

# Food Noise, Control of Eating, and Mental Health Outcomes During Carbohydrate-Reduced Nutrition Therapy in Adults with Overweight or Obesity

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## Article

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# Abstract

**Background/Objectives:** Food noise has emerged as an important patient-centered outcome in obesity treatment. Glucagon-like peptide-1 receptor agonists (GLP-1RAs) have been associated with reduced food noise, but effects of nutrition therapy are not well-studied, and the relationships between food noise, eating behavior, and mental health remain poorly understood. This study evaluated changes in food noise, control of eating, depression, and anxiety during carbohydrate-reduced nutrition therapy (CRNT), examined whether these changes differed by GLP-1RA use, and assessed relationships among these outcomes.

**Subjects/Methods:** This observational study included adults with overweight or obesity enrolled in a remote CRNT program. Participants completed assessments of food noise, control of eating, depression, and anxiety at baseline and six months. Adjusted linear mixed-effects models evaluated changes over time. Multivariable regression analyses examined associations among outcomes.

**Results:** Participants (N=501; mean age 45.7 years; 80.1% female; mean BMI 34.4 kg/m<sup>2</sup>) experienced significant reductions in food noise (8.7 to 5.6;  $p<0.001$ ), depressive symptoms (PHQ-8: 6.6 to 3.7;  $p<0.001$ ), and anxiety symptoms (GAD-7: 5.3 to 3.7;  $p<0.001$ ), with improvements in craving control, hunger, sweet and savory cravings, and mood. Participants also exposed to GLP-1RAs experienced greater improvements in food noise, craving control, food cravings, depression, and anxiety than those receiving CRNT alone. Reduced food noise was independently associated with improved craving control, sweet and savory cravings, hunger, and depression and anxiety scores.

**Conclusions:** Participation in CRNT was associated with significant improvements in food noise, control of eating, depression, and anxiety. Improvements in food noise occurred regardless of GLP-1RA use, although greater reductions occurred among participants exposed to GLP-1RAs with nutrition therapy. This suggests food noise is responsive to nutrition-based obesity treatment and may represent a clinically meaningful patient-centered outcome.

## 1 Introduction

Obesity is a complex, chronic disease encompassing interconnected metabolic, behavioral, cognitive, and psychological processes. In addition to an increased risk of cardiovascular disease, type 2 diabetes, certain cancers, and premature mortality (1, 2), individuals with overweight and obesity experience higher rates of depression, anxiety, impaired quality of life, and eating-related distress (3–6). The relationship between obesity and mental health is bidirectional, with psychological distress potentially contributing to maladaptive eating behaviors, reduced physical activity, alterations in the hypothalamic-pituitary-adrenal axis, elevated cortisol levels, and weight gain, while living with obesity may contribute to depression, anxiety, internalized weight bias, and reduced psychosocial well-being (7). Increasing evidence suggests that obesity should be viewed not as an isolated metabolic disorder but as a

condition with dynamic interactions among biological, behavioral, and psychological factors that may influence both treatment response and long-term weight management.

Reports of reductions in food-related thoughts and cravings among individuals using glucagon-like peptide-1 receptor agonists (GLP-1RAs) have drawn attention to “food noise,” an emerging construct characterized by persistent, intrusive, and distressing thoughts about food that may interfere with daily functioning and healthy behaviors (8–10). Although related to cravings and appetite, food noise appears to represent a distinct cognitive and emotional experience. A related construct, control of eating, reflects an individual’s perceived ability to manage food-related urges and eating behaviors. Together, these constructs may provide insight into the cognitive and behavioral experiences of people living with obesity and their response to treatment. As such, interventions that improve the pathophysiology of obesity, eating behaviors, and psychological well-being may also influence these constructs.

Carbohydrate-reduced nutrition therapy (CRNT) is an effective intervention for weight loss and metabolic health improvement in individuals with overweight, obesity, and related metabolic conditions. CRNT has also been associated with improvements in perceived control of eating, hunger, appetite regulation, depression, and anxiety (11–14). These effects may be mediated, in part, through improvements in appetite regulation, reductions in hunger-related hormones, and the metabolic effects of nutritional ketosis (12). However, little is known about whether food noise changes during CRNT, how it relates to control of eating and mental health, or whether these relationships differ with concurrent GLP-1RA use. Therefore, the primary aim of this study was to evaluate changes in food noise, control of eating, depression, and anxiety over 6 months in adults with overweight or obesity participating in a remotely-delivered CRNT program. Secondary aims were to examine associations among food noise, control of eating, and mental health outcomes; to identify predictors of 6-month outcomes; and to evaluate whether changes in these outcomes differed according to GLP-1RA use.

## **2 Materials & Methods**

### **2.1 Study Design and Participants**

This pre-post observational study evaluated changes in patient-reported outcomes among adults participating in a remotely-delivered nutrition intervention. Participants nationwide were recruited into the study via email after enrollment into Virta Health and before starting dietary changes (Fig. 1). Eligibility criteria included qualification for Virta Health’s Sustainable Weight Loss program (with overweight, obesity, or prediabetes) and willingness and intent to participate in the usual care provided by the program for at least six months. Individuals were excluded if they did not meet program eligibility requirements, including the presence of advanced-stage renal, cardiac, hepatic, or other advanced chronic disease, or if they were pregnant, lactating, or planning pregnancy. Participants completed online surveys at baseline (before dietary changes), and after six months in the program.

The study focused on individuals enrolled in the nutrition therapy program for weight loss. Some participants were using GLP-1RAs at enrollment and either continued or discontinued therapy during participation as part of their weight loss journey. Additionally, some participants who initially pursued a nutrition-only approach subsequently initiated GLP-1RA therapy when additional weight loss support was clinically appropriate. Decisions regarding GLP-1RA use were made through routine clinical care and individualized treatment planning. Prescriptions were provided by either Virta clinicians or external healthcare providers, as clinically indicated.

The study was reviewed by the Biomedical Research Alliance of New York (BRANY) Institutional Review Board (Melville, NY, USA) and determined to qualify for exemption under Category 2(ii)(a) as detailed in 45 CFR 46.104(d). All participants provided electronic informed consent prior to participation through an IRB-approved consent process. The study was considered minimal risk and did not require direct interaction with study personnel as part of the consent process.

--Figure 1.--

## **2.2 Intervention**

Participants received a nutrition intervention through a web-based software application (app) designed to facilitate continuous remote care with a clinical care team consisting of a medical provider and health coach. Through the app, participants received individualized nutrition and lifestyle guidance, behavioral support, educational content, communications with their care team, and biomarker logging for monitoring and personalized feedback. The nutritional component of the program has been described previously (15–17) and has been tailored for people with overweight and obesity (including those on GLP-1RAs). In general, participants were encouraged to reduce carbohydrate intake to support appetite regulation, weight loss, and metabolic health, with individualized macronutrient targets according to the participant's goals, preferences, clinical needs, treatment response, and adherence. Participants were encouraged to achieve nutritional ketosis, defined as blood beta-hydroxybutyrate (BHB) levels  $\geq 0.5$  mmol/L through intake of fewer than 30 to 50 grams of carbohydrates per day,  $\sim 1.5$ -2 grams of protein per kilogram of reference body weight (i.e. medium-frame “ideal”) per day, and eating dietary fat to satiety.

## **2.3 Measures and Assessments**

### **2.3.1 Baseline Demographics and Medical Characteristics**

Demographic characteristics including race, ethnicity, and sex were obtained from baseline survey responses. Age, body mass index (BMI), hemoglobin A1c (HbA1c), and GLP-1RA use were obtained from Virta's electronic medical record. Medication use was tracked continuously by providers as part of routine clinical care, and laboratory measures were obtained through laboratory testing ordered by Virta providers and from available external laboratory records accessed through health information exchange systems. Body weight (BodyTrace Scale, New York, NY, USA) and fingerstick blood ketone levels (Keto-Mojo GK+ meter, Keto-Mojo, Napa, CA, USA) were measured using connected devices provided to all

members as part of the usual care of the program. Participants were generally encouraged to measure body weight and BHB daily at the start of the program, with frequency individualized over time based on clinical needs and treatment progress. Data from both devices were automatically transmitted to the mobile app and were available to participants and the care team for ongoing monitoring and feedback.

## **2.3.2 Food Noise and Control of Eating**

Food noise was assessed using the 5-item Food Noise Questionnaire (FNQ) (9). Items are rated on a 5-point Likert scale ranging from 0 ("strongly disagree") to 4 ("strongly agree"), with total scores ranging from 0–20; higher scores indicate greater levels of food noise. The FNQ has demonstrated excellent reliability in adults (Cronbach's  $\alpha = 0.93$ ; test–retest  $r = 0.79$ ). Consistent with prior findings, internal consistency in the current sample at baseline was excellent (Cronbach's  $\alpha = 0.92$ ).

Control of eating was assessed using the first 19 items from the Control of Eating Questionnaire (CoEQ), a validated instrument designed to measure the intensity and frequency of food cravings, as well as perceived control of eating behaviors (18). Participants are asked to reflect on experiences around eating during the previous 7 days and respond using a 100-mm visual analog scale. Scores range from 0–100, with higher scores indicating greater intensity or frequency of the measured construct. The CoEQ comprises six domains assessing craving control, sweet cravings, savory cravings, mood, hunger, and satiety. The CoEQ has demonstrated good construct validity and acceptable to excellent internal consistency across domains, with published Cronbach's  $\alpha$  values of 0.88 for craving control, 0.74 for positive mood, 0.66 for savory cravings, and 0.67 for sweet cravings (18). In the current sample, baseline Cronbach's  $\alpha$  values for the Control of Eating domains were 0.92 (craving control), 0.74 (mood), 0.67 (savory cravings), and 0.73 (sweet cravings). Hunger and satiety were assessed using single-item measures and therefore internal consistency was not calculated.

## **2.3.3 Depression and Anxiety**

Depressive symptoms were assessed using the 8-item Patient Health Questionnaire (PHQ-8), a validated instrument designed to screen for and assess severity of depressive symptoms (19). The PHQ-8 evaluates symptoms experienced during the previous two weeks using a 4-point Likert scale, ranging from 0 ("Not at all") to 3 ("Nearly every day"). Total scores range from 0–24, with higher scores indicating greater depressive symptom severity. The PHQ-8 has demonstrated excellent reliability and validity across clinical and population-based research settings (19, 20). In the current sample, internal consistency for the 8 items was excellent (Cronbach's  $\alpha = 0.87$ ) at baseline. Participants meeting the clinical cut-off for depression were identified using a PHQ-8 score  $\geq 10$ , a threshold shown to have good diagnostic accuracy for identifying major depression.

Anxiety symptoms were assessed using the 7-item General Anxiety Disorder scale (GAD-7), a validated instrument designed to screen for and assess the presence and/or severity of generalized anxiety symptoms (21). The GAD-7 evaluates symptoms experienced during the previous 2 weeks using a 4-point Likert scale ranging from 0 ("Not at all") to 3 ("Nearly every day"). Total scores range from 0–21, with higher scores indicating greater anxiety symptom severity. The GAD-7 has demonstrated excellent

reliability and validity for assessing anxiety symptoms in clinical care patients and the general population (21). In the current sample, internal consistency for the 7 items was excellent (Cronbach's  $\alpha = 0.91$ ) at baseline. Participants meeting the clinical cut-off for moderate anxiety were identified using a GAD-7 score  $\geq 10$ , a threshold associated with high sensitivity and specificity for generalized anxiety disorder.

## 2.4 Statistical Analysis

Descriptive statistics were computed to characterize the sample. To evaluate potential bias related to study attrition, independent samples t-tests were conducted comparing baseline PHQ-8, GAD-7, and food noise scores between participants who completed the 6-month assessment and those lost to follow-up. Additional independent samples t-tests were used to compare baseline clinical and questionnaire characteristics between participants who were and were not exposed to GLP-1RAs during the study.

Linear mixed-effect models were used to evaluate changes in outcomes from baseline to 6 months. Models included time as a fixed effect and an unstructured covariance matrix for repeated measurements within participants. Maximum likelihood estimation was used to account for missing outcome data. Models were adjusted for baseline age, sex, BMI, race, ethnicity, and GLP-1RA exposure during the study. Separate models evaluated change over time in the full sample and whether change differed by GLP-1RA exposure using a time-by-GLP-1RA interaction term. For depression and anxiety, additional models were conducted among participants meeting clinical cut-offs at baseline and among those meeting cut-offs who were not exposed to GLP-1RAs. As a sensitivity analysis consistent with an intent-to-treat approach, linear mixed-effects models were rerun using datasets generated with 100 multiple imputations. Additionally, among completers with both baseline and 6-month data, we used McNemar's tests to assess changes in the percentage of participants meeting the clinical cut-off for depression and anxiety.

To identify factors associated with 6-month depression, anxiety, food noise, and control of eating outcomes, we conducted multivariable linear regression analyses using estimates pooled across 100 multiple imputed datasets. Separate models were fit for each outcome, with 6-month outcome scores as dependent variables. All models adjusted for the corresponding baseline score and covariates including age, sex, race (White vs. other), ethnicity (Hispanic vs. non-Hispanic), baseline BMI, and GLP-1RA use during the study (yes/no). For depression and anxiety, predictor variables of interest included changes in food noise and control of eating domains, as well as weight change and ketone measurements where relevant. For control of eating, food noise was evaluated as the primary predictor of interest. For food noise outcomes, weight change and BHB levels were evaluated as predictors. For depression and anxiety outcomes with multiple significant predictors, secondary multivariable models were constructed that simultaneously included all significant predictors and covariates to determine the independent association of each predictor with the outcome after accounting for shared variance among predictors. Regression coefficients, standard errors, and significance tests were pooled across imputations using Rubin's rules.

Statistical significance was defined as a p-value less than 0.05. All statistical analyses were conducted using IBM SPSS Statistics software (IBM Corp., Armonk, NY, USA).

## 3 Results

### 3.1 Participant Characteristics

Baseline characteristics for the study groups are presented in Table 1. Among participants who initiated GLP-1RA therapy after enrollment, the mean duration of use over the 6-month study was 116 days. Mean PHQ-8 and GAD-7 scores in all groups corresponded to mild depressive and anxiety symptom severity, respectively.

Baseline depression ( $p=0.258$ ), anxiety ( $p=0.736$ ), and food noise ( $p=0.163$ ) scores did not significantly differ between study completers and non-completers.

--Table 1. Baseline demographics, clinical characteristics, and questionnaire scores.--

### 3.2 Food Noise and Control of Eating Outcomes

Food noise decreased significantly from baseline to 6 months in all groups ( $p < 0.001$ ; Table 2). A significant time-by-GLP-1RA interaction was observed ( $p = 0.003$ ). Estimated mean percent changes are shown in Figure 2.

Significant improvements were observed in all control of eating domains except satiety ( $p < 0.001$ ; Table 2). Time-by-GLP-1RA interactions were significant for craving control ( $p = 0.023$ ), sweet cravings ( $p = 0.006$ ), and savory cravings ( $p < 0.001$ ; Figure 2). Results were robust in sensitivity analyses using multiple imputation.

--Table 2. Food noise and Control of Eating questionnaire scores at baseline and 6 months.--

--Figure 2.--

### 3.3 Depression and Anxiety Outcomes

Depressive symptoms decreased significantly in the full sample and all subgroups including those with clinically elevated symptoms at baseline ( $p < 0.001$ ; Table 3). A significant time-by-GLP-1RA interaction was observed ( $p = 0.043$ ; Figure 3). Among participants with both baseline and 6-month data, the proportion meeting the clinical cut-off for depression decreased by 20.5 percentage points, from 27.3% at baseline to 6.8% at 6 months (McNemar  $p < 0.001$ ).

Anxiety symptoms decreased significantly from baseline to 6 months in the full sample and among participants with clinically elevated anxiety symptoms at baseline ( $p < 0.001$ ; Table 3). A significant time-by-GLP-1RA interaction was also observed ( $p < 0.001$ ; Figure 3). Among participants with both baseline and 6-month data, the proportion meeting the clinical cutoff for anxiety decreased by 6.8 percentage

points, from 17.2% at baseline to 10.4% at 6 months (McNemar  $p = 0.008$ ). Findings were consistent in sensitivity analyses using multiple imputation for both outcomes.

--Table 3. Depression and Anxiety symptom scores at baseline and 6 months.--

--Figure 3.--

### **3.4 Metabolic Markers**

Weight loss at 6 months for the full sample was 6.6% and was 6.2% and 8.7% for the nutrition only and GLP-1RA exposure groups, respectively, and continued through the end of the study. (Supplementary Figure 1).

Mean BHB levels across the study period did not differ between GLP-1RA users versus the Nutrition only intervention (both 0.5 mmol/L).

### **3.5 Association analyses**

In multivariable regression analyses, improvements in food noise and multiple control of eating measures were independently associated with lower depression and/or anxiety over 6 months (Supplementary Table 1). When significant predictors were entered simultaneously into fully adjusted models, improvement in mood related to eating remained the only independent predictor of both lower depression and anxiety scores. Decreased food noise also independently predicted improved craving control, sweet cravings, savory cravings, and hunger at 6 months.

## **4 Discussion**

Participation in a carbohydrate-reduced nutrition therapy program was associated with significant improvements in food noise, control of eating, depression, and anxiety over 6 months among adults with overweight or obesity. Food noise decreased by over one-third in the overall cohort (35%), with significant reductions observed among participants receiving nutrition therapy alone (31%) and even greater reductions among those additionally exposed to GLP-1RAs (50%). The magnitude of improvement observed in the present study is consistent with recent work reporting a 48% reduction in FNQ scores among individuals treated with semaglutide (22). Importantly, the reduction observed among participants receiving nutrition therapy without GLP-1RA exposure suggests that improvements in food-related cognition are not unique to pharmacotherapy. Rather, food noise may be responsive to multiple obesity treatment approaches, including behavioral and nutritional interventions. Our findings are further supported by recent preliminary data, which demonstrated reductions in food noise among participants enrolled in a behavioral weight management program regardless of GLP-1RA use, although larger reductions were observed among those initiating GLP-1RA therapy (23). Together, these findings suggest that while GLP-1RAs may amplify reductions in food noise, behavioral and nutrition-based

interventions alone may also meaningfully improve food-related cognition. Given the limited literature evaluating food noise in response to nutrition-focused interventions, our study provides some of the first evidence that a CRNT intervention may substantially reduce food noise independent of obesity medications.

Reductions in food noise were associated with improvements in both mental health and multiple domains of eating behavior, suggesting that food-related cognition may represent an important and underrecognized component of the psychological experience. Significant improvements were observed across nearly all domains of control of eating. These findings are consistent with previous observations demonstrating improved perceived control of eating during CRNT (11), as well as evidence that ketogenic nutrition interventions may improve appetite regulation and attenuate hunger responses that typically accompany weight loss (24). Similar improvements in hunger, food cravings, and perceived control of eating have also been observed with semaglutide treatment (25, 26), suggesting that both nutritional and pharmacological approaches may influence common eating-related experiences. Notably, reductions in food noise were independently associated with improvements in craving control, sweet cravings, savory cravings, and hunger. While this study supports the emerging conceptualization of food noise as a construct that is related to, yet distinct from, traditional measures of appetite and eating behavior (8, 9, 18), the findings also suggest that food noise and control of eating may capture different aspects of the eating experience. Whereas control of eating reflects an individual's perceived ability to regulate eating behaviors, food noise may capture the frequency and intrusiveness of food-related thoughts that may influence behavior.

Greater weight loss was independently associated with lower food noise scores, whereas ketone levels were not independently associated with food noise or other psychological outcomes after adjustment for covariates. This finding should be interpreted in the context of the close relationship between ketosis and weight loss during CRNT (27, 28). While ketone levels may reflect dietary adherence and metabolic response, they are also subject to substantial variability due to factors such as timing of measurement, fasting status, physical activity, hydration, and individual metabolic differences. Consequently, intermittent ketone measurements may not accurately represent an individual's overall exposure to ketosis. In contrast, weight loss reflects the cumulative effects of sustained behavioral and metabolic changes and may therefore provide a more stable indicator of intervention response. Given the strong correlation between ketosis and weight loss, weight loss may have captured much of the benefit associated with long-term adherence to the intervention, thereby diminishing the apparent independent contribution of ketone levels. It is also possible that reductions in food noise facilitate adherence to dietary recommendations by decreasing intrusive food-related thoughts and reducing the cognitive burden of food-related decision-making, which in turn supports greater weight loss. Together, these findings suggest a complex and potentially bidirectional relationship among ketosis, weight loss, and psychological outcomes that warrants further investigation.

The improvements in food-related cognition and eating behavior were also accompanied by clinically meaningful reductions in depressive (44%) and anxiety (30%) symptoms. Notably, the proportion of

participants who met the clinical cut-off for depression decreased from 27.3% at baseline to 6.8% at 6 months, representing a relative reduction of 75%. Similarly, the proportion of participants meeting the clinical cutoff for anxiety decreased from 17.2% at baseline to 10.4% at 6 months, representing a relative reduction of 39.5%. This is consistent with previous reports that ketogenic diets improve depression symptoms (29). In the same meta-analysis, there was no significant effect of ketogenic diets on reducing anxiety symptoms, so the findings in this study represents a signal not previously demonstrated in controlled trials.

In patients with obesity and mild-to-moderate depression, the effect of GLP-1RAs on mood remains unestablished, as pivotal trials excluded this group (30) and observational data are conflicting (31, 32). Our finding that GLP-1RAs were associated with enhanced mood and anxiety within a CNRT intervention is reassuring that these interventions can be safely combined and may provide additive benefits on mood and anxiety.

Importantly, reductions in food noise, hunger, and craving-related measures were each associated with improvements in both depression and anxiety when evaluated individually, suggesting that changes in food-related cognition may be closely intertwined with psychological well-being. However, when all significant predictors were considered simultaneously, improvement in mood emerged as the strongest independent predictor of both outcomes. This pattern suggests substantial overlap among these constructs and is consistent with prior evidence demonstrating close interrelationships among mood, appetite regulation, food cravings, and eating behavior (25, 26, 33, 34). Together, these findings raise the possibility that improvements in food-related cognition and eating behavior may contribute to psychological well-being, at least in part, through broader changes in mood and emotional functioning.

## 4.1 Clinical Implications

Recent recommendations from the Lancet Diabetes & Endocrinology Commission emphasize that obesity management should extend beyond weight loss and consider broader effects on health, functioning, and well-being (35). As GLP-1RA use continues to expand, effective non-pharmacologic options remain important for individuals who are unable to access, do not tolerate, or prefer not to use obesity medications. Our findings support the role of CRNT as a viable alternative or complementary strategy to GLP-1RAs, with the potential to support dietary adherence, behavior change, and long-term weight maintenance. Beyond its effects on weight loss, CRNT may positively influence food-related cognitions, psychological well-being, and other behavioral and psychosocial aspects of obesity. These findings are consistent with the evolving paradigm of obesity management, which emphasizes improvements in overall health, functioning, and well-being in addition to weight reduction, underscoring the value of comprehensive treatment approaches that address the multifaceted nature of obesity.

## 4.2 Strengths and Limitations

This study is among the first to investigate food noise in a nutrition-based obesity intervention and provides novel data on the relationships among food noise, control of eating, and mental health.

Additional strengths include inclusion of participants both with and without GLP-1RA exposure and the intervention's real-world applicability. Several limitations should be considered. The study employed a single-arm design without a comparator group, limiting causal inference. Participant attrition over the 6-months may have introduced bias. Although approximately 30% of participants discontinued the program during this period, this occurred within a large, real-world program operating across diverse geographic regions, health plans, and employer groups. The reasons for discontinuation were not systematically assessed and may have reflected factors unrelated to treatment response, including changes in insurance coverage, program access, or other unmeasured circumstances. The cohort was predominantly White and female, which may also limit generalizability. The GLP-1RA-exposed subgroup was relatively small, reducing statistical power for subgroup analyses and limiting our ability to characterize differences between treatment approaches. In addition, we did not include a comparison group receiving GLP-1RAs without nutrition intervention, making it difficult to isolate the independent contributions of nutrition therapy and pharmacotherapy to the observed changes in food noise and related outcomes. The study population was self-selected, introducing the potential for selection bias and limiting generalizability to broader populations seeking obesity treatment. Future research should continue to evaluate food noise as both a treatment target and an outcome measure to understand its role in obesity management and psychological well-being. Longitudinal and controlled studies, including direct comparisons of nutrition-based, pharmacologic, and combined treatment approaches, are needed to clarify the mechanisms underlying changes in food noise and determine whether these improvements are sustained long-term.

## 5 Conclusions

In conclusion, participation in carbohydrate-reduced nutrition therapy was associated with improvements in food noise, control of eating, depression, and anxiety among adults with overweight or obesity. Improvements in food noise were observed among participants both with and without GLP-1RA exposure, highlighting the potential role of nutrition-based interventions in improving food-related cognition. Furthermore, these findings indicate that food noise is a clinically relevant and patient-centered outcome that warrants further investigation as both a treatment target and an indicator of psychological well-being during obesity treatment.

## Declarations

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### Author Contribution

Alison Zoller: Conceptualization, Methodology, Formal Analysis, Investigation, Project Administration, Data curation, Writing – original draft, Writing – review & editing. Shaminie Athinarayanan: Formal

Analysis, Writing – review & editing. Matthew Bernstein: Writing – original draft, Writing – review & editing. Rebecca Adams: Conceptualization, Methodology, Formal Analysis, Data curation, Writing – review & editing. Michelle Cardel: Writing – review & editing

## Competing Interests

ARZ and SJA are currently employed by Virta Health, and RNA was previously employed by Virta Health. All three have been granted stock options. The other authors declare no competing interests.

## Data Availability Statement

The data analyzed in this study is subject to the following licenses/restrictions: data is available upon appropriate request to the corresponding author, accompanied by a detailed proposal outlining how the data will be used.

## References

1. Ng M, Fleming T, Robinson M, Thomson B, Graetz N, Margono C, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980-2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet*. 2014; 384(9945):766-81.
2. GBD 2015 Obesity Collaborators; Afshin A, Forouzanfar MH, Reitsma MB, Sur P, Estep K. Health effects of overweight and obesity in 195 countries over 25 Years. *N Engl J Med*. 2017; 377(1):13-27.
3. Pereira-Miranda E, Costa PRF, Queiroz VAO, Pereira-Santos M, Santana MLP. Overweight and obesity associated with higher depression prevalence in adults: a systematic review and meta-analysis. *J Am Coll Nutr*. 2017; 36(3):223-233.
4. Simon GE, Von Korff M, Saunders K, Miglioretti DL, Crane PK, van Belle G, et al. Association between obesity and psychiatric disorders in the US adult population. *Arch Gen Psychiatry*. 2006; 63(7):824-30.
5. Kolotkin RL, Andersen JR. A systematic review of reviews: exploring the relationship between obesity, weight loss and health-related quality of life. *Clin Obes*. 2017; 7(5):273-289.
6. van Strien T. Causes of emotional eating and matched treatment of obesity. *Curr Diab Rep*. 2018; 18(6):35.
7. Luppino FS, de Wit LM, Bouvy PF, Stijnen T, Cuijpers P, Penninx BW, et al. Overweight, obesity, and depression: a systematic review and meta-analysis of longitudinal studies. *Arch Gen Psychiatry*. 2010; 67(3):220-9.
8. Dhurandhar EJ, Maki KC, Dhurandhar NV, Kyle TK, Yurkow S, Hawkins MAW, et al. Food noise: definition, measurement, and future research directions. *Nutr Diabetes*. 2025; 15(1):30.
9. Diktas HE, Cardel MI, Foster GD. Development and validation of the Food Noise Questionnaire. *Obesity (Silver Spring)*. 2025; doi: 10.1002/oby.24216.

10. Hayashi D, Edwards C, Emond JA, Gilbert-Diamond D, Butt M, Rigby A, et al. What Is Food Noise? A conceptual model of food cue reactivity. *Nutrients*. 2023; 15(22):4809.
11. Adams RN, VanTieghem M, Volk BM, Athinarayanan SJ, McKenzie AL. Perceived control over eating improves following initiation of carbohydrate-restricted nutrition therapy in a continuous remote care model [abstract]. *Diabetes*. 2022; 71(Supplement\_1):50-LB. <https://doi.org/10.2337/db22-50-LB>
12. Martins C, Nymo S, Truby H, Rehfeld JF, Hunter GR, Gower BA. Association between ketosis and changes in appetite markers with weight loss following a very low-energy diet. *Obesity (Silver Spring)*. 2020; 28(12):2331-2338.
13. Adams RN, Athinarayanan SJ, McKenzie AL, Hallberg SJ, McCarter JP, Phinney SD, et al. Depressive symptoms improve over 2 years of type 2 diabetes treatment via a digital continuous remote care intervention focused on carbohydrate restriction. *J Behav Med*. 2022; 45:416–427.
14. Bellamy EL. A retrospective evaluation of an online group ketogenic metabolic therapy intervention on mental health outcomes. *Front Nutr*. 2026; 13:1751564.
15. McKenzie AL, Athinarayanan SJ, McCue JJ, Adams RN, Keyes M, McCarter JP, et al. Type 2 diabetes prevention focused on normalization of glycemia: a two-year pilot study. *Nutrients*. 2021; 13:749.
16. Hallberg SJ, McKenzie AL, Williams PT, Bhanpuri NH, Peters AL, Campbell WW, et al. Effectiveness and safety of a novel care model for the management of type 2 diabetes at 1 year: an open-label, non-randomized, controlled study. *Diabetes Ther*. 2018; 9:583-612.
17. Athinarayanan SJ, Adams RN, Hallberg SJ, McKenzie AL, Bhanpuri NH, Campbell WW, et al. Long-term effects of a novel continuous remote care intervention including nutritional ketosis for the management of type 2 diabetes: a 2-year non-randomized clinical trial. *Front Endocrinol*. 2019; 10:348.
18. Dalton M, Finlayson G, Hill A, Blundell J. Preliminary validation and principal components analysis of the Control of Eating Questionnaire (CoEQ) for the experience of food craving. *Eur J Clin Nutr*. 2015; 69:1313-1317.
19. Kroenke K, Spitzer RL, Williams JB. The PHQ-9: validity of a brief depression severity measure. *J Gen Intern Med*. 2001; 16(9):606-13.
20. Kroenke K, Strine TW, Spitzer RL, Williams JB, Berry JT, Mokdad AH. The PHQ-8 as a measure of current depression in the general population. *J Affect Disord*. 2009; 114(1-3):163-73.
21. Spitzer RL, Kroenke K, Williams JBW, Löwe B. A brief measure for assessing generalized anxiety disorder: the GAD-7. *Arch Intern Med*. 2006; 166(10):1092–1097.
22. Arnaut T, Duncan S, Faurby M, Hahn-Pedersen JH, Kvist K, Steenackers N, et al. Retrospective assessment of food noise changes after initiation of injectable semaglutide for weight management in the USA: the INFORM survey. *Adv Ther*. 2026. doi: 10.1007/s12325-026-03636-x.
23. Diktas HE, Goldstein SP, Cardel MI, Foster GD, Martin CK. Changes in food noise in two weight management programs: effects of GLP-1 receptor agonists [abstract]. Presented at: 33rd European Congress on Obesity (ECO); 2026; Istanbul, Turkey. Abstract 1276.

24. Deemer SE, Plaisance EP, Martins C. Impact of ketosis on appetite regulation- a review. *Nutr Res.* 2020; 77:1-11.
25. Blundell J, Finlayson G, Axelsen M, Flint A, Gibbons C, Kvist T, et al. Effects of once-weekly semaglutide on appetite, energy intake, control of eating, food preference and body weight in subjects with obesity. *Diabetes Obes Metab.* 2017; 19(9):1242-1251.
26. Friedrichsen M, Breitschaft A, Tadayon S, Wizert A, Skovgaard D. The effect of semaglutide 2.4 mg once weekly on energy intake, appetite, control of eating, and gastric emptying in adults with obesity. *Diabetes Obes Metab.* 2021; 23(3):754-762.
27. Adams RN, Athinarayanan SJ, Roberts CGP, Volk BM. Real-world ketone targets in carbohydrate-restricted nutrition therapy for obesity. *Obesity (Silver Spring).* 2024; 32: 55-308.
28. McKenzie AL, Athinarayanan SJ, Adams RN, Volk BM, Phinney S, Ratner RE. Mean blood beta-hydroxybutyrate predicts clinically significant weight loss following 90 days carbohydrate restricted nutrition therapy [abstract]. *Diabetes.* 2021; 70(Supplement 1):307-OR.  
<https://doi.org/10.2337/db21-307-OR>
29. Janssen-Aguilar R, Vije T, Peera M, Al-Shamali HF, Meshkat S, Lin Q, et al. Ketogenic diets and depression and anxiety: a systematic review and meta-analysis. *JAMA Psychiatry.* 2026; 83(1):13-22.
30. Wadden TA, Brown GK, Egebjerg C, Frenkel O, Goldman B, Kushner RF, et al. Psychiatric safety of semaglutide for weight management in people without known major psychopathology: post hoc analysis of the STEP 1, 2, 3, and 5 trials. *JAMA Intern Med.* 2024; 184(11):1290-1300.
31. Taipale H, Taylor M, Lähteenenvuo M, Mittendorfer-Rutz E, Tanskanen A, Tiihonen J. Association between GLP-1 receptor agonist use and worsening mental illness in people with depression and anxiety in Sweden: a national cohort study. *Lancet Psychiatry.* 2026; 13(4):327-335.
32. Kornelius E, Huang JY, Lo SC, Huang CN, Yang YS. The risk of depression, anxiety, and suicidal behavior in patients with obesity on glucagon like peptide-1 receptor agonist therapy. *Sci Rep.* 2024; 14(1):24433.
33. Macht M. How emotions affect eating: a five-way model. *Appetite.* 2008; 50(1):1-11.
34. Konttinen H, Männistö S, Sarlio-Lähteenkorva S, Silventoinen K, Haukkala A. Emotional eating, depressive symptoms and self-reported food consumption. A population-based study. *Appetite.* 2010; 54(3):473-9.
35. Rubino F, Cummings DE, Eckel RH, Cohen RV, Wilding JPH, Brown WA. Definition and diagnostic criteria of clinical obesity. *Lancet Diabetes Endocrinol.* 2025; 13(3):221-262. Erratum in: *Lancet Diabetes Endocrinol* 2025; 13(3):e6. doi: 10.1016/S2213-8587(25)00006-3.

## Tables

Tables 1 to 3 are available in the Supplementary Files section.

# Figures

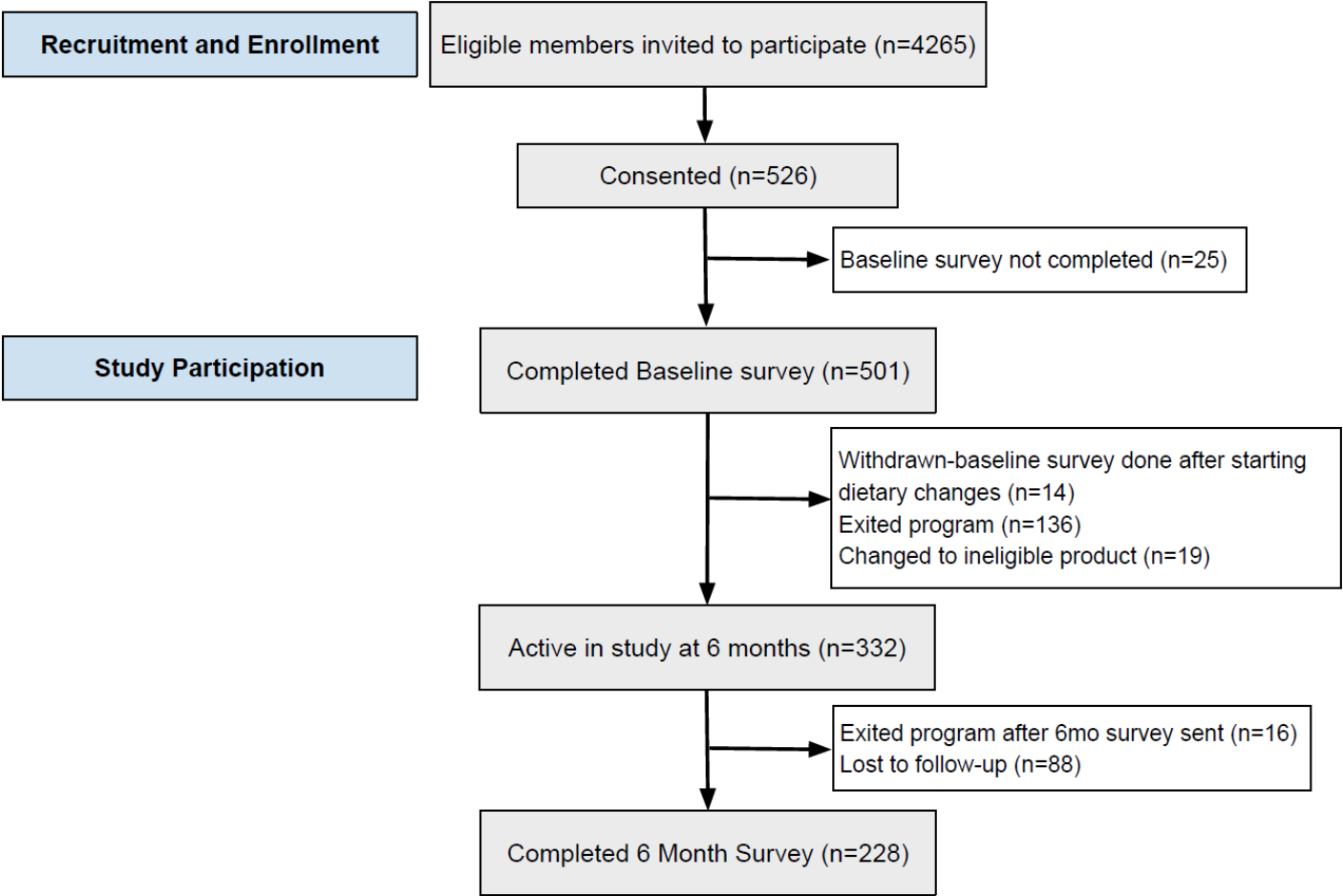


Figure 1

Flowchart of participants in the study from recruitment through study completion.

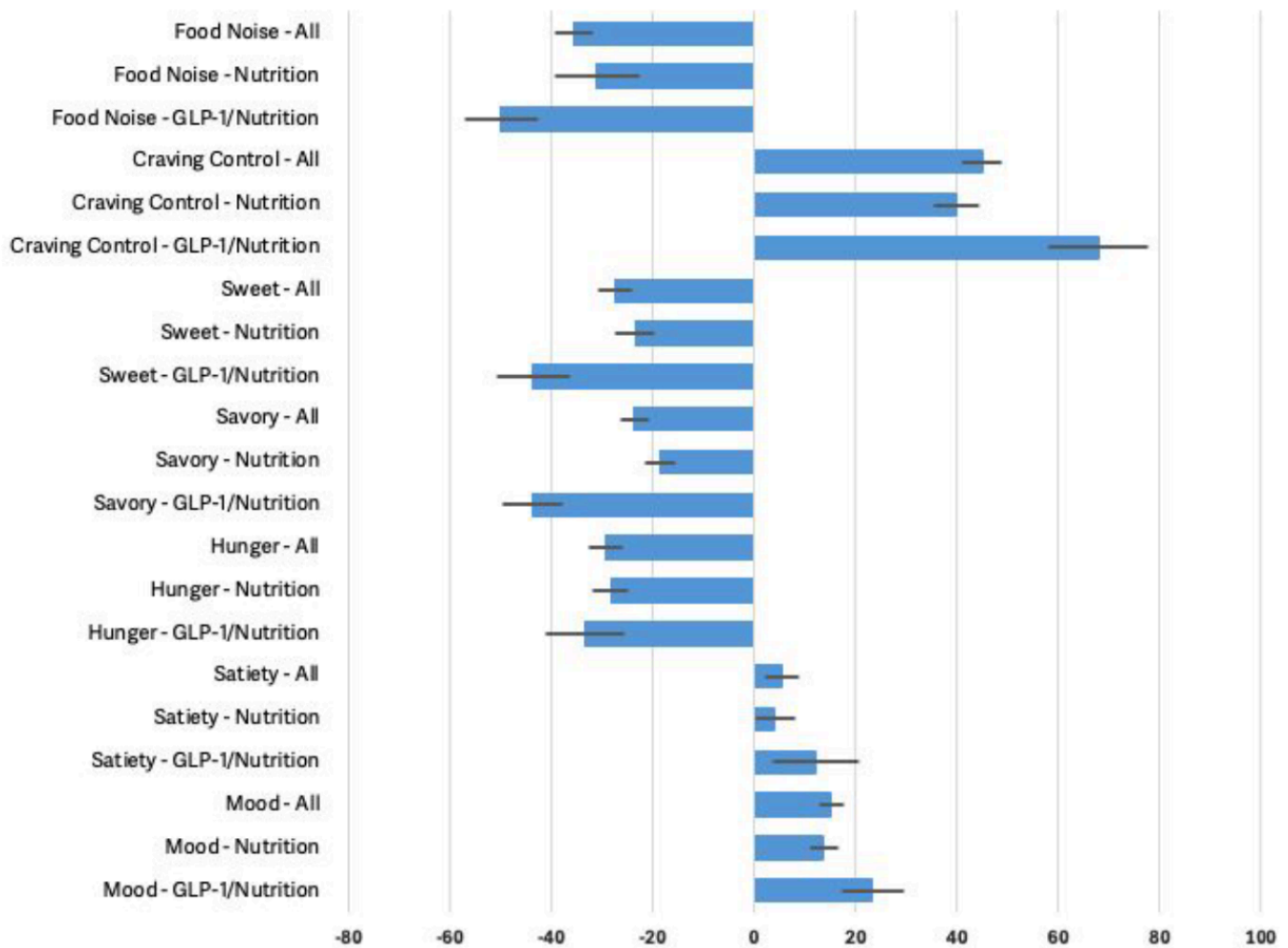


**Figure 2**

Percent change in food noise and control of eating outcomes from baseline to 6 months. Bars represent estimated mean percent change derived from linear mixed-effects models and were calculated as the change in mean values from baseline to 6 months divided by the mean baseline value  $\times 100$ . Negative values indicate a decrease from baseline, whereas positive values indicate an increase. Negative values for food noise, cravings for sweet and savory, and hunger indicate improvement, whereas positive values for craving control, satiety, and mood indicate improvement. Error bars represent  $\pm$ SE and were calculated as  $100 \times (6\text{-month value SE}) / (\text{baseline value})$ .

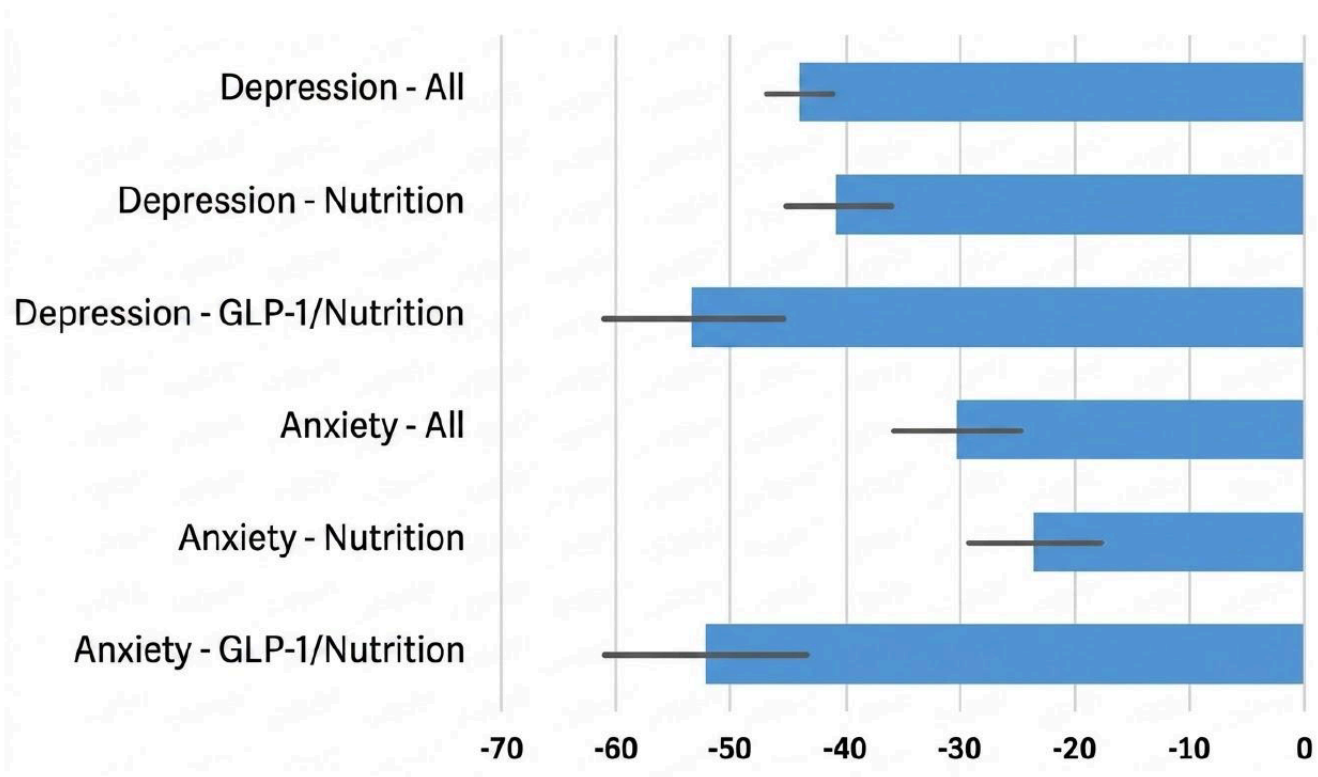


**Figure 3**

Percent change in depression and anxiety outcomes from baseline to 6 months. Bars represent estimated mean percent change derived from linear mixed-effects models and were calculated as the change in mean values from baseline to 6 months divided by the mean baseline value  $\times 100$ . Negative values indicate a decrease from baseline and therefore represent improvement. Error bars represent  $\pm$ SE and were calculated as  $100 \times (6\text{-month value SE}) / (\text{baseline value})$ .

## Supplementary Files

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

- [SupplementaryMaterials.docx](#)
- [Table1.xlsx](#)
- [Table2.xlsx](#)
- [Table3.xlsx](#)