *n*=48	48 (50%) *n*=96
yes	29 (60.4%)	19 (39.6%)	48 (50%)
Types of medication			
Antidepressants	15 (31.2%) *n*=48	12 (25%) *n*=48	27 (28.1%) *n*=96
Mood stabilizers	4 (8.3%)	0	4 (8.3%)
Benzodiazepines	3 (6.2%)	2 (4.2%)	5 (5.2%)
Sleep aid/sedative other	3 (6.2%)	2 (4.2%)	5 (5.2%)
ADHD medicine	12 (25%)	9 (18.8%)	21 (21.9%)
Antipsychotics	3 (6.2%)	4 (8.3%)	7 (7.3%)
CTQ[b] total score			
≤ 35 (less or equal to 35)	23 (48.9%) *n*=47	20 (42.6%) *n*=47	43 (45.7%) *n*=94
>35 (more than 35)	24 (51.1%)	27 (57.4%)	51 (54.3%)
Alcohol intake (units/week) (SD)	1.9 (3.5) *n*=47	3.0 (4.2) *n*=48	2.5 (3.9) *n*=95
Substance use (last year)	2 (4.3%) *n*=48	15 (31.2%) *n*=48	17 (17.7%) *n*=96
Self-harm past month	4 (8.3%) *n*=48	3 (6.3%) *n*=48	7 (7.3%) *n*=96
Suicide			
Suicide attempts ever	15 (31.2%) *n*=48	11(22.9%) *n*=48	26 (27.1%) *n*=96

Suicide attempts past six months	3 (6.3%) *n*=48	0 (0%) *n*=48	3 (3.1%) *n*=96

Table legend: Values are presented as *n* (%), indicating the frequency and its corresponding percentage of the total; *n*(*n*-*n*) indicates the mean value and its 95%CI. [a]EDE-Q: Level of eating disorder symptoms measured with the Eating Disorder Examination Questionnaire (EDE-Q) global score at baseline. Scored on a 7-point Likert scale ranging from 0-6, with higher scores meaning higher levels of eating disorder symptoms. [b]CTQ: Childhood Trauma Questionnaire is scored on 5-point Likert scale. Scores >35 equals moderate to severe trauma exposure.

The first assessment at treatment cessation took place on April 19th, 2024, and the final follow-up assessment on December 18th, 2025. At treatment cessation (the primary endpoint), 8 participants (16.7%) in the VR avatar group and 9 participants (18.8%) in the TAU group were lost to follow-up. At follow-up, attrition remained comparable between groups with 6 participants (12.5%) lost in the VR avatar group and 10 (20.8%) in the TAU group.

Participants allocated to the VR avatar intervention completed an average of 6.5 VR sessions (95% CI 6.0, 6.9). Five participants (10.4%) discontinued the intervention after attending between one and six sessions, and two (4.2%) did not initiate treatment, while 41 (85.4%) completed all seven sessions. Reported reasons for discontinuation included time constraints (3), mental health related difficulties (1), psychiatric admission (1), and the VR intervention being perceived as too intense (1) (fig 1).

Between baseline and treatment cessation, participants in the VR avatar group received an average of 7.2 TAU sessions (95% CI 4.2- 10.3) compared with 5.8 sessions (95% CI 3.4- 8.2) in the TAU group (Table 2). TAU consisted of various forms of treatment. Information on number (%) of participants in each TAU category by treatment arm is shown in table 3.

Table 2 Mean primary care sessions at 12 and 24 weeks by treatment arm.

Mean primary care	VR avatar	TAU
12 weeks		
Mean (SD)	7.2 (9.1) *n*=37	5.8 (7.1) *n*=36
Mean 95% CI	(4.17, 10.26)	(3.42, 8.24)
Median	4.0	5.0
Range	0.0 - 32.0	0.0 - 36.0
24 weeks		
Mean (SD)	6.4 (8.0) *n*=32	5.9 (13.1) *n*=34
Mean 95% CI	(3.56 - 9.31)	(1.38 - 10.51)
Median	2.5	2.0
Range	0.0 - 24.0	0.0 - 21.0

Table legend: Values are presented as mean (s.d.), mean 95% confidence interval (CI), median and range, with sample sizes (n=) indicated for each group.

Table 3 Number (%) of participants in each primary care category across both treatment arms from baseline to treatment cessation and from treatment cessation to follow-up.

12 weeks	VR avatar	TAU
Received care		
yes	26 (66.7%) *n*=39	24 (66.7%) *n*=36
no	13 (33.3%)	12 (33.3%)
Type of care		
- Specialized eating disorder treatment	21 (53.8%) *n*=39	20 (55.6%) *n*=36
- General mental health care	9 (23.1%) *n*=39	8 (22.2%) *n*=36
- Nutritional treatment	1 (2.6%) *n*=39	1 (2.8%) *n*=36
- Social/community-based support	3 (7.7%) *n*=39	1 (2.8%) *n*=36
24 weeks		
Received care		
yes	21 (61.8%) *n*=34	19 (55.9%) *n*=34
no	13 (38.2%)	15 (44.1%)
Type of care		
- Specialized eating disorder treatment	15 (44.1%) *n*=34	13 (38.2%) *n*=34
- General mental health care	5 (14.7%) *n*=34	5 (14.7%) *n*=34
- Nutritional treatment	1 (2.9%) *n*=34	1 (2.9%) *n*=34
- Social/community-based support	5 (14.7%) *n*=34	3 (8.8%) *n*=34

Table legend: Number (%) of participants receiving primary care across treatment arms at 12 and 24 weeks. Care categories were not mutually exclusive. Percentages are based on participants with available data at each timepoint.

The mean interval between baseline and treatment cessation assessments was 14.1 (95% CI 13.3-14.8) weeks in the VR avatar group and 13.2 (95% CI 12.8-13.67) in the TAU group. The corresponding mean interval to follow-up was 27.2 (95% CI 26.3, 28.1) and 26.1 (95% CI 25.3 - 27.0) weeks, respectively.

Primary outcome

The primary endpoint was change from baseline in eating disorder symptoms at treatment cessation, measured by the EDE-Q global score. There was no statistically significant difference between the groups: participants in the VR avatar group showed a 0.28-point greater reduction compared with TAU (95% CI −0.67 to 0.11; Cohen's d = -0.33; P = 0.15) (table 4). Effect sizes for the primary, secondary, and exploratory outcomes are shown in Fig. 2.

Table 4 Adjusted between-group difference in change from baseline and effect sizes on primary and secondary outcomes.

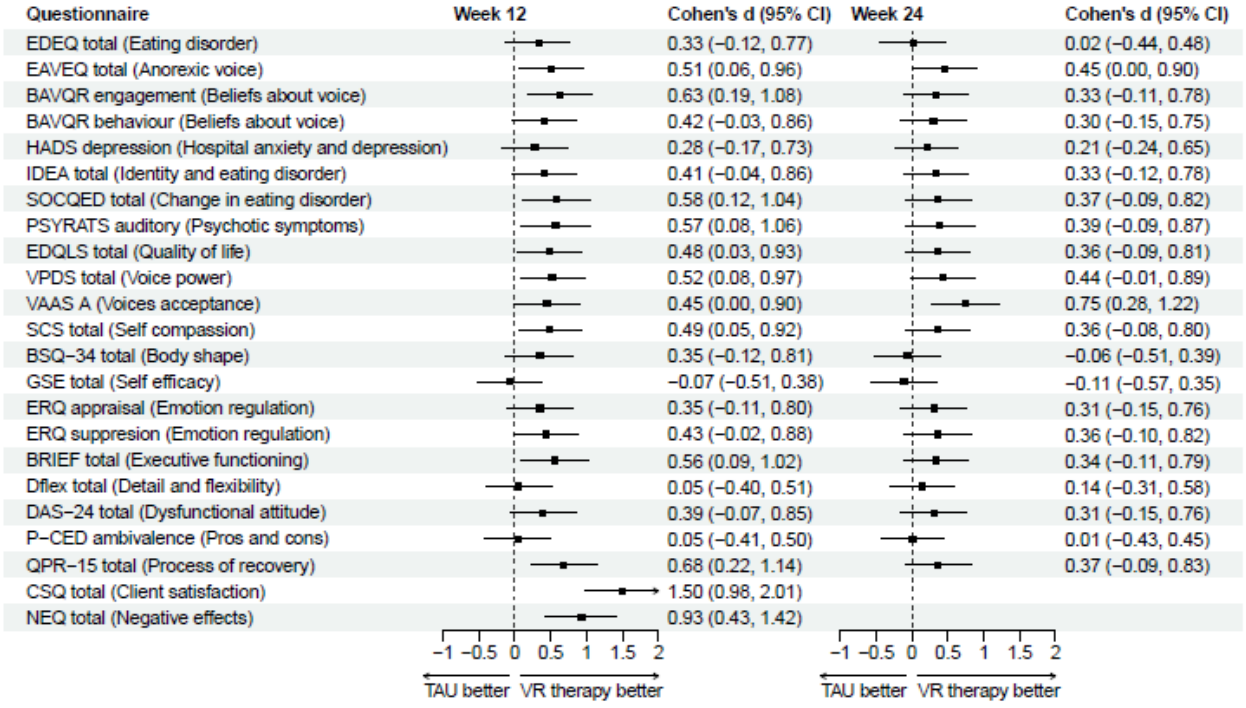
	VR avatar change (95% CI)	**TAU change (95% CI)**	**Between-group difference (s.e)**	**95% CI; *P* value**	**Cohen's *d* (95% CI)**
Primary outcome					
EDE-Q global					
Baseline	4.1 (3.9, 4.4) *n*=48	4.1 (3.8, 4.3) *n*=48	-	-	-
Treatment cessation	−1.08 (−1.35, −0.81) *n*=40	−0.80 (−1.08, −0.51) *n*=40	−0.28 (0.196)	(−0.67, 0.11); 0.1501	−0.33 (−0.77, 0.12)
Follow-up	−0.92 (−1.28, −0.57) *n*=40	−0.90 (−1.27, −0.54) *n*=38	0.022 (0.257)	(-0.536, 0.492); 0.9319	−0.02 (−0.48, 0.44)
Secondary outcomes					
EAVE-Q total					
Baseline	56.7 (54.2, 59.3) *n*=48	57.6 (55.0, 60.1) *n*=48	-	-	-
Treatment cessation	-7.072(-9.802, -4.341) *n*=39	-2.709(-5.414, -0.004) *n*=39	**-4.363 (1.924)**	**(-8.203, -0.523); 0.0265**	−0.51 (−0.96, −0.06)

Follow-up	-7.453(-11.063, -3.843) *n*=38	-2.383(-6.110, 1.344) *n*=36	**-5.070 (2.582)**	**(-10.227, 0.087); 0.0539**	−0.45 (−0.90, −0.00)
BAVQR – engagement affective total					
Baseline	3.8 (2.9, 4.6) *n*=46	4.2 (3.4, 5.1) *n*=46	-	-	-
Treatment cessation	−1.56 (−2.37, −0.74) *n*=37	0.05 (−0.74, 0.85) *n*=38	**−1.61 (0.572)**	**(−2.75, −0.47); 0.0064**	−0.63 (−1.08, −0.19)
Follow-up	−0.94 (−1.79, −0.10) *n*=36	−0.07 (−0.92, 0.78) *n*=36	−0.87(0.594)	(−2.05, 0.32); 0.1477	−0.33 (−0.78, 0.11)
HADS – Depression total					
Baseline	8.8 (7.7, 9.9) *n*=48	7.6 (6.3, 8.8) *n*=48	-	-	-
Treatment cessation	−1.76 (−2.75, −0.76*)* *n*=40	−0.88 (−1.91, 0.16) *n*=38	−0.88 (0.723)	(−2.32, 0.56); 0.2278	−0.28 (−0.73, 0.17)
Follow-up	−1.62 (−2.65, −0.59) *n*=40	−0.96 (−1.99, 0.08) *n*=38	−0.67 (0.734)	(−2.13, 0.80); 0.3656	−0.21 (−0.65, 0.24)
SOCQ-ED total					
Baseline	29.7 (27.1, 32.3) *n*=48	30.6 (27.8, 33.3) *n*=48	-	-	-
Treatment cessation	−7.71 (−10.33, −5.10) n=40	−2.78 (−5.56, −0.00) n=38	**−4.93 (1.935)**	**(−8.79, −1.07); 0.0131**	−0.58 (−1.04, −0.12)
Follow-up	−6.44 (−9.25, −3.63) n=39	−3.14 (−6.21, −0.07) n=38	−3.30 (2.086)	(−7.47, 0.86); 0.1181	−0.37 (−0.82, 0.09)
IDEA total					
Baseline	2.1 (2.0, 2.3) n=46	2.3 (2.1, 2.5) n=46	-	-	-
Treatment cessation	−0.33 (−0.51, −0.14) n=37	−0.09 (−0.27, 0.09) n=38	−0.24 (0.133)	(−0.50, 0.03); 0.0765	−0.41 (−0.86, 0.04)
Follow-up	−0.32 (−0.52, −0.13) n=36	−0.12 (−0.32, 0.08) n=36	−0.20 (0.142)	(−0.49, 0.08); 0.1546	−0.33 (−0.78, 0.12)

Figure legend: Between-group differences in change from baseline after adjusting for EDE-Q baseline value, treatment, and recruitment site, along with the estimated effect size. All analyses are ANCOVA models based on the ITT principle and handled with multiple imputations. Values are presented as mean (95% CI), indicating the mean value and its 95% CI, and n = indicates the number of observations. Bold indicates $P < 0.05$. Time points: treatment cessation, mean = 14.1 weeks (95% CI 13.30-14.83) after baseline for the VR avatar group and 13.2 (95% CI 12.79-13.67) weeks for the TAU group; follow-up mean = 27.2 weeks after baseline for the VR avatar group (95% CI 26.28-28.07) and 26.1 (95% CI 25.30 - 26.97) weeks for the TAU group. EDE-Q, Eating Disorder Examination Questionnaire; EAVE-Q,

Experience of An Anorexic Voice Questionnaire; BAVQR – engagement affective, Revised Beliefs About Voices Questionnaire', subscore engagement affective; HADS – Depression, Hospital Anxiety and Depression Scale, subscale depression; SOCQ-ED, Stages of Change in Eating Disorders Questionnaire; IDEA, Identity and Eating Disorder Questionnaire.

Fig 2 Effect size forest plots of primary, secondary and exploratory



For main analyses, data is imputed using a MCMC multivariate normal model with treatment, baseline and post baseline visit values as variables. Analysis model is ANCOVA of change from baseline, with site, treatment and baseline as variables. 50 datasets were analyzed and pooled using Rubin's rules. For NEQ and CSQ, a simple observed cases ANCOVA model at week 12 was run instead with observed value as outcome and site and treatment as variables. Cohen's d are computed by deriving Cohen's d estimate and SE for each imputation model and then using Rubin's rule to pool estimates. In the case of NEQ and CSQ, the (single) observed cases model was used instead as no imputations were performed.
Where applicable, questionnaire scores were multiplied by −1 so that for every questionnaire higher scores indicate better performance.

Secondary outcomes

A total of 3 out of 5 prespecified secondary outcomes showed significant treatment effect of the VR avatar intervention compared to TAU at treatment cessation: Compared with TAU, participants receiving the VR avatar intervention reported lower intrusiveness of the eating disorder voice on the Experience of An Anorexic Voice Questionnaire (EAVE-Q)[34] (score -4.36 points; 95% CI −8.20 to −0.52; Cohen's *d*=-0.51, *P*= 0.03, reduced emotional engagement with the eating disorder voice on the Revised Beliefs About Voices Questionnaire (BAVQR) emotional engagement scale)[35] (–

191 1.61 points; 95% CI -2.75, −0.47; Cohen's *d*= -0.63; *P*= 0.006), and improved motivation for
192 change on the Stages of Change in Eating Disorders Questionnaire (SOCQ-ED) [36] (score −4.93
193 point, lower score means more motivation; 95% CI −8.79 to −1.07; Cohen's *d*= -0.58; *P*= 0.01).
194 Decrease in voice intrusiveness (EAVE-Q scores), were sustained at 24-weeks follow-up (EAVE-Q
195 score −5.07 points; 95% CI −10.23, 0.09; Cohen's d=-0.45; P=0.05) and was the only secondary
196 outcome to reach this threshold. No statistically significant between-group differences were
197 observed for depressive symptoms on The Hospital Anxiety and Depression Scale (HADS),
198 subscale Depression[37] and in identification with the eating disorder and level of embodiment on the
199 Identity and Eating Disorder Questionnaire (IDEA)[38] (table 4).

200 Adverse events and harms

201 Serious adverse events (SAEs) were prospectively monitored and reviewed by the principal
202 investigator and the research ethics committee. No deaths were reported. No SAEs were considered
203 related to study participation. No suicide attempts occurred in either group from baseline to
204 treatment cessation; one attempt (2.6%) was reported in the VR avatar group between treatment
205 cessation and follow-up, and none in the TAU group. Hospitalizations occurred in both groups:
206 from baseline to treatment cessation, three participants (6.2%) in the VR avatar group and two
207 (4.3%) in the TAU group; from treatment cessation to follow-up, six (13%) and two (4.3%),
208 respectively. Self-harm within the past week was reported by three participants (7.5%) in the VR
209 avatar group and one (2.6%) in the TAU group between baseline and treatment cessation, and by
210 one (2.6%) and four (11.1%), respectively, at follow-up.

211 The Negative Effects Questionnaire (NEQ) [39], included as an exploratory measure of emotional and
212 cognitive adverse effects from treatment showed lower total negative impact in the VR avatar group
213 compared with TAU D (score 3.32; 95%CI 4.69, 1.94); Cohens *d*= 0.93, *P*= <0.0001 .

Cybersickness assessed using the Simulation Sickness Questionnaire (SSQ) [40], during VR sessions 2, 3, and 7, remained low throughout treatment (mean total scores: session 2, 4.6; session 3, 3.4; session 7, 4.0), consistent with minimal symptom burden.

Exploratory outcomes

Several exploratory outcomes showed more favorable effects in the VR avatar group at treatment cessation. Across voice-related measures, participants receiving the VR avatar intervention reported reduced distress associated with the eating disorder voice on an adapted version of the Psychotic Symptoms Rating Scale, Auditory Hallucinations (PSYRATS-AH)[41] (score −3.51 points; 95% CI −6.58 to −0.44; Cohen's *d*=-0.57; *P*=0.03), lower perceived voice power on the Voice Power Differential Scale (VPDS)[42] (score −2.13 points; 95% CI −3.94 to −0.32; Cohen's *d*=-0.52, *P*=0.02), with effects lasting until follow-up and greater acceptance of the voice on the Voices Acceptance Scale, subscale Acceptance (VAAS-A)[43] (score +2.36 points; 95% CI 0.01 - 4.70; Cohen's *d*=0.45; *P*=0.05), with effects increasing by follow-up (VAAS-A score +4.27 points; 95% CI 1.62, 6.92; Cohen's *d*=0.75, *P*=0.002) relative to TAU.

Beyond voice-specific outcomes, the VR avatar intervention was associated with greater improvement in quality of life on the Eating Disorder Quality of Life Scale (EDQLS)[44] (score +8.32 points; 95% CI 0.41 -16.23; Cohen's *d*=0.48; *P*=0.04) and personal recovery on the Questionnaire about Process of Recovery (QPR-15)[45] (score +4.92 points; 95% CI 1.61 - 8.23; Cohen's *d*=0.68, *P*=0.004) compared to TAU at treatment cessation.

Participants in the intervention group also showed higher self-compassion on the Self-Compassion Scale (SCS)[46] (score 0.23 points; 95% CI 0.02 - 0.44; Cohen's *d*=0.49; *P*=0.03), and improved cognitive flexibility on the Behavior Rating Inventory of Executive Functioning (BRIEF) questionnaire[47] (score −8.25, lower score means greater cognitive flexibility; 95% CI −15.22 to

−1.29; Cohen's *d*=-0.56; *P*= 0.02) relative to TAU at treatment cessation. At follow-up the effects were no longer present. Client satisfaction, measured with the Client Satisfaction Questionnaire (CSQ)[48] at treatment cessation, was substantially higher in the VR avatar group (score 6.84; 95% CI 4.84, 8.85; Cohen's *d*=1.50, *P*=<0.0001).

There were no statistically significant between-group differences observed for dissatisfaction with body shape on the Body Shape Questionnaire (BSQ-34)[49], positive and negative aspects of the eating disorder on the Pros and Cons of Eating Disorders questionnaire (P-CED)[50], self-efficacy on the General Self-Efficacy Scale (GSE)[51], eating disorder related cognitive inflexibility on the Detail and Flexibility Questionnaire in Eating Disorders (Dflex)[52], ambivalence towards the eating disorder (P-CED), general dysfunctional attitudes on the Dysfunctional Attitude Scale questionnaire (DAS-24)[53], or emotion regulation on the Emotion Regulation Questionnaire (ERQ)[54] (table 5).

Table 5 Adjusted between-group difference in change from baseline and effect sizes on exploratory outcomes.

Variable	VR avatar change (95% CI)	TAU change (95% CI)	Between-group difference (s.e.)	95% CI; *P* value	Cohen's *d* (95% CI)
PSYRATS – AH total					
Baseline	26.4 (25.5, 27.4) n=47	25.6 (24.5, 26.7) n=48	-	-	-
Treatment cessation	−5.38 (−7.33, −3.43) n=39	−1.87 (−4.04, 0.31) n=38	**−3.51 (1.530)**	**(−6.58, −0.44); 0.0256**	−0.57 (−1.06, −0.08)
Follow-up	−5.81 (−7.85, −3.76) n=37	−3.32 (−5.51, −1.12) n=36	−2.49 (1.568)	(−5.63, 0.65); 0.1183	−0.39 (−0.87, 0.09)
EDQLS total					
Baseline	104.4 (99.1, 109.7) n=48	107.3 (101.7, 112.9) n=48	-	-	-
Treatment cessation	17.60 (12.12, 23.08) n=40	9.28 (3.58, 14.98) n=37	**8.32 (3.961)**	**(0.41, 16.23); 0.0395**	0.48 (0.03, 0.93)

Follow-up	17.44 (11.46, 23.42) n=40	10.55 (4.15, 16.95) n=37	6.89 (4.335)	(−1.76, 15.54); 0.1165	0.36 (−0.09, 0.81)
VPDS total					
Baseline	24.1 (23.2, 25.1) n=46	23.4 (22.4, 24.4) n=46	-	-	-
Treatment cessation	−3.58 (−4.87, −2.28) n=37	−1.45 (−2.73, −0.17) n=38	**−2.13 (0.907)**	**(−3.94, −0.32); 0.0219**	−0.52 (−0.97, −0.08)
Follow-up	−4.02 (−5.52, −2.52) n=36	−1.94 (−3.47, −0.41) n=36	**−2.08 (1.074)**	**(−4.22, 0.07); 0.0573**	−0.44 (−0.89, 0.01)
VAAS – A total					
Baseline	35.1 (33.6, 36.6) n=46	35.8 (33.9, 37.6) n=46	-	-	-
Treatment cessation	4.46 (2.81, 6.12) n=37	2.11 (0.46, 3.75) n=38	**2.36 (1.174)**	**(0.01, 4.70); 0.0487**	0.45 (0.00, 0.90)
Follow-up	5.97 (4.14, 7.80) n=36	1.70 (−0.15, 3.55) n=36	**4.27 (1.329)**	**(1.62, 6.92); 0.0021**	0.75 (0.28, 1.22)
SCS total					
Baseline	2.2 (2.0, 2.4) n=47	2.2 (2.1, 2.4) n=48	-	-	-
Treatment cessation	0.40 (0.25, 0.54) n=39	0.17 (0.02, 0.32) n=37	**0.23 (0.104)**	**(0.02, 0.44); 0.0308**	0.49 (0.05, 0.92)
Follow-up	0.14 (−0.02, 0.29) n=39	0.31 (0.16, 0.46) n=37	0.17 (0.106)	(−0.04, 0.38); 0.1134	0.36 (−0.08, 0.80)
BSQ-34 total					
Baseline	132.6 (123.4, 141.8) n=48	127.4 (118.4, 136.4) n=48	-	-	-
Treatment cessation	−17.92 (−25.73, −10.11) n=40	−9.43 (−17.50, −1.35) n=38	−8.49 (5.817)	(−20.12, 3.14); 0.1494	−0.35 (−0.81, 0.12)
Follow-up	−12.15 (−20.37, −3.93) n=40	−13.76 (−22.23, −5.30) n=37	1.61(6.001)	(−10.37, 13.59); 0.7890	0.06 (−0.39, 0.51)
GSE total					
Baseline	25.8 (23.7, 27.8) n=46	27.0 (25.2, 28.9) n=46	-	-	-
Treatment cessation	0.56 (−0.71, 1.83) n=37	0.82 (−0.41, 2.05) n=37	−0.26 (0.886)	(−2.03, 1.50); 0.7662	−0.07 (−0.51, 0.38)
Follow-up	0.34 (−0.89, 1.58)	0.76 (−0.53, 2.04)	−0.41 (0.904)	(−2.22, 1.39); 0.6489	−0.11 (−0.57, 0.35)
ERQ – cognitive reappraisal					

Baseline	3.8 (3.5, 4.2) n=46	4.2 (3.8, 4.5) n=48	-	-	-
Treatment cessation	0.33 (0.09, 0.56) n=38	0.08 (−0.15, 0.31) n=37	0.25 (0.164)	(−0.08, 0.57); 0.1376	0.35 (−0.11, 0.80)
Follow-up	0.32 (0.06, 0.58) n=38	0.08 (−0.19, 0.34) n=37	0.24 (0.184)	(0.06, 0.58); 0.1881	0.31 (−0.15, 0.76)
ERQ – emotion suppression					
Baseline	4.0 (3.6, 4.3) n=46	4.3 (4.0, 4.7) n= 48	-	-	-
Treatment cessation	−0.38 (−0.71, −0.04) n=38	0.05 (−0.27, 0.37) n=37	−0.43 (0.227)	(−0.88, 0.03); 0.0642	−0.43 (−0.88, 0.02)
Follow-up	−0.41 (−0.74, −0.08) n=38	−0.05 (−0.38, 0.28) n=37	−0.36 (0.233)	(−0.83, 0.10); 0.1245	−0.36 (−0.82, 0.10)
BRIEF total					
Baseline	67.1 (57.8, 76.4) n=46	58.6 (49.9, 67.3) n=48	-	-	-
Treatment cessation	−8.06 (−13.12, −3.00) n=38	0.20 (−4.60, 4.99) n=37	**−8.25 (3.483)**	**(−15.22, −1.29); 0.0209**	−0.56 (−1.02, −0.09)
Follow-up	−6.15 (−11.26, −1.03) n=37	−0.91 (−6.00, 4.19) n=37	−5.24 (3.531)	(−12.29, 1.80); 0.1423	−0.34 (−0.79, 0.11)
Dflex total					
Baseline	89.6 (83.8, 95.4) n=46	86.6 (81.4, 91.8) n=48	-	-	-
Treatment cessation	−3.47 (−7.22, 0.28) n=38	−2.89 (−6.38, 0.59) n=37	−0.58 (2.578)	(−5.73, 4.57); 0.8232	−0.05 (−0.51, 0.40)
Follow-up	−4.13 (−8.04, −0.22) n=36	−2.51 (−6.40, 1.37) n=37	−1.61 (2.720)	(−7.04, 3.82); 0.5555	−0.14 (−0.58, 0.31)
DAS-24 total					
Baseline	108.2 (101.9, 114.6) n=44	110.9 (105.4, 116.4) n=46	-	-	-
Treatment cessation	−9.42 (−13.71, −5.12) n=36	−4.50 (−8.51, −0.49) n=36	−4.91 (2.959)	(−10.82, 1.00); 0.1018	−0.39 (−0.85, 0.07)
Follow-up	−12.43 (−18.24, −6.62) n=34	−7.22 (−12.78, −1.65) n=36	−5.21 (3.960)	(−13.12, 2.70); 0.1926	−0.31 (−0.76, 0.15)
P-CED total					
Baseline	10.7 (4.7, 16.6) n=46	14.2 (7.2, 21.2) n=48	-	-	-
Treatment cessation	−0.77 (−6.46, 4.92) n=38	0.03 (−5.42, 5.48) n=37	−0.81(4.017)	(−8.83, 7.22); 0.8416	−0.05 (−0.50, 0.41)

Follow-up	−0.18 (−5.32, 4.97) n=37	−0.05 (−5.35, 5.26) n=37	−0.13 (3.622)	(−7.35, 7.09); 0.9714	−0.01 (−0.45, 0.43)
QPR-15 total					
Baseline	35.2 (32.5, 37.9) n=46	35.6 (32.5, 38.7) n=48	-	-	-
Treatment cessation	6.53 (4.16, 8.91) n=38	1.61 (−0.69, 3.92) n=37	**4.92 (1.656)**	**(1.61, 8.23); 0.0041**	0.68 (0.22, 1.14)
Follow-up	5.58 (2.86, 8.30) n=37	2.57 (−0.12, 5.26) n=37	3.01 (1.885)	(−0.75, 6.78); 0.1147	0.37 (−0.09, 0.83)
CSQ total					
Treatment cessation	27.80 (26.40, 29.19) n=40	20.95 (19.52, 22.38) n=38	**6.84 (1.003)**	**(4.84, 8.85); <0.0001**	1.50 (0.98, 2.01)
NEQ total					
Treatment cessation	3.32 (4.69, 1.94) n=40	7.59 (8.93, 6.25) n=38	**4.27 (0.96)**	**(2.34, 6.20); <0.0001**	0.93 (0.43,1.42)

Figure legend: Between-group treatment effect differences in change from baseline after adjusting for EDE-Q baseline value, treatment, and recruitment site, along with the estimated effect size. All analyses are ANCOVA models of change from baseline based on the ITT principle and handled with multiple imputations.

The Client Satisfaction Questionnaire (CSQ) and Negative Effects from Therapy Questionnaire (NEQ) are not adjusted for baseline measurement as they were not administered at baseline. For CSQ and NEQ an observed cases ANCOVA model with observed value as outcome, treatment effect variable adjusted for recruitment site and treatment and no imputations were performed. The number of observations in the analysis were n=40. Values are presented as adjusted means (95% CI), indicating the mean value and its 95% CI, and n = indicates the number of observations. Bold indicates $P < 0.05$. Time points: treatment cessation, mean = 14.1 weeks (95% CI 13.30-14.83) after baseline for the VR avatar group and 13.2 (95% CI 12.79-13.67) weeks for the TAU group; follow-up mean = 27.2 weeks after baseline for the VR avatar group (95% CI 26.28-28.07) and 26.1 (95% CI 25.30 - 26.97) weeks for the TAU group.

PSYRATS-AH, Psychotic Symptoms Rating Scale – Auditory Hallucinations; EDQLS, Eating Disorder Quality of Life Scale; VPDS, Voice Power Differential Scale; VAAS-A, Voices Acceptance Scale, section A; SCS, Self-Compassion Scale; BSQ-34, Body Shape Questionnaire; GSE, General Self-Efficacy Scale; ERQ - Cognitive reappraisal, Emotion Regulation Questionnaire; BRIEF, Behavior Rating Inventory of Executive Function; Dflex, Detail and Flexibility Questionnaire; DAS-24, Dysfunctional Attitude Scale; P-CED, Pros and Cons of Eating Disorders Questionnaire; QPR-15, Questionnaire about the Process of Recovery.

Sensitivity analyses

Three prespecified sensitivity analyses were conducted to assess the robustness of the primary outcome. First a mixed model analysis including participants with baseline and at least one post-baseline measurement, yielded an adjusted mean difference at treatment cessation of −0.30 (95% CI −0.69 to 0.09; $P = 0.13$), similar to the ANCOVA estimate of −0.28 (95% CI −0.67 to 0.11; $P = 0.15$).

Second, a mixed model including past-year drug abuse, which was strongly associated with missingness, also produced a similar adjusted mean difference at treatment cessation (−0.47; 95% CI: −1.26 to 0.32; P=0.24).

Third, a mixed model including a fixed effect for therapists to account for potential clustering of outcomes by therapist, yielded a slightly larger, but still non-significant adjusted mean difference at treatment cessation (−0.47; 95% CI −0.96 to 0.02; $P = 0.062$) compared to the primary analysis. The overall interpretation of the primary outcome was unchanged.

An exploratory per-protocol analysis including participants who completed all seven therapy sessions and all TAU participants yielded results consistent with the intention-to-treat analysis (adjusted mean difference −0.32; 95% CI −0.72 to 0.07; P = 0.11), indicating that findings were robust to protocol adherence.

A post-hoc analysis also compared complete-case ANCOVA results of observed scores vs. log transformed scores (using fold change from baseline as outcome and log baseline as covariate instead). Residual plots and significance of treatment effect did not show meaningful differences that would favor using logarithmic transformation. Overall, all sensitivity analyses showed very similar treatment effect estimate results.

Moderation analyses

Prespecified exploratory moderation analysis suggested that treatment effects on eating disorder symptoms at treatment cessation differed by baseline childhood trauma. Among participants with low to moderate trauma (CTQ ≤ 35) the VR avatar intervention was associated with a greater reduction in symptoms compared with TAU (adjusted mean difference −0.64, 95% CI −1.22 to −0.06; P = 0.03). In contrast, no treatment effect was observed among participants with high trauma exposure (CTQ > 35; adjusted mean difference 0.03; 95% CI −0.52 to 0.59; P = 0.91). The effect observed in the low-to-moderate trauma subgroup was not sustained at follow-up.

Moderation by baseline psychiatric comorbidity did not indicate differential treatment effects. Participants with 0–1 comorbid diagnoses (adjusted mean difference of −0.28 (95% CI −0.89 to 0.34; P = 0.37) and those with two or more comorbid diagnoses (adjusted mean difference of −0.32 (95% CI −0.86 to 0.23; P = 0.25) showed similar outcomes.

Correlation analyses

Greater sense of presence in the virtual environment was associated with lower eating disorder symptom severity at treatment cessation, with numerically stronger associations for presence measured later in treatment (Session 7) compared with earlier sessions (Session 7: Pearson's r = −0.35; 95% CI −0.60 to −0.04; P = 0.028; Session 2: Pearson's r = −0.15; 95% CI −0.46 to 0.20; P = 0.41) (fig 3).

Associations between simulation sickness (SSQ), assessed in session two, three and seven, and symptom outcomes were small, with no consistent pattern across sessions. (Session 7: Pearson's r = 0.16; 95% CI −0.17 to 0.45; P = 0.35; Session 3: Pearson's r= 0.19; 95% CI −0.15 to 0.50; P= 0.263; Session 2: Pearson's r = −0.01; 95% CI −0.32 to 0.31, P = 0.98) (fig 4).

Discussion

To our knowledge, this is the first fully powered randomized trial to evaluate an avatar-based therapy targeting anorexia nervosa and bulimia nervosa. Contrary to our primary hypothesis, the intervention delivered alongside TAU did not result in a statistically significant reduction in global eating disorder symptoms, compared with TAU alone. This finding was consistent across prespecified sensitivity analyses.

Despite the absence of an effect on the primary clinical outcome, the intervention produced consistent changes in its targeted psychological processes. Participants receiving the avatar intervention showed significantly greater improvements relative to TAU across prespecified secondary outcomes related to the eating disorder voice, including reduced intrusiveness and emotional engagement, supported by convergent effects across exploratory measures of voice-related distress, perceived power, and acceptance. Improvements were also observed in motivation for change and in several exploratory patient-centered outcomes, including self-compassion, personal recovery, quality of life, and cognitive flexibility. Together, these findings suggest that the intervention successfully modified psychological processes consistent with its theoretical framework, although most effects were not sustained at follow-up.

The lack of correspondence between changes in targeted psychological processes and improvements in global eating disorder symptoms indicates that process-level effects do not readily translate into broader clinical outcomes. One explanation is that interventions addressing a limited set of psychological mechanisms may be insufficient to alter overall symptom expression in a complex, multidetermined disorder such as eating disorders. Similar patterns have been reported for other adjunctive approaches, including exposure-based interventions (such as VR–based exposure), motivational interviewing, and cognitive remediation therapy, which can modify targeted processes

(for example, fear responses, motivation, and cognitive flexibility) without robust improvements in global eating disorder symptoms when added to standard care[55,56 57].

A second consideration is intervention dose. The present intervention was brief and may not have allowed sufficient opportunity for consolidation or generalization of change. Established psychological treatments for eating disorders, such as cognitive behavioral therapy, typically involve substantially longer treatment courses (e.g., 15-26 weeks)[58], and interventions targeting related processes to the VR avatar intervention, such as self-criticism, generally rely on repeated practice across multiple sessions (≥12 sessions) to achieve downstream effects on global symptoms[59]. The present format may therefore have been adequate to initiate change in targeted processes but insufficient to yield sustained effects at the symptom level.

It is also possible that the processes targeted by the intervention, although they may be clinically relevant are not sufficiently proximal to core behavioral pathology. Cognitive-behavioral models emphasize the central role of behavioral modification, particularly the normalization of eating patterns, in symptom reduction[60]. Accordingly, interventions focused primarily on cognitive or emotional processes may have limited clinical impact unless integrated with approaches that directly target eating-related behaviors[60].

In a prespecified exploratory moderation analysis, the intervention was associated with greater reductions in global eating disorder symptoms at treatment end among participants with low to moderate levels of childhood trauma, whereas no additional benefit was observed among those with higher trauma exposure. Although the study was not powered to test interaction effects, this finding suggests that individual characteristics may influence the extent to which mechanism engagement translates into clinical benefit. Individuals with higher levels of trauma exposure may be less likely to benefit from the intervention, potentially due to reduced tolerability. Although preliminary and

hypothesis-generating, this interpretation is consistent with our prior qualitative pilot findings indicating that the intervention's immersive, emotionally activating nature may exceed some individuals' window of tolerance in the context of trauma, leading to avoidance or disengagement[32].

The observed improvements in processes addressed in the intervention (such as increased power over the eating disorder voice and motivation for change) are consistent with several plausible mechanisms. A central feature of the intervention is the externalization of the eating disorder voice through the avatar format. Individuals with eating disorders often describe a sense of fusion with disorder-related cognitions or experience these thoughts as controlling or intrusive [21,61]. Enabling patients to engage with these cognitions as an external entity may facilitate psychological distance and enhance perceived agency, expanding imagery-based approaches such as chair work[62,63] through a more concrete and interactive representation. Speculating, the externalization of the eating disorder voice may also reduce identification with overall self-critical cognitions and facilitate more compassionate self-responding, consistent with the observed increases in self-compassion[61]. A second proposed mechanism relates to the immersive format. While verbal and imagery-based interventions engage emotional processes via internally generated representations, VR enables real-time interaction with emotionally salient material, potentially increasing the immediacy and intensity of affective responding [32,62]. This is consistent with the observed association between presence and symptom outcomes along with findings from avatar-based interventions in psychosis[31].

Beyond symptom outcomes, the intervention was associated with improvements in personal recovery and quality of life with effect sizes comparable to those reported for established psychological treatments despite substantially shorter duration of the intervention[64]. These findings align with lived-experience perspectives that emphasize agency, identity, and self-compassion as

central components of recovery[65],[66] and may reflect clinically meaningful change not captured by symptom-based outcomes alone.

The intervention was also associated with high acceptability, with a significant effect size above one, indicating greater satisfaction relative to TAU. Together with observed improvements in motivation for change, this suggests potential relevance for treatment engagement and adherence, factors that are strongly associated with long-term outcomes[67–69].

Several limitations should be considered. The inclusion of multiple secondary and exploratory outcomes increases the risk of type I error, and these findings should be interpreted cautiously. The absence of an active control group limits attribution of effects to intervention-specific mechanisms. In addition, a pragmatic definition of TAU resulted in heterogeneity in concurrent treatment exposure, which may have reduced sensitivity to detect additive effects of the intervention. Additionally, moderation analyses were exploratory and underpowered, and findings related to trauma exposure require replication. Finally, the underrepresentation of males and the absence of data on ethnicity and migrant status limit generalizability to male and minority populations.

In conclusion, we did not observe a statistically significant difference between the intervention delivered alongside TAU and TAU alone on the primary outcome of global eating disorders. However, the intervention engaged key psychological mechanisms consistent with its theoretical framework and improved several patient-centered outcomes, including quality of life, recovery, and treatment engagement. These findings underscore the distinction between mechanism engagement and clinical outcome and suggest that avatar-based interventions may be most useful as adjunctive approaches, potentially requiring greater intensity, behavioral integration, or stratified application to achieve sustained clinical benefit.

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Methods

Study design and participants

This study was an assessor-masked, randomized parallel group superiority trial conducted at the Mental Health Centre Copenhagen, Copenhagen University Hospital, Capital Region of Denmark. Participants were recruited from eating disorder outpatient services within the Mental Health Services in the Capital Region and Region Zealand, private clinics, municipal services, and patient interest groups. Individuals with an eating disorder diagnosis could also self-refer via social media advertisements and the online platform trialtree.com[70], that creates contact between research projects and potential participants. The trial was approved by the Committee on Health Research Ethics of the Capital Region of Denmark (H-22067692) and the Danish Data Protection Agency (P-2022-932). All participants provided informed consent. The study protocol has been published elsewhere[62]. The trial was overseen by a project management group (PMG), consisting of the principal investigator (PI), the trial coordinator/lead assessor, and the principal therapist.

Eligibility criteria

All referrals were screened for eligibility based on the following inclusion criteria: (1) 18 years or older, (2) ability to give informed consent (3), a diagnosis of eating disorder: Anorexia Nervosa, Bulimia Nervosa, Atypical Anorexia Nervosa, Atypical Bulimia Nervosa (ICD-10, F50.00 – F.50.30), (4) a global score of ≥ 2.77 EDE-Q[71], (5) and recognizing having an internal eating

615 disorder voice. Participants were excluded if (1) they had an organic brain disease, (2) comorbid
616 psychosis (ICD-10, F20.00-F29.00), (3) psychotic depression (ICD-10, F33.30-33.31), (4)
617 immediate suicide risk, (5) risk of refeeding syndrome, (6) insufficient proficiency in Danish or
618 English to engage meaningfully in therapy.

619 Randomization and masking

620 Participants were randomly assigned (1:1) to VR-based avatar intervention + TAU or TAU alone,
621 stratified by recruitment site/primary care to ensure both groups had a comparable range of TAU
622 interventions. The randomization sequence was generated by an independent statistician not
623 otherwise involved in the trial, using a concealed fixed block size of 6, and trial personnel remained
624 unaware of block size throughout the trial. The sequence was inaccessible to study personnel
625 involved in enrollment or assessment.

626 Randomization occurred after completion of baseline assessment via a secure, computer-generated
627 allocation system created in Stata by the independent trial statistician. Non-masked personnel (i.e.,
628 trial therapists), informed participants of their group assignment.

629 Outcome assessors remained masked throughout the study by conducting assessments at a separate
630 location from the VR therapy sessions and participants were instructed not to disclose their
631 randomization allocation. Unmasking occurred on two occasions, but only after completion of all
632 assessor-rated components of the relevant assessments. Data analyst and statistician were masked to
633 treatment allocation during the efficacy analyses.

Procedure

VR-based avatar intervention

The VR-treatment manual and software was an adaption of a previously validated immersive, VR-based avatar intervention for psychosis [72]. Initial adaptation was informed by individual interviews with eight individuals with lived experience of eating disorders and a focus group with six clinicians, shaping therapy content, avatar design and session structure. The manual was subsequently refined based on participant feedback from a pilot study, maximizing clinical relevance and acceptability[32]. Individuals with lived experience also contributed to stakeholder engagement, including meetings with policymakers, and were involved in dissemination activities such as public presentations and media engagement.

Participants allocated to the experimental intervention received seven weekly individual VR therapy sessions alongside treatment as usual (TAU). The intervention is a brief, mechanism-focused adjunct targeting the perceived power dynamic between individuals and their eating disorder voice. Using an individually adapted therapist-operated avatar, the voice is externalized within a virtual environment, enabling real-time dialogue between the voice and the patient. Through assertive expression of personal values, wishes and boundaries, participants are supported in gaining greater perceived control over the voice, with the aim of reducing identity fusion and enhancing motivation for change, treatment engagement and psychological flexibility. Based on user input, the VR avatar manual for psychosis was adapted by reducing therapy modules and shifting focus from self-esteem enhancement to increasing dissonance between participants and their eating disorder voice. The VR software, developed by Heka VR, was similarly modified to better reflect eating disorder pathology, including reduced emphasis on the avatar's body and the incorporation of food-related stimuli to enhance ecological validity.

The intervention was delivered by two psychologists: one with four years of experience in eating disorder treatment (conducted 29 therapy courses) and one with 10 years of experience in cognitive behavioral therapy, primarily within psychosis (conducted 17 therapy courses). Both received formal training in avatar-based therapy through our previous psychosis trial[73], with weekly internal and monthly external supervision provided throughout.

Session one lasted 90 minutes; sessions two to seven lasted 60 minutes, with approximately 15 minutes spent in VR and the remainder allocated to preparation and reflection. The intervention comprised two flexible phases: exposure and confrontation (sessions 2–3), identity and values (sessions 4–6), and a closing session focused on evaluation and planning of subsequent therapist-independent work (session 7). Session allocation could be adjusted based on clinical progression, and therapists continuously monitored distress and adjusted interaction intensity accordingly. All sessions were conducted face to face in a dedicated therapy room.

During the first session, participants identified key distressing verbal content and characteristics of their eating disorder voice and collaboratively designed an avatar to embody this voice, with options to customize gender, age, facial features, body size, and skin and hair color. A voice modulation program was used to alter the therapist's voice to match the tone and pitch of each participants imagined eating disorder voice.

In subsequent sessions, participants wore a VR headset and noise-cancelling headphones while engaging in dialogue with the avatar. Within the virtual environment, participants were seated opposite the avatar in a neutral living room setting. The therapist was not visible in VR but operated the avatar and alternated between speaking as the avatar (using the transformed voice) and as a supportive therapist (Fig. 3).

Fig 3 Photograph of therapy set-up and VR equipment



To promote skill consolidation, participants were provided with an image of their avatar and audio recordings of avatar dialogues for between-session review, intended to reinforce perceived control and motivation for change, maintain therapeutic gains, and facilitate discussion with significant others or care providers.

Treatment as usual

Participants in both groups received TAU, which was not standardized and varied across individuals. TAU included individual or group psychotherapy within public mental health services or private clinics, dietary guidance and/or meal support, consultations with private dietitians, psychotherapists, psychiatrists or general practitioners (see supplementary table 1).

Outcomes

The primary outcome was the EDE-Q global score at treatment cessation. The EDE-Q is a widely used self-report measure, range 0-6, with reliability and validity across clinical and community samples [71,74–76]. The primary outcome was also measured at 24-week follow-up as an exploratory outcome. All outcome measures were self-report questionnaires, with the exception of the PSYRATS-AH, which was administered as a semi-structured interview.

Secondary outcomes, all measured at treatment cessation, were as follows:

- The **EAVE-Q**[34].
- The **BAVQR**, subscale Engagement, divided into emotional and behavioral ways of reacting[35].
- The **HADS**, subscale depression[37].
- The **IDEA** [38].
- The **SOCQ-ED**[36].

All secondary outcomes were also assessed at the 24-week follow-up as exploratory outcomes. Exploratory treatment outcomes, measured at treatment cessation and follow up, except for CSQ and NEQ, that were only administered at treatment cessation:

- The **PSYRATS-AH** [41].
- The **EDQLS** [44].
- The **VPDS** [42].
- The **VAAS**[43]. Only the subscale VAAS acceptance was included in the analysis due to a small n for the VAAS subscale action.
- The **SCS**[46].

- The **BSQ-34** [49].
- The **GSE** [51].
- The **ERQ** [54].
- The **BRIEF** [47].
- The **Dflex** [52].
- The **DAS-24** [53].
- The **P-CED** [50].
- The **QPR-15** [45].
- The **CSQ** [48].
- The **NEQ** [39].

Potential moderators of therapy outcome:

- The **MINI** (diagnostic interview)[77] at baseline to asses comorbid diagnoses according to ICD10.[78]
- The **CTQ**[79] at baseline.
- The **MPS**[80] modified version, only including subscales relevant to the VR-based avatar intervention's virtual environment. Administered at VR therapy sessions 2 and 7.
- The **SSQ**[40] at VR therapy sessions 2, 3 and 7. The global score was calculated using an unweighted approach.

Inter-rater reliability and fidelity to treatment manual

Assessments were conducted at baseline, treatment cessation (12 weeks post baseline), and follow-up (24 weeks post baseline) by two trained psychologists. Internal supervision on outcome assessment procedures was provided as needed throughout the study period. The lead assessor, responsible for conducting diagnostic interviews in cases where participants were referred without an established eating disorder diagnosis, received formal training in eating disorder assessment and diagnosis prior to trial initiation. Additional external supervision on diagnostic procedures was provided by an international expert on eating disorders.

As all primary and secondary outcomes were self-reported, and only one exploratory outcome involved clinician rating (Psychotic Symptoms Rating Scale – Auditory Hallucinations; PSYRATS-AH), inter-rater reliability was not formally assessed.

Fidelity to the treatment manual was assessed for therapists delivering the VR-based avatar intervention. All VR-based therapy sessions were audio-recorded and eight therapy courses (56 sessions) were randomly selected and rated by an independent clinical psychologist holding a specialist degree in psychotherapy, who was not otherwise involved in the trial.

Fidelity was assessed using a manual adapted from the English AVATAR therapy fidelity manual (revised in 2015 [27]), modified to target eating-disorder psychopathology. The fidelity measure consisted of two subscales: (1) fidelity to the treatment manual, with a total score ranging from 0 to 23, and (2) therapist nonspecific factors (e.g., empathy, appropriate responding, handling of person specific aspects (e.g., cultural background, sex, history of trauma), with a total score ranging from 6 to 30. Higher scores indicated greater manual adherence and higher levels of nonspecific therapist competence. The therapists demonstrated ‘good’ to ‘very good’ fidelity with a mean score of 21.4

(SD 1.4; 95% CI 20.2-22.6) and high levels of nonspecific therapist competence with a mean of 28.0 (SD 2.4; 95% CI 26.0-30.0).

Adverse events and harms

All prespecified serious adverse events (SAEs) were recorded in accordance with the study protocol[62] to descriptively assess serious adverse events by treatment group. SAEs were defined as hospital admission, suicide attempt, self-harm, death, or violent incidents requiring police involvement, and were assessed at each therapy session. Adverse events (AEs), including deterioration in eating disorder symptoms or other psychiatric symptoms, were recorded in the same procedure.

All AEs and SAEs were reviewed by the trial safety group, comprising the principal investigator and lead therapist, both unblinded to treatment allocation, and classified according to relatedness to therapy, device, or assessment procedures as related, possibly related, or unrelated. SAEs were reported to the Committee on Health Research Ethics of the Capital Region of Denmark within seven days, and AEs were reported annually, in accordance with regulatory requirements.

Medical records were reviewed for SAEs in both treatment arms at 12- and 24-weeks post-baseline. Self-harm in the preceding week was assessed at post-baseline interviews (12 weeks and 24 weeks post baseline) to supplement clinical records.

As prespecified in the statistical analysis plan, exploratory participant-reported adverse effects were assessed at treatment cessation (12 weeks post baseline) using the Negative Effects Questionnaire (NEQ)[39].

Given the immersive and emotion-focused nature of the intervention, transient distress was anticipated. Participants were informed of this risk before enrolment, and therapists continuously

monitored distress during sessions and provided appropriate clinical support and follow-up as needed, in compliance with standardized procedures described in the published trial protocol[62]. Virtual-reality–specific side effects were monitored using the SSQ, administered during VR sessions 2, 3, and 7.

SAEs were summarized descriptively by treatment group as counts and proportions of participants with at least one event and as total event counts, including multiple events per participant to . No inferential analyses of SAEs were prespecified in the statistical analysis plan or conducted. As prespecified, between-group comparisons were performed for participant-reported adverse effects (NEQ) using the same approach as for the primary outcome (see 'Statistical Analysis').

Statistical analysis

The sample size calculation was based on the primary outcome measure, the EDE-Q global score. Previous research identified a clinically meaningful change of 0.83 points on the EDE-Q (SD = 1.31)[81], corresponding to a standardized effect size (Cohen's d) of 0.63. Assuming a two-sided significance level of $\alpha = 0.05$ and 80% power required 40 participants per group. Allowing for 20% attrition, the target sample size was set at 96 participants (48 per group).

Statistical analyses were conducted using R 4.5.1.[82] Tests were two-sided with a significance level of $\alpha = 0.05$. Where applicable, results were reported as estimates with 95% confidence intervals (CIs) and corresponding P values. The statistical analysis plan was preregistered before outcome analyses were conducted and is publicly available via OSF (https://osf.io/um638/overview).

The primary analysis followed the intention-to-treat (ITT) principle, including all randomized participants according to assigned allocation.

The primary analysis for the primary outcome was analyzed using an analysis of covariance (ANCOVA) model of change from baseline, with treatment group and recruitment site as factors and baseline EDE-Q score as a covariate. Adjusted mean differences between treatment groups with 95% CIs and p-values are reported.

Missing outcome data were assumed to be missing at random (MAR) and handled using multiple imputations. The prespecified imputation model included treatment group, recruitment site, baseline EDE-Q score, and EDE-Q scores at weeks 12 and 24 as variables. As also stated in the SAP, the site variable was dropped from the imputation model (but was included in the analysis model) due to separability issues. Fifty imputed datasets were generated, and ANCOVA parameter estimates of all datasets were combined using Rubin's rules.

Several sensitivity analyses were planned and conducted to assess robustness of the primary analysis conclusions:

a) A linear mixed effect model analysis on the mITT population (everyone with baseline and at least one post-baseline assessment) of change from baseline with treatment and recruitment site as factors and baseline score as covariate, with treatment and baseline nested within visit, and an unstructured covariance matrix.
b) An extension of model under a) planned to include a random effect for therapists to account for potential clustering of effect. The actual analysis included therapists as fixed effects nested within visit.
c) Tipping point-analysis, for the case where the primary endpoint shows statistical significance, to explore how departures from the MAR assumption impact the primary analysis conclusions. As per SAP, due to non-significance of the primary endpoint, this analysis was not performed.

d) An extension of the original imputation model was planned that includes (individually, one at a time) the baseline variables associated with missingness at post-baseline visits. The only variable highly associated with missingness was drug abuse in the past year. Due to limitations of the imputation software[83] used, an extension of the mixed effects model under a) was used instead, adding drug abuse in the past year as factor in the model nested within visit and treatment.

e) An exploratory per protocol sensitivity analysis including participants in the VR avatar group receiving all 7 therapy sessions and all TAU participants.

A post-hoc sensitivity analysis also compared complete case analysis results using original scores vs. logarithmically transformed scores (using instead fold change from baseline as outcome and log baseline score as covariate).

Two baseline moderation variables were identified in the SAP and used for subgroup analyses:

I. Moderation by baseline psychiatric comorbidity was examined using (1) active diagnoses documented in health records and (2) current symptom-based diagnoses assessed with the Mini International Neuropsychiatric Interview (MINI). Participants were categorized as having an eating disorder with one comorbid diagnosis or more than two comorbid diagnoses.

II. Moderation by childhood trauma was assessed using the Childhood Trauma Questionnaire (CTQ), analyzed as a continuous variable and additionally dichotomized using a predefined cutoff (>35) to indicate moderate-to-severe exposure.

All subgroup analyses were planned to be conducted by extending the original imputation model. However, similarly as for point d) of sensitivity analyses, an extension of the mixed effects model under a) was used instead, by adding (individually) the number of diagnoses (<= 1 vs. > 1),

continuous CTQ, and binary CTQ (<= 35 vs. >35), respectively, as factors/covariates in the model nested within visit and treatment. The treatment effect difference estimates for each subgroup were reported for comparison of magnitude of treatment effect across subgroups.

Prespecified exploratory correlation analyses were conducted to examine relationships between treatment outcomes and measures of virtual reality experience. Mean levels of immersion, assessed after 2 and 7 using a modified version of the Multi-Modal Presence Scale (MPS), and simulator sickness, assessed using the Simulator Sickness Questionnaire (SSQ), were summarized across sessions 2, 3 and 7 for each participant. These measures were examined in relation to eating disorder symptom severity at 12 weeks (EDE-Q) using scatter plots and Pearson correlation coefficients.

Secondary and exploratory efficacy outcomes were analyzed using the same modelling approach as the primary analysis for the primary outcome.

Continuous variables were summarized as means with standard deviations or medians with interquartile ranges depending on distribution, and categorical variables as counts and percentages. No adjustments were made for multiple comparisons; therefore, the reported p-values for secondary and exploratory are considered nominal.

No interim analyses were planned or conducted; recruitment continued until the prespecified sample size was achieved.

Protocol deviations

To facilitate recruitment, the definition of TAU was broadened in September 2025 to include consultations with private dietitians and private psychiatrists or general practitioners as part of routine clinical care. These modifications were intended to reflect the range of services accessible to

patients alongside specialized hospital treatment while preserving the randomized design, as described in the study protocol[62]. Participants without a prior diagnosis underwent a diagnostic interview conducted by the lead assessor.

Some sensitivity and moderation analyses were planned to be performed by running the extended imputations and analyzed using ANCOVA. Due to the software limitations and since the number of missing data on the primary endpoint was quite low, these analyses were instead run using mixed effect models, anticipating the conclusions from the two approaches to be very similar. The sensitivity analysis expanding the mixed effect model by adding a random effects term for therapists instead added a fixed effect term for therapists, nested within visit.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

Open access information on the Dialogue trial is published on ClinicalTrials.gov (registration: NCT06345040). The final protocol and subsequent update are published in PLOS One. All deidentified trial data are available through the Danish National Archives (Rigsarkivet), a public data repository, for an unlimited period. Access requests can be submitted via www.rigsarkivet.dk. Due to the Danish Archives Act (Arkivloven), the Danish Archives Executive Order (Arkivbekendtgørelsen), the General Data Protection Regulation (Databeskyttelsesforordningen) and the Danish Data Protection Act (Databeskyttelsesloven), access is restricted. For the first 20 years, data access is subject to prior review by the research group. Access must always be approved by the Danish Data Protection Agency (Datatilsynet), as the data are considered sensitive personal

information. After 75 years, the data will be openly accessible without the need for approval. In principle, the research group will grant access to academic or clinical researchers conducting noncommercial, ethically approved research. An initial response to access requests will be provided within 1 month. A Data Access Agreement must be signed before data sharing. Source data are provided with this paper.

Code availability

The code along with a data dictionary is available at: https://osf.io/um638/overview

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Acknowledgements

We would like to express our gratitude to all participants for dedicating their time and effort to take part in our project. We would further like to thank people with lived experiences, who provided valuable feedback in the development of our treatment manual, contributed to stakeholder engagement activities and supported dissemination efforts. We are also grateful for the assistance provided by research assistants Katrine Rasmussen and Linnea Rosalinde Køber and therapist Tina Højsgaard Tinglef. We would additionally like to thank Center for Eating and Feeding Disorders Research (CEDaR), headed by Nadia Micali, and Psychiatric Center Ballerup for their contributions

911 to the study. We would also like to thank Foreningen Spiseforstyrrelser og Selvskade,
912 Kompetencecenter for Spiseforstyrrelser, ROBUS and Askovhus for their support. The study
913 funders were: Independent Research Fund Denmark (reference-number: 2096-00078B) and
914 Research Fund of the Mental Health services - Capital Region of Denmark.

915 AI declaration

916 The authors declare the use of generative artificial intelligence (GAI) in the research and writing
917 process. According to the GAIDeT (Generative Artificial Intelligence Delegation Taxonomy; 2025),
918 the following tasks were delegated to GAI tools under full human supervision: code
919 generation/trouble shooting, translation, proofreading, and editing. The GAI tool used was ChatGPT
920 (version 5.3; OpenAI). Responsibility for the final manuscript lies entirely with the authors. GAI
921 tools are not listed as authors and do not bear responsibility for the final outcomes.

922 Author contributions

923 Conceptualization: NKH, ESR, LBG; Methodology: NKH, ESR, CH, GL, LBG; Formal analysis: NKH, GL;
924 Investigation: NKH; Data curation: NKH; Visualization: NKH, GL; Project administration: NKH, LBG;
925 Supervision: VC, CH, TW, LBG; Funding acquisition: LBG; Resources: LBG; Writing - original draft:
926 NKH; Writing - review and editing: BTA, ESR, LCS, MN, VC, CH, GL, TW, LBG. All authors reviewed
927 and approved the final manuscript.

928 Funding

929 This trial was funded by Independent Research Fund Denmark (reference-number: 2096-00078B) and
930 Research Fund of the Mental Health services - Capital Region of Denmark. The funders had no role in the
931 design or conduct of the trial; collection, management, analysis, or interpretation of the data; preparation,
932 review, or approval of the manuscript; or the decision to submit the manuscript for publication.

Competing interests

The authors declare no competing interests.

Supplementary table 1: Table of all the care types registered across both treatment arms from baseline to treatment cessation and from treatment cessation to follow-up.

12 weeks	VR avatar	TAU
Received care		
yes	26 (66.7%) *n*=39	24 (66.7%) *n*=36
No	13 (33.3%)	12 (33.3%)
Specialized eating disorder treatment		
Psychiatric care (ED specific)	13 (33.3%) *n*=39	8 (22.2%) *n*=36
Psychologist (ED specific)	7 (17.9%) *n*=39	9 (25.0%) *n*=36
Muncipal (ED specific)	2 (5.1%) *n*=39	3 (8.3%) *n*=36
General mental health care		
Psychiatric care (other)	6 (15.4%) *n*=39	4 (11.1%) *n*=36
Psychologist (other)	3 (7.7%) *n*=39	1 (2.8%) *n*=36
Psychotherapist	0 (0.0%) *n*=39	3 (8.3%) *n*=36
Nutritional treatment		
Dietician	1 (2.6%) *n*=39	1 (2.8%) *n*=36
Social/community-based support		
Municipal care (other)	2 (5.1%) *n*=39	0 (0.0%) *n*=36
Meal support (ED)	0 (0.0%) *n*=39	0 (0.0%) *n*=36
Home support	1 (2.6%) *n*=39	1 (2.8%) *n*=36
Other	0 (0.0%) *n*=39	0(0.0%) *n*=36
24 weeks		
Received care		
yes	21 (61.8%) *n*=34	19 (55.9%) *n*=34
no	13 (38.2%)	15 (44.1%)

Specialized eating disorder treatment		
Psychiatric care (ED specific)	12 (35.3%) *n*=34	8 (23.5%) *n*=34
Psychologist (ED specific)	3 (8.8%) *n*=34	5 (14.7%) *n*=34
Muncipal (ED specific)	1 (2.9%) *n*=34	0 (0.0%) *n*=34
General mental health care		
Psychiatric care (other)	4 (11.8%) *n*=34	2 (5.9%) *n*=34
Psychologist (other)	1 (2.9%) *n*=34	0 (0.0%) *n*=34
Psychotherapist	0 (0.0%) *n*=34	4 (8.3%) *n*=34
Nutritional treatment		
Dietician	1(2.9%) *n*=34	1 (2.9%) *n*=34
Social/community-based support		
Municipal care (other)	2 (5.9%) *n*=34	1 (2.9%) *n*=34
Meal support (ED)	1 (2.9%) *n*=34	1 (2.9%) *n*=34
Home support	0 (0.0%) *n*=34	1 (2.9%) *n*=34
Other	2 (5.9%) *n*=34	0 (0.0%) *n*=34

Table legend: Number (%) of participants reporting care types across treatment arms at 12 and 24 weeks. Care categories were not mutually exclusive. Percentages are based on participants with available data at each timepoint.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- CONSORT2025checklistDialogueRCT.docx