Longer Oral Exposure with Modified Sham Feeding Does Not Slow Down Gastric Emptying of Low- and High-Energy-Dense Gastric Loads in Healthy Young Men 1–3

Anne GM Wijlens, Alfrun Erkner, Monica Mars, and Cees de Graaf

Division of Human Nutrition, Wageningen University, Wageningen, The Netherlands; and Nestec Ltd, Nestlé Research Centre, Lausanne, Switzerland

Abstract

Background: A long oral exposure to food and a high-energy density of food have been shown to increase satiety feelings. The effect of energy density is predominantly caused by an inhibition of gastric emptying. It is hypothesized that prolonging oral exposure may have an additional effect on this inhibition of gastric emptying. However, little human data are available to support this hypothesis.

Objective: The objective was to assess the effect of the duration of oral exposure to food on gastric emptying rate of gastric loads (GLs) low and high in energy density and on satiety feelings.

Methods: Twenty-six healthy men [mean ± SD age: 22 ± 3 y; BMI (in kg/m²): 23 ± 1] participated in a randomized crossover trial with 4 treatments and a control. Treatments consisted of either 1- or 8-min modified sham feeding (MSF) of cake, and a GL of either 100 or 700 kcal infused in the stomach via a nasogastric tube (500 mL, 62.5 mL/min). The control consisted of no MSF and a GL of 500 mL of water. Gastric emptying rate was assessed with a 13C breath test. Breath samples and satiety feelings were collected at fixed time points until 90 min after start of the treatment.

Results: Gastric emptying rate and satiety feelings were not affected by duration of MSF (P ≥ 0.27). However, the 700-kcal GL treatments slowed gastric emptying [41% lower area under the curve (AUC)] and increased satiety feelings (22–31% higher AUC) compared with the 100-kcal GL treatments (P < 0.001). No interaction between MSF duration and energy density of GL was found (P ≥ 0.44).

Conclusions: Higher gastric energy density inhibited gastric emptying and increased satiety feelings in healthy young men. However, prolonging oral exposure to food did not have an additional effect. This study provides more insight in satiety regulation.

This trial was registered at trialregister.nl as NTR3601.


Keywords: oral exposure, oro-sensory exposure, modified sham feeding, intragastric infusion, gastric load, energy density, satiety, appetite, gastric emptying, healthy men

Introduction

The oral exposure to food is an important signal for satiety and short-term food intake. A longer oral exposure to food is found to decrease food intake (1–3), and it is suggested that oral exposure to food is necessary to achieve optimal satiety (4). It is proposed that longer oral exposure to food increases satiety feelings and decreases food intake through an inhibition of gastric emptying rate (5, 6). Evidence for this mechanism was found in an animal experiment by Molina et al. (7). They showed that, when rats ingested 15 mL of a dextrin solution, the solution was emptied from the stomach at a slower rate than when infused intragastrically via a fistula. That is, at 5, 45, and 150 min after consumption, the stomach volume of the rats was smaller than with intragastric infusion.

It is well known that foods high in energy density are emptied from the stomach at a slower rate than foods with a lower energy density and therefore enhance satiety, for example (8, 9). Therefore, both the oral exposure duration and the energy density of food contribute to satiety; it is, however, not clear how these signals interact. Only a limited number of human studies investigated the hypothesis that oral exposure to food may inhibit gastric emptying rate (5, 10). Cecil et al. (5) showed in
humans an inhibiting effect on gastric emptying on consumption of a high-fat soup compared with the same soup infused intragastrically. To our knowledge no studies investigated the relation between duration of oral exposure to food and gastric emptying rate with simultaneous but independent manipulations of oral exposure duration and gastric energy density.

In a previous study we investigated the effect of oral exposure duration and gastric volume on appetite and energy intake. In that study we varied oral exposure time from 1 to 8 min through modified sham feeding (MSF). At the same time we infused a volume of 100 or 800 mL intragastrically via a nasogastric tube (3). We found that treatments with 8-min MSF decreased subsequent food intake compared with a control, whereas treatments with 1-min MSF did not. Intragastric infused volumes of 800 mL did not result in stronger suppression of food intake compared with the 100-mL volumes. We hypothesized that the finding that 8-min MSF decreased food intake, whereas 1-min MSF did not, might be mediated by an inhibiting effect of oral exposure duration on gastric emptying rate.

In the present study we investigated whether oral exposure duration to food affects the gastric emptying rate of gastric loads (GLs) low and high in energy. Subjects performed MSF for 1 or 8 min and simultaneously received a GL that varied in energy density via a nasogastric tube, that is, a GL of 100 or 700 kcal in 500 mL. Besides gastric emptying rate we measured satiety feelings with appetite ratings. We hypothesized that gastric emptying would be delayed for the treatments with 8-min MSF compared with the treatments with 1-min MSF. In addition, we hypothesized that gastric emptying would be delayed for the treatments with a GL of 700 kcal in 500 mL compared with the treatments with a GL of 100 kcal in 500 mL. We expected that appetite ratings would be lower after longer oral exposure and after a GL with a higher energy density.

**Methods**

**Subjects**

Healthy young men were recruited from Wageningen, The Netherlands, and surroundings. Subjects had to be between 18 and 40 y old with a normal BMI (18.5–25.0 kg/m²). They needed to have good mental and physical health as judged by themselves and a stable body weight (defined as a maximum body weight change of 5 kg in the past 2 mo). Exclusion criteria were smoking, gastrointestinal diseases, diabetes, thyroid diseases or any other endocrine disorder, lack of appetite, hypersensitivity or food allergy for products used in the study, or medication or drug use (light pain-relieving medications that are available over the counter, such as paracetamol, were allowed).

In total, 41 men were assessed for eligibility (Figure 1). Six men were excluded on the basis of a screening questionnaire: smoking (n = 1), BMI too high (n = 1), BMI too high (n = 2), and use of medication (n = 2). The remaining 35 subjects were invited for an additional screening and information meeting. During this meeting the inclusion and exclusion criteria were checked, and subjects rated the pleasantness of the sponge cake. They had to rate at least 3 on a 5-point scale with 1 being not at all pleasant and 5 being extremely pleasant. Furthermore, subjects’ height and weight were measured. Six subjects were excluded because their BMI was too high (n = 3) or because they foresaw difficulties to plan the test sessions (n = 3). The remaining 29 subjects completed a training session in which they had to perform all study procedures of treatment 8 min/700 kcal. The study procedures are explained in Study procedures.

Two subjects withdrew after their training session because of scheduling problems. The other 27 subjects were enrolled in the study. One of the 27 subjects withdrew after his first session because of scheduling conflicts.

Twenty-six subjects completed the study. They had a mean ± SD age of 22 ± 3 y, a height of 179 ± 8 cm, and a BMI of 23 ± 1 kg/m². The subjects gave a mean ± SD rating for the pleasantness of the sponge cake of 3.9 ± 0.6.

**Design**

The study had a randomized crossover design with 4 treatments and a control condition (Table 1). The washout period between conditions was at least 5 days. In all conditions subjects had a nasogastric tube inserted. In the treatment conditions subjects were orally exposed to a food while they received a GL via a nasogastric tube. In the control condition subjects received a noncaloric GL, but they did not perform MSF. Treatments were randomized by means of 5 × 5 Latin Squares (Williams Design) (11).

Subjects gave written informed consent before the start of the procedures. The study was approved by the Medical Ethical Committee of Wageningen University (NL40863.081.12) and was registered in the Dutch trial register at www.trialregister.nl as NTR3601 before the start of the study. All subjects who participated in the training sessions and onward received financial compensation.

**TABLE 1 Outline of the 5 conditions that the healthy men (n = 26) received in randomized order**

<table>
<thead>
<tr>
<th>Oral exposure duration, min</th>
<th>Gastric load energy, kcal</th>
<th>Gastric load volume, mL</th>
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<tr>
<td>Control</td>
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<td>1 min/100 kcal</td>
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Subjects came to the laboratory on 5 occasions. Arrival time was identical within 1 subject but differed between 0800 and 1030 between subjects. Subjects were instructed to refrain from products that are naturally rich in $^{13}$C (such as maize and millet), to avoid any intensive physical activity, and not to eat anything or drink any energy-containing beverages from the preceding evening onward. Every study morning subjects ate a small standardized breakfast (Friesche Vlag Breaker Aardbei, Arla Foods) 1 hour before arrival at the study center (Table 2). Subjects were allowed to drink noncaloric drinks during breakfast, but this had to be the same before each session. After the breakfast any consumption was prohibited. Compliance to the instructions was this had to be the same before each session. After the breakfast any consumption was prohibited. Compliance to the instructions was monitored with a study diary that was kept by the subjects.

Study procedures for a study morning are shown in Figure 2. A nasogastric tube was inserted within 30 min after arrival (between $t = -60$ and $t = -30$). The treatment started 1 hour after arrival ($t = 0$); subjects received the GL and performed MSF, both starting at the same time.

Sponge cake was used for the MSF and for the GLs (Euroshopper, Neerlandia Banket B.V.; Table 2). A dietician prepared the GLs according to strict hygiene guidelines of the division of Human Nutrition of Wageningen University. Energy and macronutrient contents of the sponge cake, the GLs, and the standard breakfast were determined by chemical analysis (Table 2).

**MSF.** Subjects were orally exposed to the cake for 1 or 8 min with the MSF technique. With this technique subjects chew a food without swallowing it and then expectorate it. Subjects were free to choose their own bite size and pace of chewing, and they received a plate with an excess amount of sponge cake: 100 g for 1-min MSF and 350 g for 8-min MSF. The amount of cake that subjects chewed was $30 \pm 13$ g for 1 min/100 kcal, $178 \pm 65$ g for 8 min/100 kcal, $29 \pm 14$ g for 1 min/700 kcal, and $176 \pm 59$ g for 8 min/700 kcal. The energy content of the amount of chewed cake was $126 \pm 57$ kcal ($320 \pm 238$ kJ) for 1 min/100 kcal, $757 \pm 275$ kcal ($3172 \pm 1153$ kJ) for 8 min/100 kcal, $125 \pm 61$ kcal ($522 \pm 257$ kJ) for 1 min/700 kcal, and $746 \pm 251$ kcal ($3128 \pm 1053$ kJ) for 8 min/700 kcal.

Compliance to the instructions for MSF was checked by analyzing the dry mass of the expectorants that we described previously (3). The recovery had to be $\geq 85\%$ at the treatment sessions. This percentage is shown to be a feasible threshold and is comparable with other studies (3, 12, 13). During the training sessions the recovery threshold was set at $\geq 90\%$ to ensure a recovery $\geq 85\%$ during the real treatments.

**Intragastric infusion.** Subjects received a nasogastric tube by following the same procedures as described in our previous research (3). The caloric GLs consisted of sponge cake blended with water. The control GL consisted of water only. The loads were heated to 37°C and kept at 37°C in a stove before infusion. The loads were infused by a calibrated pump (520U; Watson-Marlow Inc.) at an infusion rate of 62.5 mL/min during all treatments. The tube was removed between $t = 8$ and $t = 22$.

### Measurements

**Gastric emptying.** The rate of gastric emptying was measured indirectly with a noninvasive breath test that is described in Braden et al. (14). For this test the GLs were labeled with 150 mg of the stable isotope $^{13}$C-acetate ($^{13}$C; 99%; Campro Scientific GmbH). Ten breath samples were collected every test session: 2 at baseline and 1 at $t = 8$, 15, $t = 22$, $t = 30$, $t = 45$, $t = 60$, $t = 75$, and $t = 90$ (Figure 2). Breath analyses were analyzed within a week after collection with an Isotope Ratio Mass Spectrometer (IRIS-Doc; Wagner Analysen Technik). This device analyzes the isotopic composition of the carbon present in breath samples.

**Appetite and well-being.** Feelings of appetite and well-being were measured at 9 time points: $t = 0$ (baseline), $t = 8$, $t = 15$, $t = 22$, $t = 30$, $t = 45$, $t = 60$, $t = 75$, and $t = 90$ (Figure 2). Subjects scored their hunger, fullness, prospective consumption, desire to eat, desire to eat something sweet, desire to eat something savory, thirst, well-being, and nausea on a 100-mm visual analogue scale (11). The scales were anchored not at all on the left and extremely on the right.

**Statistical analysis**

Data were analyzed with the statistical package SAS, version 9.2 (SAS Institute). $P < 0.05$ was considered significant. Values in text are expressed as means $\pm$ SDs.

Sample size was calculated with the difference in time to peak of the recovery of the stable isotope as the outcome variable. An SD of 20 min was used, based on the SD$\pm$person of Wanders et al. (15). We hypothesized that a difference in time to peak between treatments of 12 min was realistic. With a power of 0.80 it was estimated that 22 men would be enough to detect this difference. To account for a dropout of $\sim 10\%$, based on a previous study (3), and missing values we had to include 27 men in the study.

Effects on recovery of $^{13}$C and appetite and well-being ratings were analyzed with total AUC. AUCs were calculated from $t = 0$ through $t = 90$ by using the trapezoidal method and were tested with mixed model ANOVAs. Subject was incorporated in the model as random factor, condition as fixed factor, and the baseline value as covariable. First, data of all conditions were analyzed for an effect of condition. Second, the data of the treatments with MSF (so without control condition) were analyzed for individual effects of oral exposure duration and gastric energy density. Post hoc tests with Bonferroni correction were performed when significant overall effects were found.

Baseline ratings of appetite and well-being were tested to see whether subjects came to the study center in the same state every test session. Furthermore, cake recovery percentages were compared between the 4 treatments with MSF to see whether that could have affected the outcomes. Mixed model ANOVAs were used for these tests with subject as random factor and condition as fixed factor.

For 2 of the 26 subjects who completed the study, the recovery percentage of cake was too low for 1 of their sessions (Figure 1). Because these subjects did not comply with the protocol on those sessions, we removed the data of these sessions for all outcome measures and treated them as missing. Furthermore, we found a recovery percentage of 115% of 1 person for treatment 1 min/100 kcal; this implies that something went wrong with storage of the sample. Because we do not know the true recovery percentage, data of this session were also removed for all outcome measures and treated as missing. Data on the recovery of $^{13}$C of the control...
condition of 1 subject were removed and treated as missing because he accidentally received a double dose of the isotope. Data on the recovery of $^{13}$C of treatment 8 min/700 kcal of another subject were removed and treated as missing because the Isotope Ratio Mass Spectrometer gave extremely low, impossible, outcome values, indicating that the samples were not correctly measured.

**Results**

The mean cake recovery percentage of all treatments with MSF was 97.0% ± 3.0%. Per treatment this was 96.2% ± 3.8% (1.1 ± 1.2 g swallowed) for 1 min/100 kcal, 97.6% ± 2.3% (4.3 ± 5.0 g swallowed) for 8 min/100 kcal, 96.2% ± 3.0% (1.0 ± 1.0 g swallowed) for 1 min/700 kcal, and 97.8% ± 2.6% (3.6 ± 5.4 g swallowed) for 8 min/700 kcal. The recovery percentage was significantly different between treatments (ANOVA, $P = 0.02$). However, post hoc analysis showed that this difference could not be attributed to a specific difference between 2 treatments ($P ≥ 0.13$). Furthermore, we checked whether subjects arrived at the study center in the same, satiated, state for every study morning by comparing the appetite and well-being ratings at baseline ($t = 0$). At baseline the treatments did not differ in ratings of appetite ($P ≥ 0.11$) or well-being ($P ≥ 0.72$).

**Gastric emptying**

The AUC of the recovery of $^{13}$C is presented in Figure 3. Mean time to peak values were 28 ± 17 min for the control condition, 32 ± 21 min for 1 min/100 kcal, 27 ± 11 min for 8 min/100 kcal, 69 ± 18 min for 1 min/700 kcal, and 56 ± 27 min for 8 min/700 kcal.

**Treatment effect**. A significant difference between the conditions was found (AUC, $P < 0.001$). The treatments with a GL of 700 kcal resulted in smaller AUCs than the control and the treatments with a GL of 100 kcal (AUC, $P < 0.001$). The treatments with a GL of 100 kcal did not differ from each other nor did the treatments with a GL of 700 kcal (AUC, both $P = 1$). Furthermore, the control had a larger AUC than treatment 8 min/100 kcal (AUC, $P = 0.02$), but the control did not differ from treatment 1 min/100 kcal (AUC, $P = 0.08$).

**Individual effects of oral and gastric stimulation**. The recovery of $^{13}$C was significantly different between energy densities (AUC, $P < 0.001$). The treatments with a GL of 700 kcal resulted in a 41% lower AUC than the treatments with a GL of 100 kcal ($P < 0.001$). No effect of oral exposure duration or an effect of oral exposure duration × gastric energy density interaction was found (AUC, $P = 0.62$ and $P = 0.85$, respectively).

**Appetite ratings**

AUCs of hunger, fullness, and desire for something sweet are presented in Figure 4. Desire to eat, prospective consumption, and desire for something savory show similar results as hunger and are therefore not displayed. Figures of the mean ratings over time are presented as online supporting material (Supplemental Figure 1).

**Treatment effect**. All appetite ratings were significantly different between treatments (AUC, $P < 0.001$). The AUC of the appetite ratings were lower for 1 min/700 kcal and 8 min/700 kcal than for control, except for fullness in which the AUC was higher than control ($P < 0.001$). Treatment 1 min/100 kcal resulted in a higher AUC than treatment 1 min/700 kcal and 8 min/700 kcal for all ratings; for fullness this was in the opposite direction ($P ≤ 0.04$). Desire for something sweet was the only exception; the control had a higher AUC than the other treatments ($P ≤ 0.003$), but no other differences were found ($P ≥ 0.10$). Post hoc, further significant differences were found; however, these were not consistent over all appetite ratings.

**Individual effects of oral and gastric stimulation**. All appetite ratings were significantly affected by energy density (AUC, $P < 0.001$). The AUCs of all appetite ratings were 22–26% larger for the treatments with a GL of 100 kcal than for the treatments with a GL of 700 kcal, except for fullness whereby the AUCs were 31% smaller for the 100-kcal GL treatments than for the 700-kcal GL treatments ($P < 0.001$). Oral exposure did not affect appetite, nor was there an interaction effect of oral exposure duration × gastric energy density (AUC, $P ≥ 0.27$ and $P ≥ 0.44$, respectively).

**FIGURE 3** Recovery of $^{13}$C per treatment expressed as DOB (A) and AUC (B) from baseline (time 0) until 90 min after the treatment. Treatments consisted of oral exposure with MSF and at the same time infusion of a 500-mL GL via a nasogastric tube. Healthy men (22 ± 3 y, 23 ± 1 kg/m$^2$) received in randomized order 1-min MSF and a 100-kcal GL (n = 24), 8-min MSF and a 100-kcal GL (n = 26), 1-min MSF and a 700-kcal GL (n = 26), 8-min MSF and a 700-kcal GL (n = 24), or a control condition with no MSF and water as GL (n = 25). Values are expressed as means ± SDs and were tested with a mixed model ANOVA ($P < 0.0001$) and subsequently a Bonferroni post hoc test. Means without a common letter differ (AUC a > b > c), $P < 0.05$. DOB, Δ over baseline; GL, gastric load; MSF, modified sham feeding.
Well-being

AUCs of comfort and nausea are presented in Figure 5. Thirst is not presented in a figure because it did not change over time. Thirst, comfort, and nausea did not differ between treatments (AUC, P ≥ 0.08). No effect of oral exposure duration (P ≥ 0.26), gastric energy density (P ≥ 0.12), or their interaction term (P ≥ 0.17) was found on AUCs of thirst, comfort, or nausea. Figures of the mean ratings over time are presented as online supporting material (Supplemental Figure 1).

Discussion

The present study investigated the effect of oral exposure duration on gastric emptying rate of GLs low and high in energy density and on satiety feelings. We did not find an effect of increasing oral exposure from 1 to 8 min on gastric emptying rate nor did we find an effect on satiety feelings. However, we did find that increasing the energy density of the GL from 100 to 700 kcal slowed gastric emptying rate and increased satiety feelings.

We found that a GL with a high-energy density was emptied from the stomach at a slower rate than a GL with a low-energy density. We hypothesized that a longer oral exposure would delay gastric emptying, but we could not confirm this hypothesis. Although we increased the oral exposure time 7-fold, we could not detect an effect on gastric emptying rate. This increase in oral exposure time was accomplished with a MSF protocol. The MSF was properly performed in all treatments; the percentage was comparable with what other studies report (3, 12, 13, 20), and the mean cake recovery percentage did not differ between the short and long MSFs. Therefore, the lack of findings cannot be attributed to the performance of the MSF protocol.

Previous studies did find an inhibiting effect of longer oral exposure on gastric emptying in men (5, 10) and rats (7, 21). However, these effects seem to depend on the nutrient content of foods. Kaplan et al. (21) found that oral infusion of corn oil delayed gastric emptying in rats compared with intragastric infusion of corn oil. This effect was however not found for glucose (21). Cecil et al. (5) showed similar results in humans; normal consumption of a high-fat soup inhibited gastric emptying compared with intragastric infusion of the same high-fat soup, but this effect could not be shown with a high-carbohydrate soup. In the high-fat soup 69% of the energy was derived from fat and 27% from carbohydrates (7 g fat and 6 g carbohydrates per 100 mL). In the high-carbohydrate soup 20% of energy was derived from fat and 77% from carbohydrates (2 g fat and 18 g carbohydrates per 100 mL). In our study the energy of the cake for MSFs and the GLs was 50% derived from fat and 44% from carbohydrates. In absolute amounts, however, the cake contained less fat than carbohydrates, 1 g fat per 2 g of carbohydrates (Table 2). Fat affects the taste and texture of a food and triggers...
Oral exposure to a food elicits so-called cephalic phase responses, which are thought to prepare the body for the digestion of the tasted food (6). It was found that MSF foods with different macronutrient compositions can lead to different cephalic phase responses. For example, Witteman et al. (24) showed that MSF of walnuts and codfish reduced gallbladder volume, whereas MSF with bananas did not. Zhu and colleagues (25) showed that 3-min MSF with cereal resulted in an increased insulin response and 3-min MSF with a low-fat mozzarella cheese increased ghrelin amount compared with water and macadamia. Furthermore, Smeets and Westerterp-Plantenga (26) showed that MSF meals with different oils affected appetite ratings differently, indicating that the type of sham-fed food also can affect appetite ratings. If we had used other foods for MSF, we might have found different effects on appetite ratings and gastric emptying rate. In addition, the studies of Kaplan et al. (21) and Cecil et al. (5) compare oral consumption to gastric infusion, which might suggest that just the mere presence of oral exposure to food, irrespective of its duration, may delay gastric emptying.

The appetite ratings seem to differ between the conditions directly after the treatment (at $t = 8$; Supplemental Figure 1). To be more specific, at $t = 8$ hunger and desire to eat seem to be lower and fullness higher for treatment 8 min/100 kcal than for treatment 1 min/100 kcal and for treatment 8 min/700 kcal than for treatment 1 min/700 kcal. This was, however, only short lived and not statistically significant. This finding is in line with the results of our previous study (3) in which we also found a short-lived decreasing effect of longer oral exposure duration on appetite. Other studies also found that a longer oral exposure decreased appetite ratings (1, 2, 27). The 7-fold increase in oral exposure duration in our study resulted in a 5-fold increase in the amount of cake chewed (30 g during 1-min MSF and 180 g during 8-min MSF). It is surprising that this large difference in amount of chewed cake did not affect appetite ratings. It might be that our homogenous mixed cake reached the small intestine shortly after the start of the treatment, resulting in a fast gastric response and thereby overriding any effects of oral exposure on gastric emptying. However, then we should expect an effect in the low-energy-dense GLs, and we did not observe this.

Our study design is useful to study oral and gastric factors simultaneously but independently. However, it is experimental; therefore, generalization to real consumption should be done with caution. First of all, with the MSF technique the act of swallowing is missing. Swallowing might be for a part responsible for the appetite-reducing effect of longer oral exposure found in other studies. Further investigation is needed to elucidate the role of swallowing in appetite regulation in humans. Second, the GLs were infused at a continuous flow and were more diluted than what can be expected from food bolus delivered to the stomach during consumption of sponge cake. Furthermore, during food consumption the breakdown of starch starts in the mouth on moistening with saliva, which did not occur in the food that was infused intragastrically. Third, the cognition of subjects might have played a role because our subjects knew that none of the sham-fed food would reach the stomach. In previous studies that report an appetite-decreasing effect of longer oral exposure the food was actually swallowed (1, 2, 5). It was shown that cognition can influence appetite. For example, Cassady et al. (28) showed that subjects’ belief about a test food influenced their satiety feelings. They showed that solid foods that were perceived as becoming liquid in the stomach resulted in higher hunger and lower fullness ratings than the same solid foods that were perceived to stay solid in the

FIGURE 5 AUCs of comfort (A) and nausea (B) from baseline (time 0) until 90 min after the treatment. Treatments consisted of oral exposure with MSF and at the same time infusion of a 500-mL GL via a nasogastric tube. Healthy men ($22 \pm 3 \text{ y, } 23 \pm 1 \text{ kg/m}^2$) received in randomized order 1-min MSF and a 100-kcal GL ($n = 24$), 8-min MSF and a 100-kcal GL ($n = 26$), 1-min MSF and a 700-kcal GL ($n = 26$), 8-min MSF and a 700-kcal GL ($n = 25$), or a control condition with no MSF and water as GL ($n = 26$). Values are expressed as means ± SDs and were tested with mixed model ANOVAs. Means do not differ ($P \geq 0.08$). GL, gastric load; MSF, modified sham feeding.

receptors in the oral cavity. Furthermore, it is known that fats are emptied from the stomach slower than carbohydrates. It might be that oral exposure only slows gastric emptying when fat is, in absolute amount, the primary component of a meal.

Moreover, the effect of the composition of gastric content on gastric emptying rate, without oral exposure, is not clear. Goetz et al. (22) showed that infusion of 500 mL with different macronutrient compositions (375-kcal fat emulsion, 400-kcal glucose solution, or 375-kcal protein solution) did not affect gastric volume over time. On the contrary, Marciani et al. (23) showed that the gastric half-emptying time was 19% faster for a high-carbohydrate rice pudding than for a high-fat rice pudding. However, they state that this could be well related to the 18% higher calorie content of the high-carbohydrate pudding than the high-fat pudding. Taken together, the impact of macronutrient composition on gastric emptying rate is not clear and needs more investigation.

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stomach. They saw the same for liquid foods that were perceived as liquid or solids in the stomach.

In conclusion, as expected higher gastric energy density inhibited gastric emptying rate and increased satiety feelings in young men. Prolonging oral exposure to food did not have an additional effect. Further research should be done in a less experimental setting.

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