Effectiveness of a Digitally Assisted Obesity Interval Rehabilitation on Physical and Psychological Health-Related Quality of Life – A Quasi-Experimental Study

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Abstract

Background

Obesity presents a significant public health burden in industrialized countries due to its association with reduced life expectancy, work ability, and health-related quality of life (HRQoL). Thus, we examined the effectiveness of a digitally assisted obesity interval rehabilitation compared to conventional obesity rehabilitation with respect to physical and psychological HRQoL. This prospective, non-randomized controlled trial included 412 participants (intervention group: 222; control group: 190) recruited from nine German obesity rehabilitation clinics between 2021 and 2023. The intervention group participated in a digitally assisted obesity interval rehabilitation, while the control group attended conventional obesity rehabilitation without digital assistance. Physical and psychological HRQoL were assessed at baseline, six, and 12 months of follow-up through the 12-item short form survey. We estimated the time×group interaction using multilevel linear mixed effects models, testing random effects (participants and clinics) and fixed effects (age, gender, Body-Mass-Index, and physical activity) through stepwise modeling. Estimated marginal means are presented.

Results

No statistically significant time×group interaction was observed, suggesting that the digitally assisted obesity interval rehabilitation did not lead to different physical or psychological HRQoL outcomes compared to conventional obesity rehabilitation (physical HRQoL: β = -0.08, 95% CI [-2.01–1.85], $t(726) = -0.08$, $p = 0.935$; psychological HRQoL: β = 0.72, 95% CI [-1.44–2.87], $t(729) = 0.65$, $p = 0.514$). However, physical and psychological HRQoL showed small improvements over 12 months (physical HRQoL: β = 3.29, 95% CI [1.92–4.66], $t(708) = 4.72$, $p < 0.001$; psychological HRQoL: β = 2.07, 95% CI [0.54–3.60], $t(710) = 2.65$, $p = 0.008$) in both groups. Sensitivity analyses confirmed primary analysis and highlighted a potential relevance of BMI change in predicting HRQoL.

Conclusion

Digitally assisted obesity interval rehabilitation was not associated with superior physical or psychological HRQoL outcomes compared with conventional obesity rehabilitation. However, both approaches resulted in small improvements in physical and psychological HRQoL over 12 months. Given the similar HRQoL trajectories, digital assistance might be a useful complementary format within obesity rehabilitation in Germany. Further research may benefit from focusing on mitigation of attrition bias, longer follow-up periods and evaluating within-person variations.

Trial registration

The trial was registered with the German Register of Clinical Studies (DRKS) on June 30, 2021 under the registration number: DRKS00024836.

Background

Since 1990, global adult obesity has more than doubled (1), with a 20% prevalence of obesity projected for most European countries by 2025 (2), and rising rates of morbid obesity (3). In Germany, the proportion of individuals with statutory health insurance diagnosed with obesity increased from 9.2% in 2009 to 11.2% in 2018 (4). Self-reported obesity rates exceeded these figures, amounting to 17% in 2022 (5). Obesity has been associated with reduced life expectancy, impaired workforce productivity (3), and low health-related quality of life (HRQoL) (6), and is a major determinant of disability and death in the WHO European Region (7). Driven by increasing obesity-related risk factors (8) and a substantial economic burden, there is an urgent need for improved obesity prevention and treatment (3, 9–11). To address this challenge, digital health interventions might offer a cost-effective and scalable approach (12).

As a multifactorial disease, obesity involves abnormal or excessive fat accumulation posing a risk to health (1, 13). Adverse effects of obesity include musculoskeletal, metabolic, and cardiovascular complications, and an increased risk of several types of cancer (7, 13). Moreover, associations between obesity and diverse mental health conditions have been established (14–16), especially with depression (17–19). Given these obesity-related conditions, the effect of obesity on physical and psychological HRQoL warrants further investigation.

HRQoL, reflecting an individual’s perception of health, illness and it´s treatment, is a multidimensional construct encompassing physical, psychological, and social well-being (20). Obesity has been associated with lower overall HRQoL (6, 21–23). While overweight and obesity are linked more strongly with lower physical than psychological HRQoL, severe obesity has been associated more strongly with decreased psychological than physical HRQoL (6, 24). Individuals with obesity experience diminished HRQoL regardless of whether they seek treatment or not (21, 25, 26).

Obesity treatment encompasses dietary and physical activity therapy, pharmacotherapy, and surgery (13). To date, evidence on the effectiveness of non-surgical lifestyle interventions on HRQoL remains inconclusive (22, 23, 27–32), including in the context of digital health (33–37). Digital obesity intervention related overall quality of life (QoL) improvements were attributed to increased physical activity and weight reduction (37). Although weight loss has often been associated with QoL improvements (22, 23, 32, 38–40), physical HRQoL was found to improve more frequently than mental HRQoL (23, 32, 41). Differences in physical and psychological HRQoL outcomes might be related for instance to Body-Mass-Index (BMI) levels and applied measurements instruments (24).

In Germany, obesity rehabilitation comprises two overarching phases: rehabilitation and rehabilitation aftercare (42). Challenges related to the implementation and long-term effectiveness of obesity rehabilitation include limited accessibility in rural areas (43), complex application processes and the transition from in-patient rehabilitation to outpatient aftercare (44). Although telerehabilitation or digitally assisted obesity rehabilitation might help address these challenges, it has not yet been routinely implemented in Germany (11, 44). Digital rehabilitation approaches in Germany have been investigated from different angles (11, 34, 45–53). However, related research on obesity rehabilitation is scarce (44, 48, 53).

Evidence on the effectiveness of digital health interventions regarding HRQoL outcomes in individuals with obesity remains limited and inconclusive (33–35, 37, 53–58). This is particularly true for digitally assisted rehabilitation approaches embedded in routine obesity care in Germany. Hence, we aimed to examine trajectories of physical and psychological HRQoL over twelve months in participants undergoing digitally assisted obesity interval rehabilitation compared with participants receiving conventional obesity rehabilitation. The primary research question was whether changes in physical and psychological HRQoL differed between the two rehabilitation approaches, as reflected in a time×group interaction. This study thereby contributes to the evidence on HRQoL outcomes in digitally assisted obesity interventions under rehabilitative care conditions in Germany.

Methods

Design of the study

The German retirement pension fund *Deutsche Rentenversicherung Knappschaft-Bahn-See*, initiated this study to compare the effectiveness of a digitally assisted obesity interval rehabilitation to conventional obesity rehabilitation. We conducted a non-randomized, quasi-experimental intervention study featuring two groups (intervention vs. control), repeated measures (baseline, six- & 12-months post-baseline) and two primary outcomes (physical and psychological HRQoL). Clinic-based allocation was used to assign participants to the study groups. The study was registered with the German Register of Clinical Studies (DRKS) on June 30, 2021 (registration number: DRKS00024836) (59). Additionally, this study was preregistered with the Open Science Framework (OSF) on 27 July 2025 (DOI: 10.17605/OSF.IO/CSP7G).

Setting and sample

The sample size calculation was based on the original study protocol (59). Because evidence on the effectiveness of digital health interventions for individuals with obesity was insufficient at the time of study planning, we assumed a small effect size. The original calculation was conducted for a repeated measures ANOVA with two groups, three measurement occasions, and a within-between interaction effect. Assuming an effect size of $\eta^2 = 0.01$, $\alpha = 0.05$, $1\text{-}\beta = 0.80$, and a correlation among repeated measures of $r = 0.30$, the required total sample size was estimated at 225 participants, approximately equally distributed across the two groups. To account for an expected dropout rate of about 50%, the recruitment target was set at 450 participants.

Recruitment was conducted from 20 July 2021 to 11 January 2023. In this time period, 222 individuals (63 females) were included in the intervention group and 190 individuals (92 females) in the control group. In total, nine obesity rehabilitation clinics across Germany recruited patients; four of these offered the digitally assisted obesity interval rehabilitation and five conventional obesity rehabilitation. Inclusion criteria were: age ≥ 18 years, BMI ≥ 30 kg/m², basic German language proficiency, and provided informed consent. Neither study staff nor patients were blinded to group allocation, and no financial compensation was provided. The amount of clinic stays was determined by the clinic's obesity rehabilitation concept. Rehabilitation continuance was generally declined if patients experienced weight gain.

A total of 412 participants were recruited at baseline. These were recruited from nine clinics; four intervention clinics with a total of 238 participants (n = 79, 75, 51, and 33)) and five control clinics with a total of 174 participants (8, 10, 102, 50, and 4). 16 participants recruited from clinics offering the digitally assisted obesity interval rehabilitation declined participation in the digital component and were therefore assigned to the control group, consistent with the allocation procedure specified in the original study protocol (59). The number of participants in the intervention group decreased from 222 at baseline to 127 at 12 months, and in the control group from 190 at baseline to 135 at 12 months (see Table 1). For one individual in the control group, data on gender, age, BMI and PA in the control group were missing completely. A PA outlier (1740 *MET – min/week)* was treated as a missing value in the dataset.

Intervention group: Digitally assisted obesity interval rehabilitation

The intervention was offered in four obesity rehabilitation clinics. The obesity interval rehabilitation consists of three in-patient clinic stays focusing on nutritional and sports therapy in individual and group sessions of a maximum of 12 participants. Participants are aimed to remain in the same group for all in-patient stays. The first in-patient stay spanned over three weeks, and the second and third in-patients stays, lasted one week each. During the six months between in-patient stays, patients were primarily tasked with independent implementation of lifestyle adaptions in their daily lives through digital assistance. The participants were introduced to the telerehabilitative (mobile) platform during their first in-patient stay. The platform provided mainly an individual PA training program, but also, theoretical content, such as muscle relaxation techniques, and nutritional advice. Patient´s activity was monitored by therapists through the platform and patients could ask for feedback on their training. Additionally, therapy could be adapted based on their health status. Continued participation in the study was a participant's decision, but if no activity was detected in six successive weeks the digital support was cancelled according to guidelines of the German retirement pension fund (60).

Control group: Conventional obesity rehabilitation

Additional five obesity clinics, offering a conventional obesity rehabilitation intervention, recruited participants for the control group. Patients from intervention clinics who declined participation in the digitally assisted program were offered inclusion in the control group. Conventional obesity rehabilitation was set up similarly to the obesity interval rehabilitation. Nutritional and exercise Therapy was organized in individual and group sessions with about 12 participants during the patient´s first in-patient stay. At the end of their first clinic stay, the patients received an exercise plan and dietary recommendations in support of implementing the acquired skills and knowledge. No digital assistance was provided in between in-patient stays. Rehabilitation duration and structure varied depending on the clinic; the first in-patient stay varied from one to six weeks and the second and third in-patient stays, if offered, varied from one to four weeks in length. As in the intervention group, the approval by the respective insurance of follow-up in-patient stays, depended on factors such as weight gain, in which case these were declined. Continued participation in the study was a participant's decision. As in the intervention group, based on the patient's health, additional therapies can be included.

Data collection and measures

Age (years), gender (male/female), BMI (kg/m²), PA (min/day), and HRQoL (SF-12) were assessed at each measurement.

Health-related quality of life

HRQoL was evaluated through the SF-12 (61). This very short survey was found to be useful for HRQoL evaluation in the context of rehabilitation interventions (61, 62). The SF-12 yields two main summary scores: the physical and psychological component summaries. These are constructed from eight underlying subscales of subjective health, with a total of 12 items (63). The physical summary scale comprises the subscales of physical functioning, physical role, bodily pain, and general health. The mental summary scale is composed of the sub-scales vitality, social functioning, emotional role, and mental health (63). The scales were found to have moderate to strong concurrent (62) and construct validity (64). Reliability analysis within the German population presented moderate to good internal consistency for physical (*Cronbach's α* = 0.79) and psychological health (*Cronbach´s α* = 0.89) (65).

Body-Mass-Index

The body weight was measured and forwarded by the obesity clinics if patient consent was provided. Alternatively, the patients were asked to report their own weight wearing no shoes and light clothes during the measurement. BMI was calculated using body weight in kilograms (kg) divided by patient reported height in meters squared (m²).

Physical Activity

For PA assessment, the Global Physical Activity Questionnaire / GPAQ (66) was applied. It comprises 16 items divided into four dimensions: PA at work, PA during traveling, PA during leisure time (67). The time related to PA was surveyed and transformed into metabolic equivalent (MET) minutes (4 MET = moderate PA and 8 MET = vigorous PA) per day (68). In the UK, moderate concurrent validity was found when comparing the GPAQ to accelerometer measurements (moderate-to-vigorous PA – min/day $r = 0.48$) (69), with the German language questionnaire being fair to moderate (*MET – min/week* $r = 0.25$) (70). The instrument exhibited a stronger 10-day reliability (r = 0.83 to 0.96) than a three-month reliability (r = 0.53 to 0.83) (67).

Statistical data analyses

Provided that at least half of the items in the SF-12 questionnaire were answered, we estimated missing values using the Expectation-Maximisation algorithm (71). Sum-scores for cases with 50% or less answered items were treated as missing. We performed multilevel linear mixed-effects model analysis with repeated measurements to evaluate changes in physical and psychological HRQoL comparing the digitally assisted obesity interval rehabilitation to conventional obesity rehabilitation through a time×group interaction. Also, we accounted for (baseline) group differences by adjusting for selected potential confounders.

We tested random intercepts and slopes for participants and clinics. Fixed effects considered were time (six-month measurement compared to baseline and 12-month measurement compared to baseline), group (categorical; intervention compared to control), age (continuous; years), gender (categorical; female compared to male), baseline BMI (continuous; body weight in kg/height in m²) and baseline PA (continuous; min/day). An interaction term between time (categorical) and group (categorical) was included throughout the modeling process to account for expected differences between both groups throughout the intervention. To account for individual differences at study entry, baseline values of the outcome HRQoL were included as a covariate. Our stepwise linear mixed effects modeling resulted in the following decisions: first, random slopes for time effects were excluded from the final model as they introduced multicollinearity. Second, we excluded clinic clustering from the final model´s random-effects structure since it showed only small between-group variation and estimation errors likely related to the small number of participants in some clinics and the clinic group sizes varying strongly (72). Third, while we tested grand- and group-mean centered age, transformations were not retained in the final model due to estimation problems. Furthermore, because of increasing missing observations over time, we treated baseline BMI and PA as time-stable values. However, due to substantially decreased observations over time for BMI (t0: n = 352 to t2: n = 186 [-50%]) and PA (t0: n = 399 to t2: n = 253 [-37%]), and the prominently reduced number of participants in the analysis (n = -72 [-18%]) when including baseline BMI and baseline PA in the model, the final linear mixed models for physical and psychological HRQoL did not include these covariates. Finally, we conducted a sensitivity analysis of BMI changes, computing the BMI mean difference between baseline and follow-up (either 6-month or 12-month or a mean if both follow-up measurements were available). However, with a strongly reduced sample size (n = 174 [42%]). Also, repeated measures ANCOVA, adjusted for age and gender were conducted for each outcome.

The statistical software R version 4.5.0 (2025-04-11 ucrt) (73) and lme4 package (74) was applied. Through a stepwise modeling approach, first, decisions on the inclusion of random effects (test for inclusion of random intercepts and slopes for clinics and participants) and second, covariate adjustment (test for confounding by baseline HRQoL, age, gender, BMI and PA) were made. To address convergence failure, we first excluded participants recruited in intervention clinics who were part of the control group. Second, the number of iterations was increased. Third, we simplified the random effects structure by excluding the random slopes component (75). Model assumptions were tested on level 1 and level 2 residuals and were not significantly violated. We compared models using the Akaike information criterion (AIC) and maximum likelihood estimates (-2LL). Restricted maximum likelihood (REML) estimation provided unbiased estimates for variance components of the random effects and standard errors of the fixed effects (74). We report Satterthwaite approximation values. Estimated marginal means with 95% confidence intervals (CIs) were computed, applying the Kenward-Roger method to determine degrees-of-freedom.

The final model specification for physical and psychological HRQoL was (subscript t = time point *and* i = participant):

Level one equation (within-person outcome changes over time):

$Y_{ti} = \beta_{0i} + \beta_{1i} \cdot \mathrm{TIMEt1}_{ti} + \beta_{2i} \cdot \mathrm{TIMEt2}_{ti} + \epsilon_{ti}$

Y_{ti} = Participant-specific HRQoL at t

β_{0i} = Random intercept

β_{1i} = Fixed slope for time dummy 1 (first follow-up vs baseline)

β_{2i} = Fixed slope for time dummy 2 (second follow-up vs baseline)

$\epsilon_{ti} \sim N(0, \sigma^2)$ = Residual error (within-person variance)

Level two equations (between-person variations):

$\beta_{0i} = \gamma_{00} + \gamma_{01} \cdot \mathrm{GROUP}_i + \gamma_{02} \cdot \mathrm{BASELINE\_HRQoL}_i + \gamma_{03} \cdot \mathrm{GENDER}_i + \gamma_{04} \cdot \mathrm{AGE}_i + u_{0i}$

$\beta_{1i} = \gamma_{10} + \gamma_{11} \cdot \mathrm{GROUP}_i$

$\beta_{2i} = \gamma_{20} + \gamma_{21} \cdot \mathrm{GROUP}_i$

γ_{00} = Population average intercept at baseline for the control group

$\gamma_{01} \ldots \gamma_{04}$ = Fixed effects of the variables assessed at baseline

$u_{0i} \sim N(0, \tau_0^2)$ = Random error for participant-level intercept (between-person variance)

γ_{10} = Effect of time point (first follow-up vs. baseline) for the control group

γ_{20} = Effect of time point (second follow-up vs. baseline) for the control group

γ_{11} = Effect of group (intervention vs. control) on the slope (cross-level interaction at the first follow-up)

γ_{21} = Effect of group (intervention vs. control) on the slope (cross-level interaction at the second follow-up)

Results

Descriptive analyses

No statistically significant mean differences were found between intervention and control group at baseline for physical HRQoL ($t(384) = 1.58$, $p = 0.118$) as opposed to psychological HRQoL ($t(396) = 2.11$, $p = 0.036$) where the intervention group presented a somewhat higher mean (see Table 1). All clinics showed similar mean trajectories across the time points. For age there was a significant difference in means with the intervention group on average being somewhat younger ($t(386) = -3.52$, $p < 0.001$) (see Table 1). Furthermore, there was a significant association between gender and group at baseline, ($\chi^2 = 17.05$; $df = 1$; $p < 0.001$) with the intervention group comprising a larger proportion of men (see Table 1). Neither BMI ($t(334) = 0.33$, $p = 0.740$) nor PA ($t(390) = 0.73$, $p = 0.465$) presented statistically significant mean differences between both groups at baseline. A small decrease in mean BMI for the intervention (-2.8 kg/m²) and the control group (-2.3 kg/m²) was observed over time (see Table 1). PA differences in means across time comparing baseline to the second follow-up showed a small increase in the intervention (35 min/day) and a small decrease in the control group (-15 min/day). Moreover, PA distribution was found to be right skewed, with many participants stating they did not or barely engage in PA.

Table 1 Descriptive data of all participants

Variable	Intervention				Control			
	Overall observations	*Baseline*	*6 Months*	*12 Months*	*Overall observations*	*Baseline*	*6 Months*	*12 Months*
	n = 507	n = 222	n = 158	n = 127	n = 469	n = 190	n = 144	n = 135
Age (years)¹	47.8 (10.0)	47.1 (10.5)	48.1 (9.6)	48.7 (9.6)	52.1 (10.6)	50.9 (11.4)	52.8 (10.0)	53.0 (10.0)
Missing	0	0	0	0	2	1	1	0
Gender*								
Male	355 (70%)	159 (72%)	110 (70%)	86 (68%)	245 (52%)	97 (51%)	75 (52%)	73 (54%)
Female	152 (30%)	63 (28%)	48 (30%)	41 (32%)	222 (48%)	92 (49%)	68 (48%)	62 (46%)
Missing	0	0	0	0	2	1	1	0
BMI (kg/m²)¹	38.8 (6.5)	40.2 (6.46)	37.0 (6.1)	37.4 (6.24)	38.6 (7.5)	40.0 (7.73)	37.2 (7.39)	37.7 (6.90)
Missing	162	42	71	49	77	18	32	27
PA (min/day)¹	208 (242)	182 (209)	236 (256)	217 (271)	164 (210)	175 (236)	153 (173)	160 (202)
Missing	21	10	8	3	16	3	7	6
HRQoL (SF-12)¹								
Physical	43.9 (9.6)	41.9 (8.98)	45.9 (9.91)	44.9 (9.44)	42.1 (10.3)	40.4 (9.99)	43.5 (10.3)	43.2 (10.6)
Psychological	46.8 (10.8)	45.2 (11.0)	48.1 (10.4)	48.3 (10.4)	42.1 (10.3)	42.8 (11.4)	47.2 (11.0)	45.2 (11.5)

Note. ¹Mean (SD); * n(%)

Primary analysis

The stepwise modeling process showed that the inclusion of baseline BMI and baseline PA generated only minor changes in the time×group interaction and time effects found (see Table 2 and 3). Therefore, and due to the strongly reduced number of participants in the analysis (n = 339 instead of n = 411), the final models for physical and psychological HRQoL did not include BMI and PA as covariates.

Table 2 Linear mixed effects models for physical and psychological HRQoL including baseline BMI and PA

	Physical HRQoL[1]				**Psychological HRQoL[1]**			
Fixed Effects	*Estimates*	*std. Error*	*CI*	*t*	*Estimates*	*std. Error*	*CI*	*t*
Intercept	**21.79 *****	3.45	15.02 – 28.56	6.32	**11.84 *****	2.95	6.05 – 17.64	4.01
6 Months vs. Baseline	**2.99 *****	0.75	1.52 – 4.46	4.00	**4.43 *****	0.84	2.78 – 6.08	5.27
12 Months vs. Baseline	**2.97 *****	0.76	1.48 – 4.46	3.91	**2.28 ****	0.85	0.61 – 3.96	2.67
Baseline Intervention vs. Control	0.19	0.75	-1.28 – 1.67	0.26	1.02	0.84	-0.62 – 2.66	1.22
Baseline HRQoL	**0.69 *****	0.03	0.63 – 0.75	22.55	**0.72 *****	0.03	0.67 – 0.77	27.46
Female vs. Male	-1.04	0.55	-2.13 – 0.05	-1.88	0.35	0.60	-0.83 – 1.54	0.58
Age	**-0.10****	0.03	-0.15 – -0.04	-3.34	0.00	0.03	-0.06 – 0.05	-0.09
Baseline BMI	**-0.09***	0.04	-0.17 – 0.00	-2.01	-0.01	0.04	-0.09 – 0.08	-0.12
Baseline PA	**0.00***	0.00	-0.01 – 0.00	-2.14	0.00	0.00	0.00 – 0.00	0.87
6 Months*Group	0.84	1.06	-1.23 – 2.92	0.80	-1.23	1.19	-3.56 – 1.10	-1.04
12 Months*Group	0.37	1.11	-1.81 – 2.55	0.33	1.38	1.25	-1.07 – 3.83	1.10
Random Effects								
σ^2 *residual variance (participants)*	39.32				49.92			
τ_{00} *Intercept variance (participants)*	6.32				6.04			
N *Participants*	339				339			
Observations	806				806			

Note. *p<0.05; **p<0.01; ***p<0.001.[1] Restricted maximum likelihood estimation; Fixed effects covariates: time (within person results - 6 months vs. baseline and 12 months vs. baseline), age (years), gender (female vs. male), baseline BMI (baseline values used for imputation of both follow-up measurements), baseline PA (MET min/day - baseline values used for imputation of both follow-up measurements) and the interaction between time and group (intervention vs. control baseline to 6 months and baseline to 12 months). Random effects (within and between person variance): random intercepts for participants. The degrees of freedom range from 342 to 760 for physical HRQoL and from 342 to 768 for psychological HRQoL.

Table 3 Final linear mixed effects models for physical and psychological HRQoL (not including BMI and PA)

	Physical HRQoL¹				Psychological HRQoL¹			
Fixed Effects	*Estimates*	*std. Error*	*CI*	*t*	*Estimates*	*std. Error*	*CI*	*t*
Intercept	**13.79 *****	1.88	10.11 – 17.47	7.35	**11.29 *****	1.70	7.95 – 14.64	6.62
6 Months vs. Baseline	**3.42 *****	0.69	2.08 – 4.77	4.99	**3.98 *****	0.76	2.48 – 5.48	5.21
12 Months vs. Baseline	**3.29 *****	0.70	1.92 – 4.66	4.72	**2.07 ****	0.78	0.54 – 3.60	2.65
Baseline Intervention vs. Control	-0.11	0.68	-1.44 – 1.22	-0.17	0.66	0.74	-0.80 – 2.12	0.89
Baseline HRQoL	**0.75 *****	0.03	0.69 – 0.80	28.72	**0.74 *****	0.02	0.69 – 0.79	31.26
Female vs. Male	**-1.26 ***	0.51	-2.26 – -0.26	-2.47	0.37	0.55	-0.71 – 1.46	0.67
Age	**-0.06 ***	0.02	-0.10 – -0.01	-2.37	-0.01	0.03	-0.06 – 0.04	-0.24
6 Months*Group	0.60	0.94	-1.24 – 2.44	0.64	-1.13	1.05	-3.19 – 0.93	-1.08
12 Months*Group	-0.08	0.98	-2.01 – 1.85	-0.08	0.72	1.10	-1.44 – 2.87	0.65
Random Effects								
σ^2 *residual variance (participants)*	37.28				46.65			
τ *Intercept variance (participants)*	7.44				6.84			
N *Participants*	411				411			
Observations	974				974			

Note. ***p<0.05; **p<0.01; ***p<0.001**. ¹ Restricted maximum likelihood estimation; Fixed effects covariates: time (within person results - 6 months vs. baseline and 12 months vs. baseline), age (years), gender (female vs. male) and the interaction between time and group (intervention vs. control baseline to 6 months and baseline to 12 months). Random effects (within and between person variance): random intercepts for participants. The degrees of freedom range from 423 to 915 for physical HRQoL and from 421 to 928 for psychological HRQoL.

The null model for physical HRQoL including a random intercept for participants, presented an ICC of 0.55, indicating that 55% of variation was between-participants, thus supporting the choice of a linear mixed effects model. Total within-person variation was strong (45%). The final model for physical HRQoL included fixed effects for a time×group interaction, time, group, baseline HRQoL, gender, and age and a random intercept for participants. The remaining between-person variation was low (17%). The time×group interaction was not statistically significant at any follow-up measurement (baseline to first follow-up: β = 0.60, 95% CI [-1.24 – 2.44], $t(705)$ = 0.64, p = 0.523; baseline to second follow-up: β = -0.08, 95% CI [-2.01 – 1.85], $t(726)$ = -0.08, p =0.935) (see Table 3). Hence, participants of the intervention group did not produce significantly different physical HRQoL improvements when compared to the control group. However, physical HRQoL showed a small overall statistically significant improvement between baseline and the second follow-up measurement (after 12 months) (β = 3.29, 95% CI [1.92 – 4.66], $t(708)$ = 4.72, p <0.001) (see Table 3). Estimated marginal means of the final model (see Figure 1) for the intervention group showed an adjusted physical HRQoL score increase from 40.8 (95% CI [39.9 – 41.7]) at baseline, to 44.8 (95% CI [43.8 – 45.5]) at the first follow up, and 44.0 (95% CI [42.9 – 45.2]) at the second follow-up. The control group presented a physical HRQoL mean increase from 40.9 (95% CI [40.0 – 41.9]) at baseline, to 44.4 (95% CI [43.3 – 45.5]) at the first follow-up, and 44.2 (95% CI [43.1 – 45.4]) at the second follow-up.

Figure 1. Estimated marginal means of physical HRQoL across baseline (t0), six months (t1), and 12 months (t2) of follow-up (final model).

Figure 2. Estimated marginal means of psychological HRQoL across baseline (t0), six months (t1), and 12 months (t2) of follow-up (final model).

For psychological HRQoL, the null model, including a random intercept for participants showed an ICC of 0.57, displayed a high amount of between-person (57%) and within-person variation (43%), thus supporting the choice of a linear mixed effects model. The final model for psychological HRQoL included fixed effects for a time×group interaction, time, group, baseline HRQoL, gender, and age, and a random intercept for participants. The remaining between-person variation was low (13%). The time×group interaction was not statistically significant at any follow-up measurement (baseline to first follow-up: β = -1.13, 95% CI [-3.19 – 0.93], $t(707)$ = -1.08, p = 0.281; baseline to second follow-up: β = 0.72, 95% CI [-1.44 – 2.87], $t(729)$ = 0.65, p = 0.514) (see Table 3). Thus, participants of the intervention group did not produce significantly different psychological HRQoL improvements when compared to the control group. However, a small overall statistically significant improvement for psychological HRQoL was found between baseline and the second follow-up measurement (a 12-month-period) (β = 2.06, 95% CI [0.54 – 3.60], $t(710)$ = 2.65, p <0.001) (see Table 3). Estimated marginal means of the final model (see Figure 2) for the intervention group showed an adjusted psychological HRQoL score increase from 44.6 (95% CI [43.6 – 45.6]) at baseline, to 47.4 (95% CI [46.2 – 48.6]) at the first follow-up, and 47.3 (95% CI [46.1 – 48.6]) at the second follow-up. The control group presented a psychological HRQoL mean increase from 43.9 (95% CI [42.8 – 44.9]) at baseline, to 47.4 (95% CI [46.2 – 48.6]) at the first follow-up, and 47.3 (95% CI [46.1 – 48.6]) at the second follow-up.

Sensitivity analyses

Additionally, sensitivity analyses were performed to assess the robustness of the observed time-by-group effect and these confirmed the primary analysis results. Adjustment for BMI change, that is BMI mean difference (see Table 4) as an additional covariate, supported the main findings of no time×group interaction and significant improvements in physical and psychological HRQoL outcomes in the intervention and control groups based on the subsample with difference values available. Also, repeated measures ANCOVA, adjusted for age and gender confirmed these findings. The linear mixed models including BMI mean difference showed the best homoscedasticity fit, and for physical HRQoL, age and gender turned statistically insignificant after adjustment (see Table 3 and 4).

Table 4 Sensitivity analysis - Linear mixed effects models for physical and psychological HRQoL (including BMI mean difference)

	Physical HRQoL¹				**Psychological HRQoL¹**			
Fixed Effects	*Estimates*	*std. Error*	*CI*	*t*	*Estimates*	*std. Error*	*CI*	*t*
Intercept	**16.00 *****	2.63	10.85 – 21.16	6.09	**12.27 *****	2.45	7.46 – 17.09	5.00
6 Months vs. Baseline	**3.25 *****	0.84	1.60 – 4.89	3.88	**4.15 *****	0.95	2.29 – 6.01	4.37
12 Months vs. Baseline	**3.05 *****	0.85	1.39 – 4.71	3.60	**2.20 ***	0.96	0.32 – 4.08	2.29
Baseline Intervention vs. Control	-0.05	0.96	-1.93 – 1.84	-0.05	1.03	1.08	-1.10 – 3.15	0.95
Baseline HRQoL	**0.69 *****	0.03	0.62 – 0.75	19.91	**0.69 *****	0.03	0.63 – 0.75	21.72
Female vs. Male	-1.22	0.67	-2.53 – 0.10	-1.82	0.63	0.75	-0.85 – 2.10	0.84
Age	-0.06	0.03	-0.13 – 0.00	-1.87	0.00	0.04	-0.07 – 0.07	0.04
BMI mean difference	**0.22***	0.10	0.04 – 0.41	2.35	0.18	0.11	-0.03 – 0.39	1.69
6 Months*Group	0.09	1.21	-2.30 – 2.47	0.07	-1.50	1.37	-4.20 – 1.20	-1.09
12 Months*Group	0.39	1.26	-2.10 – 2.87	0.31	1.73	1.43	-1.08 – 4.54	1.21
Random Effects								
σ^2 *residual variance (participants)*	42.31				54.23			
τ *Intercept variance (participants)*	8.25				9.61			
N *Participants*	237				237			
Observations	662				662			

Note. *p<0.05; **p<0.01; ***p<0.001.¹ Restricted maximum likelihood estimation; Fixed effects covariates: time (within person results - 6 months vs. baseline and 12 months vs. baseline), age (years), gender (female vs. male), BMI mean difference (baseline to 6 or 12 months after - if both available a mean between both follow-up values was computed) and the interaction between time and group (intervention vs. control baseline to 6 months and baseline to 12 months). Random effects (within and between person variance): random intercepts for participants. The degrees of freedom range from 233 to 596 for physical HRQoL and from 234 to 599 for psychological HRQoL.

Discussion

This quasi-experimental study evaluated the effectiveness of digitally assisted obesity interval rehabilitation compared to conventional obesity rehabilitation on physical and psychological HRQoL over 12 months. While we did not observe differences between the groups, both showed small improvements in physical and psychological HRQoL over time.

We found no statistically significant time×group interaction for physical or psychological HRQoL. Our observation of no group differences in HRQoL outcomes between digital and conventional interventions aligns with prior obesity (34) and non-obesity related (46) rehabilitation research. However, these findings sit within an inconclusive evidence landscape regarding overall HRQoL when comparing digital (rehabilitation) interventions to control groups for individuals with (33, 34, 36, 37, 53, 57) and without obesity (76). Evaluation of digital versus conventional obesity (rehabilitation) interventions effectiveness on HRQoL remains a challenge (33, 34, 54) and several factors might explain the absence of an added effect from the digital intervention component in our study. First, the obesity interval rehabilitation effect might have been sufficiently strong, leaving little room for the digital assistance to produce a significant incremental difference. Second, although visual inspection of crude data showed that mean HRQoL changes were similar across all clinics, heterogeneity among the control group rehabilitation concepts might have attenuated the observed relationship. Third, application of the generic HRQoL instrument SF-12 might have played a role as generic and obesity specific HRQoL instruments were found to provide different results in populations of individuals with obesity (21, 34). Generic tools might lack the sensitivity required to detect nuanced QoL changes in lifestyle interventions (28, 53, 57), whereas obesity-specific instruments seem more responsive to these changes (22). Finally, our results might have been influenced by unmeasured digital platform usage patterns. For instance, variations in digital literacy, social connectedness and communication with therapists may have allowed certain users to benefit more from the digitally assisted obesity interval rehabilitation than others.

Both the intervention and control groups in our study demonstrated small statistically significant improvements in physical and psychological HRQoL over time. These findings align with previous research on digital and conventional obesity interventions that analyzed physical and psychological HRQoL over six- and twelve-month periods using generic instruments (31, 77). Conversely, another study found that an obesity-specific instrument yielded significant time effects over three months, whereas a generic instrument failed to detect changes in physical and psychological HRQoL within the same time frame (34). Our observations are further supported by research evaluating physical and psychological HRQoL in both digital and conventional orthopedic rehabilitation settings within Germany (46). When considering overall HRQoL, however, our results fall within an inconclusive body of evidence on effectiveness comparison of digital and non-digital obesity interventions (33, 36, 37). Consequently, these findings warrant nuanced considerations. First, no clear consensus exists regarding minimally clinically important differences, as three to five point changes have previously been considered as minimally clinically relevant (78, 79). Thus, our results fall at the lower end of this range for physical HRQoL and slightly below it for psychological HRQoL. Moreover, detecting meaningful HRQoL changes in individuals with obesity may require a follow-up of more than two years, as improvements in HRQoL relating to significant weight loss were not found to be consistent after two years for non-surgical treatment (39). Therefore, while digitally assisted obesity interval rehabilitation might serve as an alternative to conventional obesity rehabilitation for improving physical and psychological HRQoL, two critical points remain; It is uncertain whether these HRQoL improvements are large enough to be clinically significant and, more importantly, whether the long-term effectiveness of either group can be adequately captured within one year of follow-up.

Our results furthermore reveal an initial six-month window from baseline during which increases in physical and psychological HRQoL mainly occur. This finding is supported by previous research on obesity and non-obesity-related rehabilitation, evaluating the effectiveness of digital (46) and conventional interventions on physical and psychological HRQoL (31, 46). Identifying a specific time frame and conditions in which individuals derive the greatest benefit from (digitally assisted) obesity rehabilitation, could be essential for optimizing HRQoL gains and maintenance afterwards.

Sensitivity analysis supported our main findings and highlighted a potential relevance of BMI change in predicting especially physical, but also psychological HRQoL in obesity rehabilitation. This finding aligns with a broad landscape of research. Supporting our results, weight reduction has often been associated with QoL improvements (22, 23, 32, 37–40), with the most pronounced gains observed following substantial weight loss (23, 38). Moreover, literature suggests that weight reduction impacts physical rather than mental QoL (32, 41). Hence, obesity interventions in addition to weight reduction, might benefit for instance from support for emotional problems when targeting a positive effect on mental health (21). Importantly, based on this study's limitations our findings must be interpreted with caution.

Practical implications

The present findings provide no evidence that digitally assisted obesity interval rehabilitation leads to superior physical or psychological HRQoL outcomes compared with conventional obesity rehabilitation over 12 months. However, both approaches were associated with small improvements in HRQoL, suggesting that digital assistance might be a useful complementary format within obesity rehabilitation. Its practical value may lie in extending support into the aftercare phase, increasing flexibility, and facilitating self-management.

Strengths and limitations

A key strength of this study is its methodological and analytical rigor, which provides an important contribution to the scarce body of research focused on digitally assisted obesity rehabilitation in Germany. This includes the utilization of linear mixed-effects modeling to capture between- and within-participant variations, a large control group, the application of the validated and widely recognized SF-12 questionnaire. Additionally, comprehensive sensitivity analyses were executed accounting for available BMI and PA data.

Despite these strengths, several limitations require consideration. First, our ability to explore the complex relationship between BMI, PA and HRQoL changes was hampered by an increasing amount of missing data over time. Furthermore, the study is subject to potential attrition bias due to a systematic dropout of participants who experienced a BMI increase and were excluded from follow-up in-patient stays due to insurance policies. Additionally, BMI was the sole anthropometric measure utilized limiting our ability to capture changes in body composition. Second, the lack of participant randomization may have introduced selection bias, for example increasing the likelihood of younger patients, and those with higher baseline HRQoL and greater digital affinity of participating in the intervention. Third, the control group comprising heterogeneous conventional rehabilitation concepts across different clinics. Finally, long-term effects could not be assessed beyond this study's follow-up period of 12 months.

Future directions

This study highlights several crucial considerations for future research to advance the field of digital obesity rehabilitation. First, to mitigate attrition bias, individuals who drop out of rehabilitation because of BMI increases should still be followed up whenever possible. Second, evaluating and enhancing therapists' and patients' digital literacy might be beneficial. Third, a longer follow-up period may be important to assess the sustained effectiveness of obesity rehabilitation as short-term gains often do not translate into long-term success. Finally, given the substantial within-person variance observed, future designs may benefit from applying ecological momentary assessment to improve the understanding of contexts and behaviors contributing to obesity. This approach could capture, for instance, fluctuations in exercise routines, stress levels and emotional states (80).

Conclusion

The present study found no evidence that digitally assisted obesity interval rehabilitation is associated with superior physical or psychological HRQoL outcomes compared with conventional obesity rehabilitation over 12 months. Both groups however, showed small improvements over time. Hence, digital assistance might be a useful complementary format within obesity rehabilitation. However, due to the quasi-experimental design and heterogeneity of the control condition, conclusions regarding substitutability should be drawn cautiously. Further research might benefit from focusing on mitigation of attrition bias, longer follow-up periods, and understanding better within-person variations.

Abbreviations

-2LL Minus two log-likelihood

AIC Akaike information criterion

ANOVA Analysis of variance

CI Confidence Interval

HRQoL Health-related quality of life

MET Metabolic equivalent

PA Physical activity

QoL Quality of life

REML Restricted maximum likelihood estimation

SF-12 12-item short form survey

SF-36 36-item short form survey

WHOQOL World Health Organization QoL

EQ-5D EuroQoL 5-Dimension health Questionnaire

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki. Study participation was voluntary. A participant could withdraw consent at any time without stating the reason and without any individual disadvantage for subsequent medical care. Their approval was documented via their signature on the informed consent forms. The Ethics Committee of the Karlsruhe Institute of Technology approved the project on 10 June 2021 and covered all obesity centers where patients were recruited from. This study was preregistered in OSF on 27 July 2025 (DOI: 10.17605/OSF.IO/CSP7G).

Consent for publication

All results are reported as group-level statistics (e.g., means, standard deviations) and tracing to the person level is not possible. The manuscript does not contain any person’s individual data in any form.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

AP, EF, DJ, JH, BB and MK were responsible for the overall conception and design of this manuscript. AP analyzed the data and drafted the manuscript. EF advised and revised data analysis. DJ developed the design of the study and is responsible for the data collection. All authors read and approved the final manuscript.

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Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

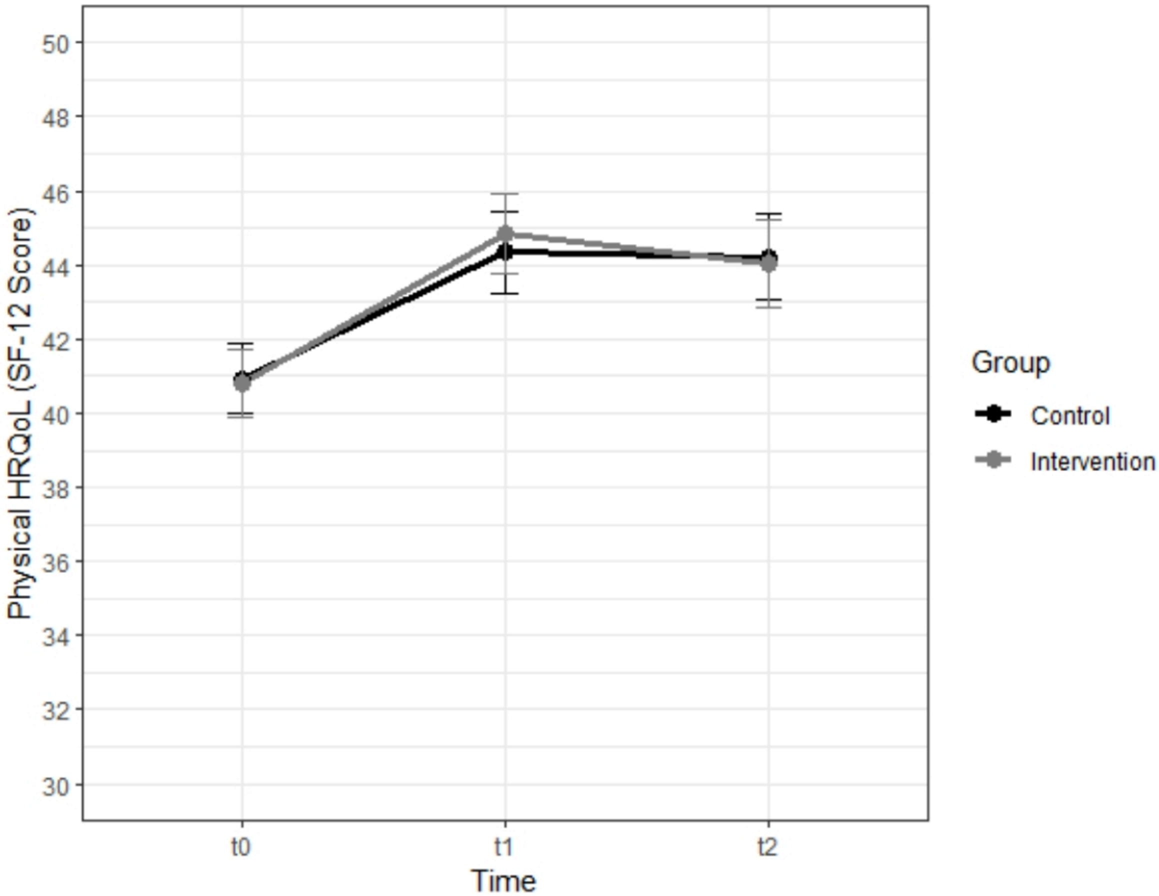

Figure 1

Estimated marginal means of physical HRQoL across baseline (t0), six months (t1), and 12 months (t2) of follow-up (final model).

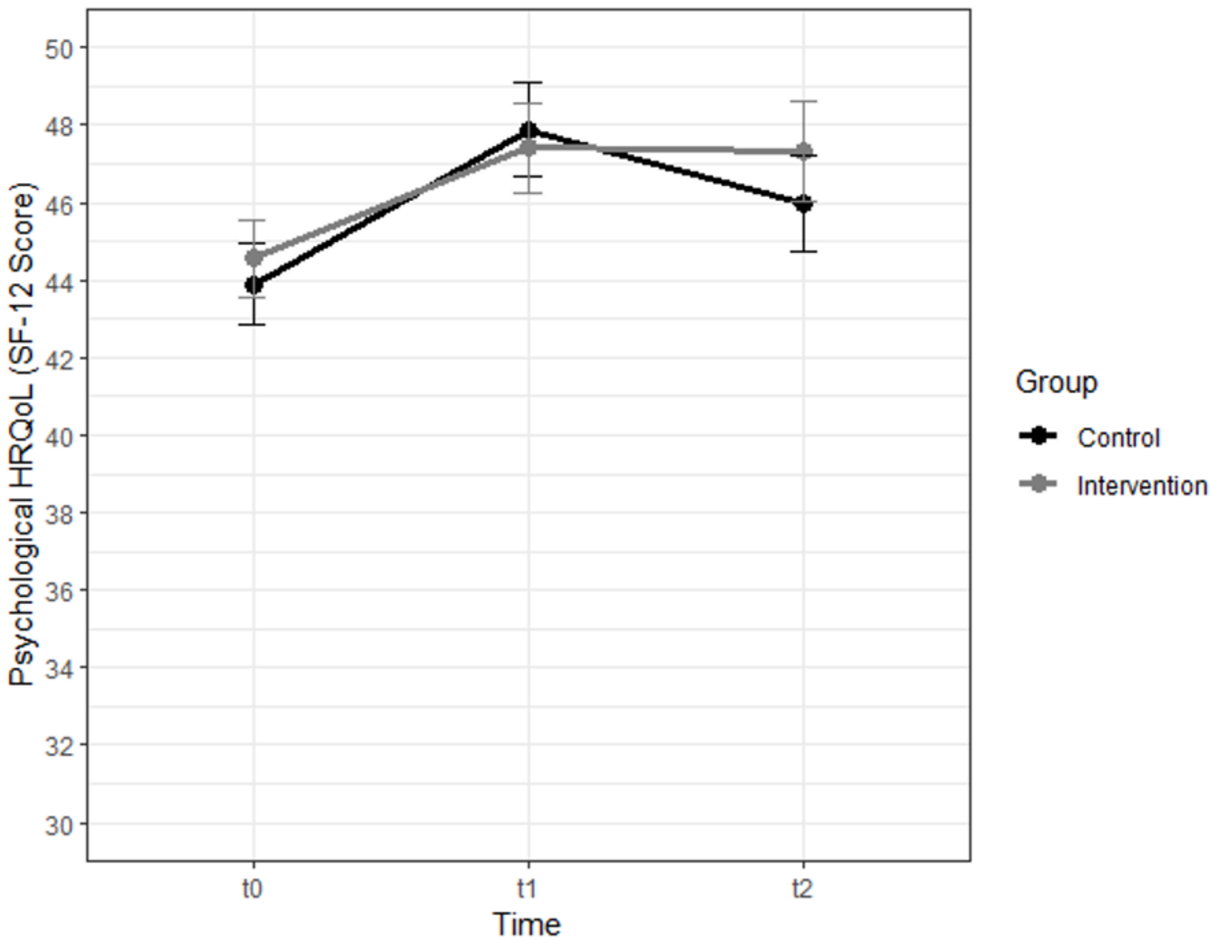

Figure 2

Estimated marginal means of psychological HRQoL across baseline (t0), six months (t1), and 12 months (t2) of follow-up (final model).