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Pilot study to reduce chewing and eating rates using haptic feedback from the OCOsense glasses

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ABSTRACT

Obesity is a global concern and chewing manipulation has shown promising results for weight management. This preliminary pilot study explored the use of the OCOsense glasses to deliver personalised haptic feedback to encourage slower chewing. It was hypothesised that feedback would reduce chewing rate. A repeated-measures experimental design was used. At T1, participants consumed pasta to collect baseline chewing rates. At T2 (one week later), participants ate pasta but received haptic feedback when chewing exceeded 80 % of their T1 rate. Additional measures included eating rate, food intake, hunger, fullness, feasibility, and acceptability. Twenty-two participants (BMI 18.5–29.9) were recruited. Chewing rate data were collected using the OCOsense glasses. Eating rate was calculated as grams/min by weighing food pre/post-meal, and hunger/fullness levels were self-reported. T-tests compared T1 and T2 data, while feasibility and acceptability were evaluated descriptively. Results showed significant reductions in chewing rate ($t(21) = 7.3$, $p < 0.001$) and eating rate ($T(N = 22) = 11$, $p < 0.001$) at T2. Despite higher hunger levels at T2 ($t(21) = -3.095$, $p = 0.005$), food intake remained unchanged ($t(21) = 0.093$, $p = 0.927$). The system ran smoothly and was deemed acceptable. In conclusion, this preliminary study suggests that haptic feedback may reduce chewing rate, highlighting potential for modifying eating behaviour. However, methodological limitations—such as lack of randomisation and control for confounders—warrant cautious interpretation. Future research should explore effects in individuals with obesity. The OCOsense glasses represent a promising tool for addressing eating habits and obesity through innovative technology.

1. Introduction

1.1. Addressing obesity's economic and health challenges

According to the World Obesity Atlas (2023), 38 % of the population lived with overweight or obesity in 2020, costing US$1.96 trillion in healthcare and reduced productivity. Being overweight means having a Body Mass Index (BMI) between 25 and 29.9, and obesity is a BMI of 30 or higher.

Individuals with obesity face a heightened risk of diseases, including diabetes, heart disease, various forms of cancer, neurodegenerative conditions, and emotional and mental health issues (Mohajan & Mohajan, 2023). Tackling overweight and obesity is a global concern, and developing effective weight management strategies is a priority for the World Health Organisation (2023).

1.2. Chewing manipulation as a strategic approach to weight management

Slyper (2021) argues that some key factors in obesity include consuming processed food and poor satiation, the process of satisfying the need for food that leads to meal termination. Processed food has a soft texture, which facilitates taking larger bites and requires less chewing; these two oral processing behaviours accelerate the eating rate and diminish meal satisfaction, leading to overconsumption (Slyper, 2021). Research has indicated that individuals who consume their meals quickly are more likely to eat more (Robinson et al., 2014) and to have a higher BMI (Ohkuma et al., 2015) than those who eat slowly. Therefore, adopting a slower eating rate, such as pausing between bites or taking smaller bites, may be an effective approach to reduce overall consumption and weight control (Simonson et al., 2020). The relationship between chewing behaviour and food intake has been demonstrated

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across several studies; for example, participants who chew more or longer, reduced their food intake across several interventions, including Cassady et al. (2009), Higgs and Jones (2013), Li et al. (2011), Smit et al. (2011), Borvornparadorn et al. (2019). However, other studies by Zhu et al. (2013) and Spiegel et al. (1993) found no difference in food intake after a chewing intervention.

Variations in results may be attributed to differences in study design (Cox et al., 2022; Sáenz- Pardo-Reyes et al., 2021), for example the timing of food intake measurements, whether during the intervention meal or a subsequent one. The type of food tested ranged from sandwiches (Higgs & Jones, 2013) and pizza (Zhu & Hollis, 2014) to pasta (Andrade et al., 2008) and pork pies (Li et al., 2011), each with unique textures and densities (McCrickerd et al., 2017). The methods of chewing manipulation differed, with some focusing on the duration of chewing (Higgs & Jones, 2013) and others on the number of chews (Cassady et al., 2009). A few studies instructed participants to take an extreme number of chews, which could potentially lead to discomfort and a premature end to the meal (Hollis, 2018). Moreover, the approach to counting chews varied, with participants counting their own chews (Zhu & Hollis, 2014) or receiving different chewing instructions from the experimenter (Higgs & Jones, 2013). Given these factors, there is a clear need for further research into how chewing modifications can effectively reduce food intake with a more standardised methodology.

Regardless, reviews by Krop et al. (2018), Venegas et al. (2022) and Miquel-Kergoat et al. (2015) confirm that, globally, chewing affects appetite and food intake. Hollis (2018) suggested several mechanisms to explain these effects. First, by breaking down food into smaller pieces, chewing increases the food's surface area, improving digestion and absorption, which may contribute to satiety, the suppression of hunger and inhibition of further eating; then, chewing triggers the secretion of gut hormones like ghrelin and cholecystokinin, which may enhance feelings of fullness; and finally, chewing can slow the pace of eating, allowing the body more time to signal that it is satisfied (Hollis, 2018).

Considering the evidence and mechanisms linking increased chewing to reduced food intake, chewing modification emerges as a viable approach for managing weight. However, the challenge lies in altering automatic habitual behaviours such as eating and chewing habits (Gardner, 2015; Wood & Rünger, 2016). Thus, implementing behaviour change techniques that address these automatic and habitual behaviours is crucial for the success of such interventions.

1.3. *The potential of haptic feedback in disrupting chewing behaviour*

Feedback is a behaviour change technique (BCT) that refers to "monitoring and providing informative or evaluative feedback on performance of the behaviour" (Michie et al., 2014, p. 262). The Feedback Intervention Theory (Kluger & DeNisi, 1996) emphasises the importance of understanding how feedback brings attention to the behaviour to regulate and proposes that individuals regulate their behaviour by comparing their actions to a goal, with feedback as a guide, which prompts individuals to assess and modify their behaviour to meet their goal. In applying this theory, Melanson et al. (2023) combined self-monitoring and verbal feedback to remind participants to take smaller bites and chew their food more and found that the eating rate of medium to fast eaters from overweight and obese populations slowed.

Biofeedback is a type of feedback defined as the use of an external monitoring device to provide feedback about the body as part of a behaviour change intervention (Michie et al., 2014). A few studies have investigated the use of biofeedback in treating several eating disorders with encouraging results (Imperatori et al., 2018). For example, in a recent experiment involving 20 participants, Nicholls et al. (2022) found that biofeedback in the form of vibrations delivered through a wristband device when medium or high eating rates were detected, and, activated by detecting automatic chewing behaviours, significantly reduced eating rates. This study opted for haptic feedback, delivering vibrations to communicate information. These discrete signals gently refocus attention on eating habits. Each participant participated in a single session with three phases: one control phase for measuring baseline eating and two self-moderation of eating rate phases with and without feedback. Their results indicated that the lowest chewing rate was observed in the feedback condition, significantly lower than the no-feedback and control conditions (Nicholls et al., 2022). This research highlights the effectiveness of real-time haptic feedback based on eating behaviour as a method for behaviour change intervention by continuously reminding participants of their chewing moderation goals.

However, the Nicholls et al. (2022) intervention required the experimenter to attach electromyography electrodes to participants' faces and connect several devices (wristband, laptop and mobile phone), which are both intrusive and cumbersome. This suggests the need for a non-invasive method that delivers objective biofeedback and measurement of oral processes such as chewing. New technology is being developed with encouraging accuracy to measure eating and chewing behaviours (He et al., 2020; Selamat & Ali, 2020). Acoustic sensing captures chewing sounds near the ear, behind the head, or on the neck (Bi et al., 2018); they have long battery life and are comfortable, but can be affected by noise. Piezoelectric sensors measure jaw movement during chewing (Farooq & Sazonov, 2016); they are simple and non-intrusive but may not work well during other activities.

Electromyography sensing measures muscle contractions (Blechert et al., 2017); signal is robust but sensors can be affected by hair and requires clean skin. Accelerometers measure body acceleration (Sharma et al., 2016); on smart watches, they preserve privacy and are user-friendly but do not measure chewing. Another development is the OCOsense glasses, a non-invasive and easy-to-use wearable device which can detect and provide haptic feedback to bring attention to chewing behaviour (Kiprijanovska et al., 2023; Stankoski et al., 2024). Given the potential of biofeedback to disrupt automatic behaviour, the OCOsense glasses represent an innovative solution for weight management.

1.4. *Aims, objectives and hypotheses*

The current pilot study examined the feasibility of using the wearable device OCOsense glasses to objectively collect chewing data and deliver haptic feedback in real-time. It was hypothesised that haptic feedback would encourage individuals to chew more slowly. The pilot also examined changes in eating rate and appetite in a controlled laboratory experiment. Study hypotheses were:

- Investigate if haptic feedback can modify chewing behaviours; it was hypothesised that feedback at T2 would decrease chewing rate.
- Examine changes in eating rate; it was hypothesised that eating rate would decrease at T2.
- Examine how changes in chewing affect appetite (fullness, hunger, food intake); it was hypothesised that hunger would decrease, fullness would increase, and food intake would reduce at T2. Verify that the OCOsense glasses can be used to deliver haptic feedback, based on chewing rate and at defined frequency and intensity; it was hypothesised that feedback would be delivered successfully.
- Explore acceptability of the intervention; the comfort and efficiency of the OCOsense glasses was assessed.

2. Method and material

2.1. *Design*

The study design comprised a repeated measures, laboratory-based experiment, and questionnaires. A summary of the variables and measures at the two-time points is presented in Table 1.

Participants took part in two laboratory sessions during which objective data about chewing rate (chews per second) were collected at two-time points using the OCOsense glasses. Time point 1 (T1) recorded

Table 1
Summary of variables and measures, at different time-points.

Variables	Measures	Time point 1 (T1) Baseline	Time point 2 (T2) Intervention
Feasibility	Number of haptic feedback		v
Acceptability	1-5-point scores experience		v
Chewing rate	Chews per second	v	v
Eating rate	Grams per minute	v	v
Food intake	Grams eaten	v	v
Hunger before and after meal	100-point VAS scale	v	v
Fullness before and after meal	100-point VAS scale	v	v

Note. Variables and measures used at T1 (baseline) and T2 (intervention).

the baseline participant's chewing rate without haptic feedback from the OCOsense glasses. Time point 2 (T2) recorded the participant's chewing rate with haptic feedback from the OCOsense glasses. At T2, participants were asked to chew more slowly. The glasses were set to vibrate every 30 s but only if the chewing rate was above 80 % of the participant's baseline chewing rate. If the participant maintained a chewing rate below the threshold, the glasses would not vibrate again until their chewing rate potentially exceeded the threshold. The haptic feedback was used as a way to bring attention to the chewing behaviour. Data from T1 and T2 were compared to determine if the haptic feedback reduced chewing rate.

2.2. Measures

Chewing rate, defined as the number of chews per second, was measured at T1 without haptic feedback and at T2 with haptic feedback. Eating rate was quantified as the grams of food consumed per minute, providing an objective measure of eating behaviour. Food intake was calculated by measuring the difference between the weight of the food before the meal and the weight after the meal, in grams.

Hunger and fullness were measured before and after each meal using 100-point Visual Analogue Scales (VAS). Participants were asked how hungry and how full they were. VAS was found to be reliable for measuring appetite and sensations (Flint et al., 2000). The feasibility of delivering haptic feedback based on chewing rate, at a defined intensity and frequency, was evaluated by monitoring system performance and recording the number of feedback instances participants received at T2. Acceptability was assessed through an experience questionnaire administered at T2.

2.3. Materials

Participants were served the Tesco Tomato & Basil Pasta Salad 550g, with 179 kcal per quarter pack (6.5g sugars, 3.9g fat, 0.3g saturates, 0.35g salt). The amount consumed was measured by weighing the meal before and after eating. Participants were given 130 ml of water to control for water intake. All questionnaires, including the screening questionnaire, hunger and fullness scales, and acceptability questionnaire, were distributed via Qualtrics. Visits were managed using Teams Booking. A series of acceptability questions after the second meal captured reflective thoughts on haptic feedback set-up, feedback efficacy and experience of modifying chewing rate. Using a 5-point Likert scale, they assessed feedback intensity, duration, and frequency (e.g., "How would you describe the intensity of the haptic feedback?"), its impact on awareness and behaviour change (e.g., "To what extent did the feedback bring your attention to your chewing?"), and the overall experience of chewing more slowly (e.g., "How would you rate your eating experience with the reduced chewing rate?").

The OCOsense glasses were used to measure chewing rate in chews per second and meal duration in seconds. At T2, they delivered haptic feedback to encourage chewing each bite more slowly. The glasses recorded the number of instances of haptic feedback and communicated with the OCOsense desktop application via Bluetooth. The researcher set the desired chewing rate, feedback frequency, and strength via the application. Only the target chewing rate threshold was personalised for each participant, while the frequency and intensity of the haptic feedback remained consistent across all participants and for every instance in which feedback was delivered.

The glasses features six OCO™ optical tracking sensors, three proximity sensors, a 9-axis IMU, an altimeter, and dual microphones for speech detection. The OCO™ sensors utilize optomyography (OMG), a non-contact optical method, to track two-dimensional skin movements caused by underlying muscle activity. Each sensor measures skin movement in the X and Y dimensions, providing two readings per sensor. These sensors function within a range of 4 mm–30 mm without requiring direct skin contact (Archer et al., 2023). Integrated into the glasses frame, the sensors monitor key facial muscle groups, including the frontalis and corrugator muscles on the forehead, the zygomaticus major and minor muscles in the cheeks, the orbicularis muscles around the eyes, and the temporalis muscles at the temples. Eating primarily involves the temporalis muscles, which control jaw movement, and the zygomaticus muscles, which activate during chewing. The OCO™ sensors on the temples and cheeks are used to capture eating activity, as chewing motions are clearly visible in their signals. Stankoski et al. (2024) showcased the effectiveness of OCO™ sensors in detecting chewing activities with high accuracy, leveraging a deep learning framework that integrates temporal modelling to differentiate chewing from other facial behaviours. The glasses are also equipped with a motor for haptic feedback, which provides vibrations to alert users when specific chewing rate thresholds are exceeded. The feedback parameters were identical for all participants, except for the vibration frequency, which depended on how many times a participant exceeded the threshold. At the end of a recording session, all row data and insights including average chewing rate, number of bites and number of chews can be downloaded as csv files.

The OCOsense platform, used in this study, has been validated in an empirical study conducted by the University of Sussex. The validation demonstrated the platform's effectiveness in using algorithmic analysis of sensor data from the OCOsense glasses to identify chewing behaviour during structured meal tests. The findings indicated high recall rates and strong agreement with manual annotations, the gold standard for behavioural studies.

To assess the performance of the chewing rate estimation algorithm, a controlled lab study using OCOsense smart glasses was conducted. Data was collected from 20 participants (8 males, 12 females, mean age 28.1 ± 4.4). Each participant completed one eating task, consuming a bagel, a yogurt, and an apple, either with or without utensils, based on preference. A continuous video recording was manually annotated to mark each chew. Ground truth chewing rates were calculated by dividing the chew count by the duration of each eating segment, defined as a continuous period of food consumption without pauses between bites. On the other hand, the predicted chewing rate for each eating segment was obtained by averaging the algorithm's output across all windows within the segment.

Table 2
Performance Metrics of the chewing rate estimation algorithm.

Metric	Naive-Average Algorithm	Chewing Rate Algorithm
MAE	0.22	0.09
MAPE	0.15	0.06
RMSE	0.29	0.13
Pearson	/	0.76

MAE – Mean absolute error; MAPE – Mean absolute percentage error, RMSE – Root mean square error.

The algorithm's performance was evaluated by comparing predicted chewing rates to ground truth values. Table 2 summarises the results for both the Naïve-Average Algorithm, which calculates the mean chewing rate across all segments, and the proposed algorithm.

Fig. 1 provides a visual summary of the model's performance. It plots predicted chewing rate values against true values, using an ordinary least-squares (OLS) regression line to model the relationship. The shaded regions around the regression line represent the 95 % confidence interval (CI) and 95 % prediction interval (PI). The CI reflects the uncertainty around the estimated mean of the predicted values, while the wider PI captures the expected variability for individual predictions. Both intervals were computed from the OLS fit using standard statistical methods for linear regression. Specifically, the CI was derived from the standard error of the mean prediction, while the PI incorporates both the mean prediction error and the variance of the residuals. The regression line follows the diagonal trend, confirming an agreement between the predicted and true chewing rates. The Pearson correlation coefficient ($\rho = 0.76$) further supports this, indicating a positive linear relationship. Most of the data points fall within the prediction interval, showing that the model generalizes well to unseen segments within the studied range. The narrow width of the confidence interval suggests that the model's estimation of the average chewing rate is reliable across the range of observed values. Some scatter is present, particularly at higher chewing rates, indicating slightly increased prediction variability in faster eaters. However, this spread remains within an acceptable range, as evidenced by the low mean absolute error (MAE = 0.09).

Some prediction deviations arise from inconsistencies in ground truth annotations, where manual chew counts introduce noise due to human error. Annotators may struggle to accurately count chews, especially given variations in individual chewing patterns, such as differences in speed or pauses. Refining annotation methods could improve accuracy. However, given the low MAE, the algorithm provides a reliable estimate of chewing rates. A detailed manuscript describing the validation process and technical aspects of the algorithm is currently being prepared for submission by the University of Sussex. To estimate the chewing rate, the algorithm analyzes sensor signals to detect chewing frequency. Chewing rate is only calculated for segments where chewing has been detected. The chewing detection process is described in Stankoski et al. (2024). The data are first filtered using a 5th-order median filter and segmented into 3.5-s windows with a 1-s slide. Each window is then processed with a 3rd-order bandpass filter (0.8–2.3 Hz) to isolate chewing-related frequencies and reduce noise. Welch's method is used to compute the power spectral density (PSD), with a segment length of 256 samples and 75 % overlap for better frequency resolution. Zero-padding extends the signal to 512 samples to further refine resolution. The frequency with the highest PSD value is identified and verified to fall within the 0.8–2.3 Hz range. If valid, it is recorded along with its PSD value. The final chewing rate for each window is determined as the frequency with the highest PSD, and the average across all windows in an eating segment is used as the segment's chewing rate.

2.4. Participants

G*Power (Faul et al., 2009) determined a sample size of 19 to achieve 95 % power at a 0.05 significance level, expecting a large effect size (Cohen's $d = 0.8$), sufficient to detect differences in chewing rates. Recruitment took place at the Sussex Innovation Centre and on local universities campus. In total, 55 individuals accessed the study information, 33 of whom met the eligibility criteria. Of these, 25 scheduled

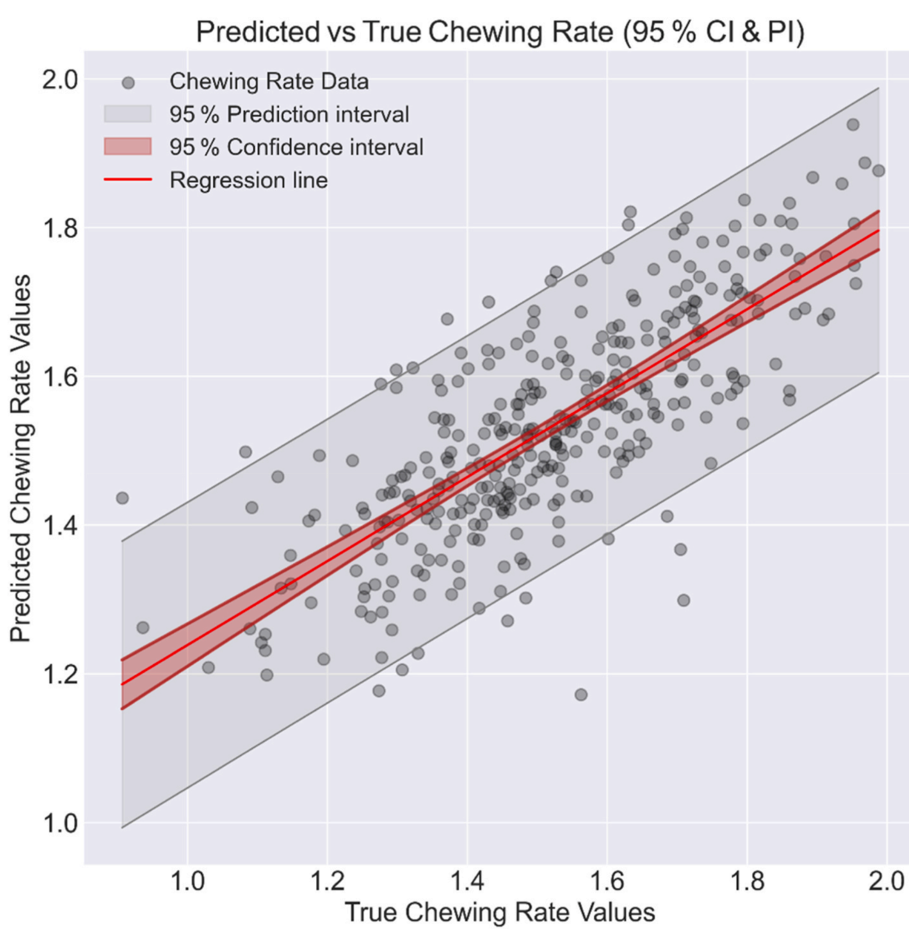

Fig. 1. Predicted vs True Chewing-Rate Estimates: Ordinary Least-Squares Fit with 95 % confidence and prediction interval.

their first visit. One person withdrew before the first visit, and two withdrew after the first visit, leaving a total of 22 participants in both visits for the study. Table 3 provides a summary of the participant demographics. All participants ate pasta as part of their usual diet.

The study included male and female participants aged 18+ with a BMI of 18.5–29.9, prioritising self-reported fast or medium-fast eaters who regularly consume pasta. Exclusions included those under 18, underweight (BMI <18.5), with obesity (BMI >29.9), or with allergies to the study meal. Participants with chronic diseases, medication affecting weight or appetite, chewing difficulties, incompatible eyewear, facial muscle disorders, pregnancy, lactation, or an eating disorder score of 2 on the SCOFF questionnaire (Morgan et al., 2000) were also excluded. Participants who completed the two laboratory sessions received £25.

2.5. Procedure

Ethical approval was obtained by The University of Derby, College of Health, Psychology, and Social Care Research Ethics Committee. Before participating, participants were required to abstain from alcohol for 24 h and from food, chewing gum, and consuming only water for 4 h prior. Non-compliance or changes in health status required rescheduling. The study occurred at Emteq Labs at the Sussex Innovation Centre on the Sussex campus, in a small room with no distractions. For each visit, the experimenter was in the next room to avoid influencing behaviour and instructions were displayed on an iPad. The quantity of food given was measured to the nearest 0.01g on a digital scale. Participants were fitted with the glasses, instructed to eat an amount they were comfortable with and to drink the whole glass of water. They could ask for another portion of food. Hunger and fullness score was measured before and after the test meal on a 100-point VAS scale.

At T2 participants were fitted with the glasses, and were presented with instructions on the iPad: "This is the second test meal. Today, as you eat, you will receive haptic feedback from the glasses – this is a gentle vibration, similar to smart phone or smart watch vibrations. The haptic feedback is to remind you to chew each bite more slowly. You do not have to eat the whole portion of food, please stop eating when you are comfortably full. If you are not feeling full, you can ask for another portion. Water is be provided, please drink all of the water during the meal." Using the individual's mean chewing rate from T1, the glasses threshold was set to vibrate when participants' chewing rate was above 80 % of their baseline and no more than every 30 s. This means if the participant started chewing at a rate that is 80 % or more of their mean rate measured at T1 and had not received haptic feedback in the last 30 s, the glasses vibrated. However, if the participant successfully slowed their chewing rate below this threshold, the glasses would not vibrate until their chewing rate exceeded the threshold again. This adaptive approach not only ensures that feedback is only given when necessary but also helps prevent notification fatigue, making the intervention more sustainable over time. The vibration signalled the participant to remember to amend their chewing rate. Participants completed the acceptability questionnaire. They were presented with the study debrief and given £25 compensation in cash. After participant departure, food intake (quantity of food eaten in grams) was calculated to the nearest 0.01 g on a digital scale, and eating rate (grams eaten per minute) was inferred.

Table 3
Participant demographics (n = 22).

Characteristics	Women (n = 11)		Men (n = 11)	
	Mean ± SD	Range	Mean ± SD	Range
Age (y)	28.55 ± 10.84	19–52	29 ± 9.64	19–52
BMI (kg/m^2)	22.92 ± 3.12	19.27–28.69	24.34 ± 2.69	19.80–29.14

3. Results

The data were screened to ensure assumptions for inferential statistical tests were met, including normality and linearity. Normality was evaluated using skewness and kurtosis, and linearity was assessed through residual scatterplots. Outliers identified by Z-scores exceeding ±3.29 were removed. When parametric assumptions were not met, non-parametric tests were used. Parametric assumptions were not met for eating rate measures, with both skewness and kurtosis exceeding the critical threshold of 1.96. Consequently, a non-parametric Wilcoxon test was run. In both measures of hunger and fullness after meal, z scores highlighted the presence of a single outlier which was removed. Both datasets exhibited significant positive skewness and moderate kurtosis, indicating distributions with rightward tails. Therefore a Wilcoxon Signed-Rank Test was conducted to test if hunger would decrease and fullness increase at T2.

3.1. Effect of haptic feedback on chewing rate, eating rate and measures of appetite

Effect on chewing rate.

A matched-pairs T-test tested whether haptic feedback would reduce the chewing rate between T1 and T2. The T-test showed a significant reduction with a large effect size [$t(21) = 7.3$, $p < 0.001$, $d = 1.556$], supporting that haptic feedback reduces chewing rate. Notably, 91 % of participants succeeded in decreasing their chewing rate, averaging 89 % of their baseline rate.

Effect on eating rate.

The study explored changes in eating rate, which were expected to decrease at T2. A Wilcoxon signed-rank test demonstrated that this difference was significant, with a large effect size, $T\ (N = 22) = 11$, $p < 0.001$, $r = 0.913$. This result supports the eating rate hypothesis. Changes in chewing and eating rate are illustrated in Fig. 2. Table 4 shows different measures at T1 and T2 for each participant (see Fig. 3).

3.1.1. Effect on food intake, hunger and fullness

The study explored whether haptic feedback would result in a change in appetite. Table 5 shows notable changes in participants' chewing and eating behaviours between T1 and T2. The mean chewing rate decreased from baseline to the intervention. Similarly, the eating rate showed a substantial reduction during the pilot study. Despite these changes, food intake remained relatively stable between the two visits. Participants reported increased hunger during the intervention, while fullness before meals decreased. After meals, hunger slightly increased from baseline to the intervention. Fullness after meals remained consistently high across both visits. While we observed an increase in relative hunger after T2, we did not investigate its underlying cause, as appetite-related outcomes were not a main measure in this experiment.

3.2. Evaluation of the OCOsense glasses to deliver feedback

Feasibility of delivering feedback.

The desired chewing rate was set at 80 % of each participant's baseline rate. A low-intensity, short-duration (0.15 s) haptic feedback was programmed to occur at a maximum frequency of once every 30 s. The frequency of this feedback was determined by each participant's chewing behaviour during the intervention. Specifically, no haptic feedback was provided if the chewing rate was below 80 % of the baseline. If the chewing rate exceeded 80 % of the baseline, the haptic feedback was triggered every 30 s. The intensity and duration of the feedback remained consistent across all participants. The glasses delivered 429 instances of haptic feedback, averaging 19.5 instances per participant, with a standard deviation of 8.71, ranging from a minimum of 6 to a maximum of 40 instances. The pilot study showed that intervention was successful, as haptic feedback was consistently delivered upon detecting chewing and adhered to the specified settings.

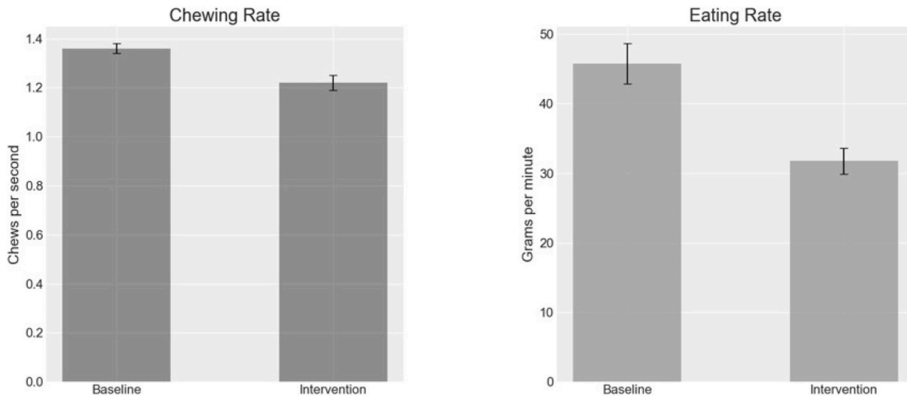

Fig. 2. Changes in Chewing and Eating Rates
Note**.** Chewing rate (chews/sec) and eating rate (grams/min) changes between baseline and intervention phases. The figure illustrates a significant reduction in both chewing rate and eating rate during the intervention phase compared to the baseline phase ($p < 0.001$).

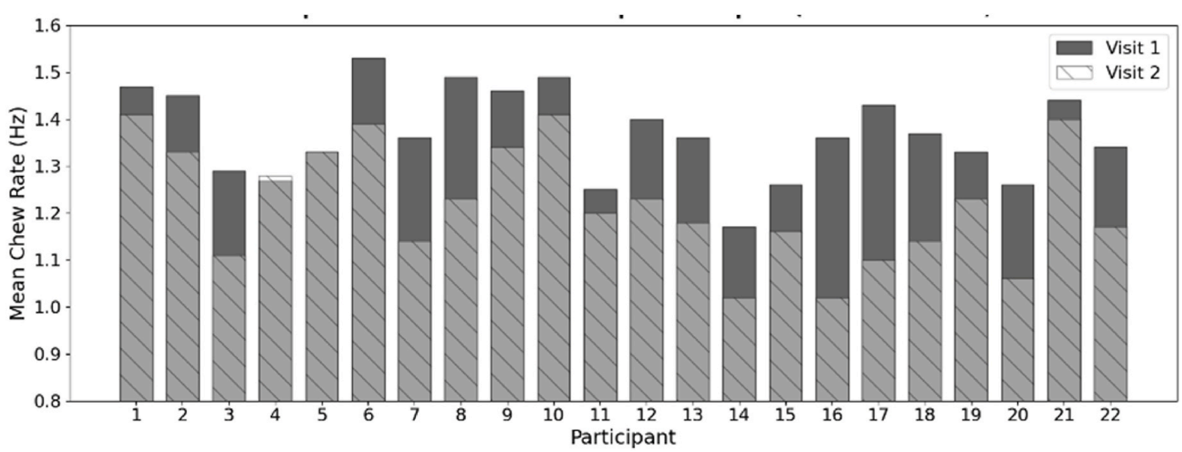

Fig. 3. Comparison of mean chew rate per participant (T1 vs T2).

Table 4
Measures at T1 and T2 for each participant.

Ppcode	Mean Chew Rate (Hz) - T1	Mean Chew Rate (Hz) - T2	Grams eaten (g) - T1	Grams eaten (g) - T2	Meal duration (min) - T1	Meal duration (min) - T2	Eating rate Grams per min T1	Eating rate Grams per min T2	Feedback received
1	1.47	1.41	390.7	368.4	11.51	9.61	33.94	38.34	13
2	1.45	1.33	378.5	499.3	8.75	14.35	43.26	34.79	6
3	1.29	1.11	474	546.5	7.9	19.42	60.00	28.14	22
4	1.27	1.28	465	390.8	12.4	13.44	37.50	29.08	7
5	1.33	1.33	540.8	540	8.3	8.9	65.16	60.67	14
6	1.53	1.39	359.8	246.4	6.46	9.07	55.70	27.17	19
7	1.36	1.14	540.2	498.5	11.19	13.77	48.28	36.20	24
8	1.49	1.23	520.7	550	10.32	26.6	50.46	20.68	18
9	1.46	1.34	267	381	10.13	15.32	26.36	24.87	32
10	1.49	1.41	536.5	536.8	18.35	23.52	29.24	22.82	40
11	1.25	1.2	494.8	506.8	10.7	12.17	46.24	41.64	23
12	1.4	1.23	386.4	292.5	10.72	7.85	36.04	37.26	11
13	1.36	1.18	627	722	7.54	22.08	83.16	32.70	11
14	1.17	1.02	428	376.6	9.79	14.84	43.72	25.38	23
15	1.26	1.16	392.22	496.6	14.35	14.04	27.33	35.37	28
16	1.36	1.02	534.1	536.5	11.52	15.24	46.36	35.20	23
17	1.43	1.1	352	263.5	6.74	10.45	52.23	25.22	6
18	1.37	1.14	531.2	436.2	12.45	18.47	42.67	23.62	27
19	1.33	1.23	439.9	348.9	7.92	9.54	55.54	36.57	19
20	1.26	1.06	221.8	204	5.94	8.62	37.34	23.67	16
21	1.44	1.4	463	535	8.5	14.74	54.47	36.30	28
22	1.34	1.17	214.2	248.8	6.68	10.83	32.07	22.97	19
Mean	**1.37**	**1.22**	**434.45**	**432.96**	**9.92**	**14.22**	45.77	31.76	19.50

Table 5
Matched pairs T-Tests or Wilcoxon tests results comparing chewing rate, appetite and eating rate at T1 and T2.

	Descriptive Statistics			Inferential Statistics			
Variable	N	T1 Mean ± SD	T2 Mean ± SD	t or T	df or ranks	p	cohen or effect size
Chewing rate (chews/sec)	22	1.36 ± 0.94	1.22 ± 0.12	7.3	21	<0.001*	1.56 (L)
Food intake (grams)	22	434.45 ± 108.45	432.96 ± 130.96	0.093	21	0.927	0.02 (S)
Hunger before (0–100)	22	68.09 ± 15.78	77.68 ± 13.19	−3.095	21	0.005*	−0.66 (M)
Fullness before (0–100)	22	31.41 ± 14.72	23.04 ± 14.91	2.26	21	0.034*	0.48 (S)
Hunger after (0–100)	21	6.43 ± 6.85	10.57 ± 9.92	40.5	18	0.05	−0.5 (L)
Fullness after (0–100)	21	88.19 ± 9.13	89.80 ± 8.35	59.5	17	0.42	−0.22 (S)

Significance levels: $p < 0.05$*; Effect sizes: small (S), medium (M), and large (L).

3.2.1. *Acceptability of glasses by participants*

Participants found the haptic feedback to be suitable in various aspects: 68 % rated the intensity as appropriate, 95 % approved of the duration, and 55 % deemed the frequency to be fitting; 86 % found haptic feedback at least moderately intuitive in altering behaviour; 73 % were neutral or comfortable using glasses with haptic feedback in their daily life, including in social context, despite having only worn them in a lab setting. More than 80 % indicated that the haptic feedback was highly effective at drawing attention to and increasing awareness of their chewing behaviour, with the potential to induce changes in chewing habits. While 64 % of participants reported some difficulty in reducing their chewing rate, 91 % reported little to no discomfort with the haptic feedback. The experience of reducing chewing rate varied widely, with 45 % rating the experience rather unpleasant, 23 % neutral and 32 % rather pleasant. Similarly, the overall eating experience also varied from somewhat negative for 32 % of the participants, neutral for 23 % and positive or very positive for 45 %. Finally, 73 % reported they would try to chew more thoroughly after the study.

To summarise, the OCOsense glasses were used to deliver automatic personalised haptic feedback to encourage participants to chew more and more slowly. The equipment was easy to set up, and the intervention was well received by the participants. The haptic feedback led to a significant decrease in chewing and eating rates at T2, and no increase in food intake despite higher hunger levels compared to T1.

4. Discussion

4.1. *Benchmarking against established chewing behaviour interventions*

4.1.1. *OCOsense glasses: proving feasible and well-accepted*

This pilot study validates the use of OCOsense glasses to deliver haptic feedback when chewing is detected. The glasses seem more straightforward than the electromyography (EMG) systems described by Nicholls et al. (2022), which typically involved a more complex setup with sensors attached to the skin to measure muscle activity. The glasses allow for real-time haptic feedback based on chewing detection. This instant feedback is crucial for effectively modifying eating behaviours as it enables users to adjust when there is a potential for positive change (Schembre et al., 2018). As noted by Cox et al., 2022, devices like the Mandometer, which involves keeping food on a portable scale to monitor intake and provide visual feedback, can restrict physical movement and be frustrating to use regularly. In contrast, the glasses are wearable and unobtrusive, making them a more practical choice for everyday use. Finally, the OCOsense glasses do not rely on participants to count their chews like in Zhu and Hollis (2014) or on experimenters to instruct when to start and stop chewing like in Higgs and Jones (2013). This independence from self-monitoring or external directions helps provide a more natural eating experience while still gathering data on eating behaviours. Overall, the OCOsense glasses represent a significant step forward in technology applied to health and eating behaviour research, providing a user-friendly, efficient, and less intrusive means of modifying and studying eating behaviours in a prevalent form factor in our societies.

Participants deemed the haptic feedback settings (duration, strength, and frequency) acceptable, and noted its efficacy in drawing attention to and modifying their chewing behaviour. The settings are customisable so that they can be personalised in future research. This personalisation is essential for effective feedback, as Schembre et al. (2018) highlighted. However, reactions to altering the chewing rate were mixed, with some experiencing positive effects and others negative. This reflects the varied responses seen in literature, such as Higgs and Jones (2013), who noted some discomfort with new eating speeds, while Andrade et al., 2008 that slower eating might enhance the experience through mindful eating. Overall, participants' acceptance of the haptic feedback indicates its potential for widespread use in modifying eating behaviours. In terms of intervention design, understanding the acceptability threshold for slowing chewing—like the window of acceptability suggested by Hawton et al. (2018)—could be crucial. Adjusting the intervention to reduce the feedback frequency to 90 % of the baseline chewing rate might balance effectiveness with comfort, avoiding extreme chewing rate decreases that are not sustainable.

4.1.2. *Haptic feedback decreased chewing rate and eating rate*

Despite some participants not thoroughly enjoying the intervention or being fully aware of the benefits of reducing their chewing rate, the intervention successfully decreased the chewing and eating rates when haptic feedback was provided at T2. This aligns with findings from Nicholls et al. (2022), who significantly decreased chew rate and eating rate using EMG and haptic feedback on the wrist, and Hermsen, Mars, Higgs, Frost, and Hermans (2019), who used haptic feedback on a fork. Additionally, some participants expressed an intent to continue practicing slower chewing after the intervention concluded. Although wearing glasses may be seen as a minor inconvenience, this is mitigated by the widespread and growing use of glasses, particularly as wearable technologies become more integrated into daily life.

4.1.3. *Challenges in measuring food intake*

Although food intake was recorded, the study was not structured to enable a precise assessment of whether participants would reduce their consumption. First, echoing the findings of Lasschuijt et al. (2020) in their initial study, participants tended to stop eating after finishing the first serving. Despite assurances that they could ask another portion, only one participant chose to do so. Offering larger portions or ad libitum meals might provide a more robust test of the effects on food intake. Moreover, in this study, measures of hunger and fullness were only taken just before and just after the meal. Hawton et al. (2018) observed that slower eating began to influence hunger levels starting 30 min post-meal. While food intake did not diminish, it did not increase either, despite participants reporting higher level of hunger prior to the intervention meal. This aligns with Andrade et al. (2008), Smit et al. (2011), McCrickerd et al., 2017, Borvornparadorn et al. (2019), who observed that increased mastication led to reduced food intake and, in some instances, enhanced satiety.

4.2. Implications for eating behaviour and obesity intervention

4.2.1. Modifying chewing behaviour in individuals with obesity

Research on eating behaviours in individuals with obesity has produced mixed results. Some studies have not confirmed a distinctive eating style among people with obesity, but most focused primarily on bite-size or pauses between bites (Mahoney, 1975; Spiegel, 2000; Stunkard et al., 1980; White et al., 2015). However, other studies have identified notable differences. For instance, Drabman et al. (1977) found that obese children took significantly more bites, fewer chews, and fewer chews per bite compared to their non-obese counterparts. Keane et al. (1981) similarly reported that children with obesity ate their meals faster in a laboratory setting. Li et al. (2011) observed that obese participants had a higher ingestion rate and fewer chews per gram of food than lean participants. These variations in findings suggest that while some aspects of eating behaviour may not differ significantly, others, including chewing rate and eating rate, do show differences in individuals with obesity. This underscores the potential effectiveness of targeted interventions, such as using the OCOsense glasses, to study and modify chewing behaviours in individuals with obesity.

4.2.2. Combining feedback and other modification strategies

Research has demonstrated that modifying chewing behaviour can significantly improve health outcomes. For instance, reviews by Venegas et al. (2022) and Miquel-Kergoat et al. (2015) have shown that intervention altering chewing behaviour can decrease food intake, enhance levels of satiety hormones, and lower long-term BMI, offering potential strategies for obesity treatment. These interventions typically involve pre-meal gum chewing (Hetherington & Regan, 2011; Julis & Mattes, 2007), modifications to food texture (Forde et al., 2013; Zijlstra et al., 2010), or direct manipulation of chewing patterns (Cassady et al., 2009; Higgs & Jones, 2013; Li et al., 2011). Cunningham et al. (2023) highlights that the consistency of eating rates among individuals can limit the effectiveness of behavioural interventions designed to slow down eating; they suggest that changing food form and texture might be a more successful approach, as these methods do not rely on the individual's conscious effort to change behaviour. However, integrating haptic feedback glasses offers a new dimension to these interventions. By providing direct and personalised feedback on chewing rate, these glasses can encourage conscious adjustments in eating behaviour. Therefore, combining such technology with changes in food texture could enhance the overall effectiveness of interventions aimed at decelerating eating rates, leveraging both subconscious and conscious behaviour modification strategies. This active, mindful engagement with the feedback differentiates it from passive modifications, such as changing the texture of food, which does not require the eater to think about their rate of eating actively.

4.2.3. OCOsense glasses for mindful eating

Mindfulness can help individuals become aware of automatic eating patterns and disengage from undesirable reactions (Kristeller, 2003). Combining haptic feedback from the OCOsense glasses with mindfulness practice could enhance eating rate regulation and overall awareness. This combination could help break the automatic cycle of fast eating and emotional responses to food. Mindful eating is a promising approach which could be used to better frame such intervention. Tapper (2022) identifies three essential aspects of mindful eating: focusing on the present moment by paying attention to sensory properties of food, bodily sensations, and thoughts or emotions; adopting an attitude of acceptance and non-judgment rather than trying to control or change experiences; and practising decentering, which involves seeing thoughts and emotions as transient and separate from oneself, rather than as accurate reflections of reality (Tapper, 2022). Haptic feedback enhances this by reminding users to attend to sensory details, promoting slower, more mindful eating (Monroe, 2015). It also encourages checking hunger cues and recognising internal signals, which supports healthier eating habits and reduces emotional eating (Khalsa et al., 2018; van Strien, 2018). By facilitating decentering, haptic feedback helps individuals view cravings as transient, fostering a more mindful and intentional approach to eating (Tapper, 2022).

4.2.4. OCOsense glasses for weight management

A growing body of research supports the association between eating rate, BMI and body fat. Ekuni et al. (2013) found that eating quickly was associated with being overweight. Maruyama et al. (2008) noted that eating quickly and eating until full were associated with overweight in Japanese men and women. Sánchez-Ayala et al. (2013) concluded that lower masticatory efficiency might increase body fat risk. Van Den Boer et al., 2017 found that a high self-reported eating rate is associated with a higher BMI in the Dutch population. These studies underscore the potential impact of eating rate on body weight and composition, suggesting that interventions with the OCOsense glasses to slow down eating could benefit weight management. Further research is needed to investigate this application.

4.3. Limitations

The study uses the OCOsense glasses, a novel, non-invasive wearable device that delivers real-time haptic feedback to modify chewing behaviour. It also uses objective measures to collect data on chewing rate, enhancing the reliability and accuracy of the results.

However, this study has several important limitations that must be acknowledged. First, the use of paired t-tests without adjustment for potential confounders (e.g., baseline hunger, meal timing, environmental context) limits the ability to attribute observed changes solely to the haptic feedback intervention.

Second, the lack of randomisation and potential bias introduced by repeated exposure to the same meal may have influenced participant behavior independently of the intervention.

These methodological constraints underscore that the findings are preliminary and should not be interpreted as definitive evidence of efficacy. Future studies should use randomized controlled designs, counterbalancing, and statistical models that account for potential confounders to better isolate the effect of haptic feedback.

Thirdly, running the intervention on healthy, non-obese individuals presents a limitation when aiming to reduce obesity, as the primary target of such interventions is those already experiencing or at high risk of obesity. Previous studies have shown that individuals with obesity may exhibit different eating behaviours, such as faster eating rates and fewer chews per bite, which are directly linked to higher BMI and body fat (Drabman et al., 1977; Ekuni et al., 2013; Li et al., 2011). By focusing on a non-obese population, this study may only partially capture the efficacy and potential benefits of the intervention in the demographic most in need of it.

4.4. Future research

One potential limitation of our initial lab study is that the instruction provided to participants may have influenced their response to haptic feedback, contributing to the observed reduction in chewing rate. Additionally, it is unclear whether the intervention would have been effective beyond a single session or whether participants would continue responding to haptic feedback over time. To explore the long-term feasibility of this approach, we conducted a follow-up study in a real-world setting. Participants wore the glasses for three weeks, and in the final week, they were offered a range of mindful eating strategies. Sixteen participants reported selecting the strategy of slowing down their chewing rate in response to haptic feedback. Statistical analysis revealed a significant effect for twelve of these participants, suggesting that the intervention remained effective beyond an initial laboratory setting. Future research should further investigate the long-term adherence and effectiveness of haptic feedback in promoting sustained changes in chewing behaviour. Specifically, questions remain regarding whether participants would continue responding to the intervention over extended periods, whether habituation effects may diminish its impact, and how individual differences influence long-term effectiveness. While these results are from a follow-up study that has not yet been published, they provide preliminary evidence supporting the effectiveness of haptic feedback in real-world settings. Future work will also explore ways to optimise feedback frequency, such as personalised thresholds or intermittent reinforcement strategies, to enhance long-term effectiveness while minimising habituation.

The reported study was conducted with healthy participants. Future research should, therefore, include obese participants to better understand how interventions like the OCOsense glasses can specifically help mitigate obesity and related health conditions. As suggested previously, although food intake was recorded, the study was not designed to precisely assess whether participants would reduce their consumption. Future research should provide larger portions or ad libitum meals that offer a more robust test of the effects on food intake.

4.5. Conclusions

The findings from this pilot study underscore the potential of the OCOsense glasses for modifying eating behaviours through haptic feedback. The intervention successfully focused attention on chewing, significantly reducing both chewing and eating rates. This indicates the device's ability to influence habitual behaviours, even without full enjoyment or awareness of its benefits. Moreover, the positive impact on appetite further supports its potential efficacy. Combining haptic feedback with mindful eating strategies could enhance the intervention's effectiveness, providing a more holistic approach to behaviour modification. This study also highlights the importance of extending research to populations living with obesity to fully assess the intervention's efficacy and benefits for those at highest risk. In conclusion, the OCOsense glasses offer a user-friendly and efficient method of modifying eating behaviour. Their ability to reduce chewing and eating rates demonstrates significant promise for addressing obesity through innovative technology.

CRediT authorship contribution statement

Claire Baert: Writing – original draft, Methodology, Formal analysis, Data curation. **Borjan Sazdov:** Writing – review & editing, Software, Data curation. **Simon Stankoski:** Software, Data curation. **Hristijan Gjoreski:** Writing – review & editing. **Charles Nduka:** Writing – review & editing. **Caroline Jordan:** Writing – review & editing, Supervision.

Ethical approval

The study was approved by The University of Derby's College of Health, Psychology, and Social Care Research Ethics Committee (ETH2324-1261).

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Declaration of competing interest

The research adheres to ethical standards, and appropriate approvals were obtained (University of Derby, Ethics Approval ID: ETH2324-1261).

Claire Baert, Borjan Sazdov, Simon Stankoski and Hristijan Gjoreski are employees of Emteq Labs, which designs the OCOsense glasses used in this study. Charles Nduka is a director of Emteq Labs. Caroline Jordan is responsible for the Masters of Behaviour Change at the university of Derby.

Claire has been an employee of Emteq for six years and remains employed by the company. However, the study was conducted independently as part of her part-time master's degree, which she fully funded herself without any financial contribution from Emteq. The initial concept for the study, focusing on reducing chewing rate using the pre-existing OCOsense platform, was first discussed with Claire's academic supervisor to ensure its suitability for her master's dissertation. Following validation by her supervisor, the proposal was shared with Emteq's CEO to secure access to a single pair of glasses for use in the study.

The OCOsense platform, including the glasses with haptic feedback, the chewing rate algorithm, and the desktop application for data recording and analysis, was fully developed prior to the study. Claire independently designed, prepared, and interpreted the study, dedicating her personal time to these tasks. The study design and final dissertation were reviewed and approved solely by her academic supervisor, Caroline Jordan, at the University of Derby, without additional input from Emteq.

Data collection was also carried out by Claire independently, on her own time, with her financial contribution, with Emteq's only involvement being the provision of the glasses and app access. Data analysis was performed by Claire during her personal time, with the support of two Emteq data scientists, who verified the results during their working hours. Claire wrote the first full draft of the manuscript in her own time, with reviews from her academic supervisor and additional input from the data scientists and Emteq's CEO and CTO during their work hours.

These contributions and interactions have been transparently disclosed to ensure clarity and integrity in reporting.

Data availability

Data will be made available on request.

References

Andrade, A. M., Greene, G. W., & Melanson, K. J. (2008). Eating slowly led to decreases in energy intake within meals in healthy women. *Journal of the American Dietetic Association, 108*(7), 1186–1191. https://doi.org/10.1016/j.jada.2008.04.026

Archer, J., Mavridou, I., Stankoski, S., Broulidakis, M. J., Cleal, A., Walas, P., Fatoorechi, M., Gjoreski, H., & Nduka, C. (2023). OCOsenseTM smart glasses for analyzing facial expressions using optomyographic sensors. *IEEE Pervasive Computing, 22*(3), 18–26. https://doi.org/10.1109/MPRV.2023.3276471. IEEE Pervasive Computing.

Bi, S., Wang, T., Tobias, N., Nordrum, J., Wang, S., Halvorsen, G., Sen, S., Peterson, R., Odame, K., Caine, K., Halter, R., Sorber, J., & Kotz, D. (2018). Auracle: Detecting eating episodes with an ear-mounted sensor. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 2*(3). https://doi.org/10.1145/3264902, 92:1-92:27.

Blechert, J., Liedlgruber, M., Lender, A., Reichenberger, J., & Wilhelm, F. H. (2017). Unobtrusive electromyography-based eating detection in daily life: A new tool to address underreporting? *Appetite, 118*, 168–173. https://doi.org/10.1016/j.appet.2017.08.008

Borvornparadorn, M., Sapampai, V., Champakerdsap, C., Kurupakorn, W., & Sapwarobol, S. (2019). Increased chewing reduces energy intake, but not postprandial glucose and insulin, in healthy weight and overweight young adults. *Nutrition and Dietetics, 76*(1), 89–94. https://doi.org/10.1111/1747-0080.12433

Cassady, B. A., Hollis, J. H., Fulford, A. D., Considine, R. V., & Mattes, R. D. (2009). Mastication of almonds: Effects of lipid bioaccessibility, appetite, and hormone response2. *The American Journal of Clinical Nutrition, 89*(3), 794–800. https://doi.org/10.3945/ajcn.2008.26669

Cox, J. S., Elsworth, R., Perry, R., Hamilton-Shield, J. P., Kinnear, F., & Hinton, E. C. (2022). The feasibility, acceptability, and benefit of interventions that target eating speed in the clinical treatment of children and adolescents with overweight or obesity: A systematic review and meta-analysis. *Appetite, 168*, Article 105780. https://doi.org/10.1016/j.appet.2021.105780

Cunningham, P. M., Roe, L. S., Keller, K. L., Hendriks-Hartensveld, A. E. M., & Rolls, B. J. (2023). Eating rate and bite size were related to food intake across meals varying in portion size: A randomized crossover trial in adults. *Appetite, 180*, Article 106330. https://doi.org/10.1016/j.appet.2022.106330

Drabman, R. S., Hammer, D., & Jarvie, G. J. (1977). Eating styles of obese and nonobese black and white children in a naturalistic setting. *Addictive Behaviors, 2*(2), 83–86. https://doi.org/10.1016/0306-4603(77)90023-5

Ekuni, D., Furuta, M., Tomofuji, T., Irie, K., Azuma, T., Iwasaki, Y., & Morita, M. (2013). Effects of eating behaviors on being overweight in Japanese university students: A cross-sectional survey at the okayama university. *Asia-Pacific Journal of Public Health, 25*(4), 326–334. https://doi.org/10.1177/1010539511425702

Farooq, M., & Sazonov, E. (2016). Automatic measurement of chew count and chewing rate during food intake. *Electronics, 5*(4), 62. https://doi.org/10.3390/electronics5040062

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Flint, A., Raben, A., Blundell, J., & Astrup, A. (2000). Reproducibility, power and validity of visual analogue scales in assessment of appetite sensations in single test meal studies. *International Journal of Obesity, 24*(1), 38–48. https://doi.org/10.1038/sj.ijo.0801083

Forde, C. G., van Kuijk, N., Thaler, T., de Graaf, C., & Martin, N. (2013). Oral processing characteristics of solid savoury meal components, and relationship with food composition, sensory attributes and expected satiation. *Appetite, 60*, 208–219. https://doi.org/10.1016/j.appet.2012.09.015

Gardner, B. (2015). A review and analysis of the use of 'habit' in understanding, predicting and influencing health-related behaviour. *Health Psychology Review, 9*(3), 277–295. https://doi.org/10.1080/17437199.2013.876238

Hawton, K., Ferriday, D., Rogers, P., Toner, P., Brooks, J., Holly, J., Biernacka, K., Hamilton-Shield, J., & Hinton, E. (2018). Slow down: Behavioural and physiological effects of reducing eating rate. *Nutrients, 11*(1), 50. https://doi.org/10.3390/nu11010050

He, S., Li, S., Nag, A., Feng, S., Han, T., Mukhopadhyay, S. C., & Powel, W. (2020). A comprehensive review of the use of sensors for food intake detection. *Sensors and Actuators A: Physical, 315*, Article 112318. https://doi.org/10.1016/j.sna.2020.112318

Hermsen, S., Mars, M., Higgs, S., Frost, J. H., & Hermans, R. C. J. (2019). Effects of eating with an augmented fork with vibrotactile feedback on eating rate and body weight: A randomized controlled trial. *International Journal of Behavioral Nutrition and Physical Activity, 16*(1), 90. https://doi.org/10.1186/s12966-019-0857-7

Hetherington, M. M., & Regan, M. F. (2011). Effects of chewing gum on short-term appetite regulation in moderately restrained eaters. *Appetite, 57*(2), 475–482. https://doi.org/10.1016/j.appet.2011.06.008

Higgs, S., & Jones, A. (2013). Prolonged chewing at lunch decreases later snack intake. *Appetite, 62*, 91–95. https://doi.org/10.1016/j.appet.2012.11.019

Hollis, J. H. (2018). The effect of mastication on food intake, satiety and body weight. *Physiology & Behavior, 193*, 242–245. https://doi.org/10.1016/j.physbeh.2018.04.027

Imperatori, C., Mancini, M., Della Marca, G., Valenti, E. M., & Farina, B. (2018). Feedback-based treatments for eating disorders and related symptoms: A systematic review of the literature. *Nutrients, 10*(11). https://doi.org/10.3390/nu10111806. Article 11.

Julis, R. A., & Mattes, R. D. (2007). Influence of sweetened chewing gum on appetite, meal patterning and energy intake. *Appetite, 48*(2), 167–175. https://doi.org/10.1016/j.appet.2006.08.003

Keane, T. M., Geller, S. E., & Scheirer, C. J. (1981). A parametric investigation of eating styles in obese and nonobese children. *Behavior Therapy, 12*(2), 280–286. https://doi.org/10.1016/S0005-7894(81)80079-2

Khalsa, S. S., Adolphs, R., Cameron, O. G., Critchley, H. D., Davenport, P. W., Feinstein, J. S., Feusner, J. D., Garfinkel, S. N., Lane, R. D., Mehling, W. E., Meuret, A. E., Nemeroff, C. B., Oppenheimer, S., Petzschner, F. H., Pollatos, O., Rhudy, J. L., Schramm, L. P., Simmons, W. K., Stein, M. B., … Zucker, N. (2018). Interoception and mental health: A roadmap. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 3*(6), 501–513. https://doi.org/10.1016/j.bpsc.2017.12.004

Kiprijanovska, I., Stankoski, S., Broulidakis, M. J., Archer, J., Fatoorechi, M., Gjoreski, M., Nduka, C., & Gjoreski, H. (2023). Towards smart glasses for facial expression recognition using OMG and machine learning. *Scientific Reports, 13*(1), Article 16043. https://doi.org/10.1038/s41598-023-43135-5

Kluger, A. N., & DeNisi, A. (1996). The effects of feedback interventions on performance: A historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological Bulletin, 119*(2), 254–284. https://doi.org/10.1037/0033-2909.119.2.254

Kristeller, J. L. (2003). Mindfulness, wisdom, and eating: Applying a multi-domain model of meditation effects. *Constructivism in the Human Sciences, 8*(2), 107–118.

Krop, E. M., Hetherington, M. M., Nekitsing, C., Miquel, S., Postelnicu, L., & Sarkar, A. (2018). Influence of oral processing on appetite and food intake – a systematic review and meta-analysis. *Appetite, 125*, 253–269. https://doi.org/10.1016/j.appet.2018.01.018

Lasschuijt, M., Mars, M., de Graaf, C., & Smeets, P. A. (2020). How oro-sensory exposure and eating rate affect satiation and associated endocrine responses—a randomized trial. *The American Journal of Clinical Nutrition, 111*(6), 1137–1149. https://doi.org/10.1093/ajcn/nqaa067

Li, J., Zhang, N., Hu, L., Li, Z., Li, R., Li, C., & Wang, S. (2011). Improvement in chewing activity reduces energy intake in one meal and modulates plasma gut hormone concentrations in obese and lean young Chinese men. *The American Journal of Clinical Nutrition, 94*(3), 709–716. https://doi.org/10.3945/ajcn.111.015164

Mahoney, M. J. (1975). The obese eating style: Bites, beliefs, and behavior modification. *Addictive Behaviors, 1*(1), 47–53. https://doi.org/10.1016/S0306-4603(75)80017-7

Maruyama, K., Sato, S., Ohira, T., Maeda, K., Noda, H., Kubota, Y., Nishimura, S., Kitamura, A., Kiyama, M., Okada, T., Imano, H., Nakamura, M., Ishikawa, Y., Kurokawa, M., Sasaki, S., & Iso, H. (2008). The joint impact on being overweight of self reported behaviours of eating quickly and eating until full: Cross sectional survey. *BMJ, 337*, Article a2002. https://doi.org/10.1136/bmj.a2002

McCrickerd, K., Lim, C. M., Leong, C., Chia, E. M., & Forde, C. G. (2017). Texture-based differences in eating rate reduce the impact of increased energy density and large portions on meal size in adults. *The Journal of Nutrition, 147*(6), 1208–1217. https://doi.org/10.3945/jn.116.244251

Melanson, K. J., Matsumoto, C. N., & Greene, G. W. (2023). Eating pace instruction is effective in slowing eating rate in women with overweight and obesity. *Eating Behaviors, 48*, Article 101701. https://doi.org/10.1016/j.eatbeh.2023.101701

Michie, S., Atkins, L., & West, R. (2014). *The behaviour change wheel: A guide to designing interventions*.

Miquel-Kergoat, S., Azais-Braesco, V., Burton-Freeman, B., & Hetherington, M. M. (2015). Effects of chewing on appetite, food intake and gut hormones: A systematic review and meta-analysis. *Physiology & Behavior, 151*, 88–96. https://doi.org/10.1016/j.physbeh.2015.07.017

Mohajan, D., & Mohajan, H. K. (2023). Obesity and its related diseases: A new escalating alarming in global health. *Journal of Innovations in Medical Research, 2*(3). Article 3.

Monroe, J. T. (2015). Mindful eating: Principles and practice. *American Journal of Lifestyle Medicine, 9*(3), 217–220. https://doi.org/10.1177/1559827615569682

Morgan, J. F., Reid, F., & Lacey, J. H. (2000). The SCOFF questionnaire. *Western Journal of Medicine, 172*(3), 164–165.

Nicholls, B., Ang, C. S., Kanjo, E., Siriaraya, P., Mirzaee Bafti, S., Yeo, W.-H., & Tsanas, A. (2022). An EMG- based Eating Behaviour Monitoring system with haptic feedback to promote mindful eating. *Computers in Biology and Medicine, 149*, Article 106068. https://doi.org/10.1016/j.compbiomed.2022.106068

Ohkuma, T., Hirakawa, Y., Nakamura, U., Kiyohara, Y., Kitazono, T., & Ninomiya, T. (2015). Association between eating rate and obesity: A systematic review and meta-analysis. *International Journal of Obesity, 39*(11). https://doi.org/10.1038/ijo.2015.96. Article 11.

Robinson, E., Almiron-Roig, E., Rutters, F., de Graaf, C., Forde, C. G., Tudur Smith, C., Nolan, S. J., & Jebb, S. A. (2014). A systematic review and meta-analysis examining the effect of eating rate on energy intake and hunger. *The American Journal of Clinical Nutrition, 100*(1), 123–151. https://doi.org/10.3945/ajcn.113.081745

Sáenz-Pardo-Reyes, E., Housni, F. E., López-Espinoza, A., Martínez Moreno, A. G., Padilla Galindo, M. D. R., & Velázquez Saucedo, G. (2021). Effect of eating speed modification techniques and strategies on food or energy intake: A systematic review and meta-analysis. *Nutricion Hospitalaria, 38*(3), 631–644. https://doi.org/10.20960/nh.03467

Sánchez-Ayala, A., Campanha, N. H., & Garcia, R. C. M. R. (2013). Relationship between body fat and masticatory function. *Journal of Prosthodontics, 22*(2), 120–125. https://doi.org/10.1111/j.1532-849X.2012.00937.x

Schembre, S. M., Liao, Y., Robertson, M. C., Dunton, G. F., Kerr, J., Haffey, M. E., Burnett, T., Basen- Engquist, K., & Hicklen, R. S. (2018). Just-in-Time feedback in diet and physical activity interventions: Systematic review and practical design framework. *Journal of Medical Internet Research, 20*(3), Article e106. https://doi.org/10.2196/jmir.8701

Selamat, N. A., & Ali, S. H. M. (2020). Automatic food intake monitoring based on chewing activity: A survey. *IEEE Access, 8*, 48846–48869. https://doi.org/10.1109/ACCESS.2020.2978260. IEEE Access.

Sharma, S., Jasper, P., Muth, E., & Hoover, A. (2016). Automatic detection of periods of eating using wrist motion tracking. In *2016 IEEE first international conference on connected health: Applications, systems and engineering technologies (CHASE)* (pp. 362–363). https://doi.org/10.1109/CHASE.2016.15

Simonson, A. P., Davis, K. K., Barone Gibbs, B., Venditti, E. M., & Jakicic, J. M. (2020). Comparison of mindful and slow eating strategies on acute energy intake. *Obesity Science & Practice, 6*(6), 668–676. https://doi.org/10.1002/osp4.441

Smit, H. J., Kemsley, E. K., Tapp, H. S., & Henry, C. J. K. (2011). Does prolonged chewing reduce food intake? Fletcherism revisited. *Appetite, 57*(1), 295–298. https://doi.org/10.1016/j.appet.2011.02.003

Spiegel, T. A. (2000). Rate of intake, bites, and chews—the interpretation of lean–obese differences. *Neuroscience & Biobehavioral Reviews, 24*(2), 229–237. https://doi.org/10.1016/S0149-7634(99)00076-7

Spiegel, T. A., Kaplan, J. M., Tomassini, A., & Stellar, E. (1993). Bite size, ingestion rate, and meal size in lean and obese women. *Appetite, 21*(2), 131–145. https://doi.org/10.1016/0195-6663(93)90005-5

Stankoski, S., Kiprijanovska, I., Gjoreski, M., Panchevski, F., Sazdov, B., Sofronievski, B., Cleal, A., Fatoorechi, M., Nduka, C., & Gjoreski, H. (2024). Controlled and real-life investigation of optical tracking sensors in smart glasses for monitoring eating behavior using deep learning: Cross-sectional study. *JMIR Mhealth Uhealth, 2024*. https://doi.org/10.2196/59469. https://mhealth.jmir.org/2024/1/e59469

Stunkard, A., Coll, M., Lundquist, S., & Meyers, A. (1980). Obesity and eating style. *Archives of General Psychiatry, 37*(10), 1127–1129. https://doi.org/10.1001/archpsyc.1980.01780230045006

Tapper, K. (2022). Mindful eating: What we know so far. *Nutrition Bulletin, 47*(2), 168–185. https://doi.org/10.1111/nbu.12559

Van Den Boer, J. H. W., Kranendonk, J., Van De Wiel, A., Feskens, E. J. M., Geelen, A., & Mars, M. (2017). Self-reported eating rate is associated with weight status in a Dutch population: A validation study and a cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity, 14*(1), 121. https://doi.org/10.1186/s12966-017-0580-1

van Strien, T. (2018). Causes of emotional eating and matched treatment of obesity. *Current Diabetes Reports, 18*(6), 35. https://doi.org/10.1007/s11892-018-1000-x

Venegas, C., Farfan-Beltrán, N., Bucchi, C., Martínez-Gomis, J., & Fuentes, R. (2022). Effect of chewing behavior modification on food intake, appetite and satiety-related hormones: A systematic review. *Revista Chilena de Nutrición, 49*(6), 760–774. https://doi.org/10.4067/S0717-75182022000700760

White, A. K., Venn, B., Lu, L. W., Rush, E., Gallo, L. M., Yong, J. L. C., & Farella, M. (2015). A comparison of chewing rate between overweight and normal BMI individuals. *Physiology & Behavior, 145*, 8–13. https://doi.org/10.1016/j.physbeh.2015.03.028

Wood, W., & Rünger, D. (2016). Psychology of habit. *Annual Review of Psychology, 67*, 289–314. https://doi.org/10.1146/annurev-psych-122414-033417

World Obesity Atlas 2023. (n.d.). World Obesity Federation. Retrieved October 3, 2023, from https://www.worldobesity.org/resources/resource-library/world-obesity-atlas-2023.

Zhu, Y., & Hollis, J. H. (2014). Increasing the number of chews before swallowing reduces meal size in normal-weight, overweight, and obese adults. *Journal of the Academy of Nutrition and Dietetics, 114*(6), 926–931. https://doi.org/10.1016/j.jand.2013.08.020

Zhu, Y., Hsu, W. H., & Hollis, J. H. (2013). Increasing the number of masticatory cycles is associated with reduced appetite and altered postprandial plasma concentrations of gut hormones, insulin and glucose. *British Journal of Nutrition, 110*(2), 384–390. https://doi.org/10.1017/S0007114512005053

Zijlstra, N., Mars, M., Stafleu, A., & de Graaf, C. (2010). The effect of texture differences on satiation in 3 pairs of solid foods. *Appetite, 55*(3), 490–497.