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Oral processing effort, appetite and acute energy intake in lean and obese adults ☆

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HIGHLIGHTS

- Chewing augmented energy intake in obese and diminished intake in lean individuals.
- Chewing had no significant effect on appetitive sensations.
- Chewing had no significant effect on gastric emptying or GI transit time.
- Chewing had no significant effect on serum glucose or hormone concentrations.

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ABSTRACT

Chewing reportedly contributes to satiation and satiety signals. Attempts to document and quantify this have led to small and inconsistent effects. The present trial manipulated oral processing effort though required chewing of gums of different hardness and measured appetitive sensations, energy intake, gastric emptying, GI transit time, and concentrations of glucose, insulin, GLP-1, ghrelin and pancreatic polypeptide. Sixty adults classified by sex and BMI (15 each of lean females, obese females, lean males and obese males) were tested in a randomized, controlled, cross-over trial with three arms. They chewed nothing, soft gum or hard gum for 15 min while sipping grape juice (10% of individual energy needs) containing acetaminophen and lactulose on one day each separated by 7 days. Electromyographic recordings and self-reports were obtained during and after chewing to quantify oral processing effort. Blood was sampled through an indwelling catheter and appetite ratings were obtained at baseline and at 0, 15, 30, 45, 60, 90, 120, 180 and 240 min after chewing initiation. Breath samples were collected at 10 min intervals for the first 2 h and at 30 min intervals for the next 2 h. No effects of chewing were observed for appetitive sensations or gut peptide concentrations. Energy intake tended to decline in lean and increase in obese participants so that daily energy intake differed significantly between the two groups when chewing either gum, while no difference was observed on the non-chewing day. Serum glucose and insulin were significantly lower at selected time points 90–240 min after chewing compared to baseline and the non-chewing day. These data indicate chewing effort does not affect appetitive sensations or gut peptide secretion, but may exert a small differential effect on acute energy intake in lean and obese individuals and lead to greater post-prandial declines of serum glucose and insulin. The efficacy of gum chewing as a substitute for eating for weight management remains uncertain.

1. Introduction

Orosensory stimulation provided by foods contributes to the appetitive and compensatory dietary responses they elicit. This has been demonstrated repeatedly by differential responses to oral versus intragastric delivery of the same foods or stimuli (e.g., [1–3]), lower energy intake for a chewed food compared to matched semi-solid or fluid items [4,5] and inverse associations between viscosity and appetitive sensations [6,7]. Moreover, the association between viscosity, gastric transit time and appetite ratings may track better with oral sensations than physical GI factors [8]. There are multiple attributes of foods that influence ingestive behavior including their expected post-ingestive effects [1] irritancy [9], macronutrient composition [10] taste [4] and, of particular present relevance, physical form. The mechanical processing required of solid food forms reportedly augments the appetitive and compensatory dietary responses to their ingestion. Studies in rodents reveal an inverse association between diet hardness and body weight [11–13]. In one assessment of free-living, Japanese females, diet hardness was negatively

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associated with energy intake and waist circumference, even after correcting for BMI, but no association was noted with BMI [14].

Mastication may exert its effects through multiple mechanisms. First, studies in rats [15] indicate that the mechanical act of chewing activates histaminergic neuronal systems present in paraventricular and ventromedial hypothalamic nuclei, both reported satiety centers. Such activation reduces food intake, especially among lean, as compared with obese animals. Administration of alpha-fluoromethylhistidine, an inhibitor of the histamine synthesizing decarboxylase enzyme, leads to increased meal size when rats are fed soft pellets versus hard pellets [15], further suggesting a role for somatosensory signals in feeding responses to foods varying in texture. Second, chewing reportedly enhances cephalic phase responses [16,17]; which, in turn, are linked to appetite [18,19]. Third, chewing efficiency may modify the intestinal phase of digestion for each macronutrient. Recent work documents that chewing efficiency influences protein metabolism in the elderly [20]. Dentate participants have a more rapid rise and greater peak of plasma amino acids than denture wearers. Chewing modifies starch digestion and the metabolic response to carbohydrate [21]. Masticatory function also alters fat absorption. When almonds are chewed only ten times, there is greater fecal fat loss than when the same loads are chewed 25 or 40 times [22]. Indeed, as much as 20% of the energy from almonds may not be bioaccessible due to inefficient chewing [23]. Such chewing-related changes in the processing of energy-yielding nutrients may modify appetite and energy balance. Several groups (see Ref. [24]) report higher satiety ratings from individuals consuming whole fruits that require chewing when compared to ratings after drinking juice from the same foods [25,26] While these findings cannot be attributed unambiguously to oral mechanical activity since the juices and whole fruits differed nutritionally as well, other work holding nutritive content constant, revealed similar results [5]. Fourth, chewing may modify gut peptide secretion. There is a reported inverse association between number of chews and ghrelin concentrations and a direct association with GLP-1 [27]. Both are consistent with greater satiation effects. Fifth, mastication stimulates salivation (e.g., [28]) and saliva alters gastric and intestinal processing via enzymatic degradation of foods, dilution of chemicals, facilitation of deglutition and alteration of pH with implications for enzymatic activity [29]. Sixth, chewing entails work resulting in energy expenditure. Chewing gum leads to an 11 ± 3 kcal/h increment in energy expenditure [30]. Seventh, gastric emptying of solids is a well regulated process with emptying linked to particle size [31]. More thorough mastication reduces the mechanical work required of the stomach to degrade foods so they may be emptied more quickly and stimulate release of gut peptides with purported satiety properties. Eighth, there is a direct relationship between duration of oral sensory exposure and satiation ratings and acute food intake [3,32]. Solid foods that require chewing are retained in the mouth longer than beverages and semisolid items that require no mechanical degradation. Ninth, it is commonly anticipated that chewy foods lead to greater satiation and this becomes a self-fulfilling expectation [32].

Given these roles for chewing, practices that enhance masticatory effort should aid in weight management. However, the literature is mixed on this point. Several trials report very modest, but statistically significant decreases of appetitive sensations as well as intake with gum chewing [33,34]. Other work reports no effects on appetite or intake with acute gum chewing [35] or on weight loss with chronic chewing [36]. Increasing masticatory effort through manipulation of the number of chews/unit weight of food consumed revealed a negative association with energy intake [27] while another trial noted calculated hardness of the diet did not correlate with BMI among Japanese females [14].

No resolution to these discrepant observations has emerged, but one potential explanation relates to the level of masticatory effort. This has rarely been quantified in vivo in trials linking mastication, appetite and energy intake, and there is evidence of a positive association between the effort required to ingest foods and their satiety value [7,37]. Consequently, in this trial we manipulated oral processing effort by varying the hardness of gum and quantified the bite strength required to chew it. Effects on appetitive sensations, acute energy intake, physical gut processing and peptide secretion were contrasted between interventions. In light of evidence of discrepant responses between rodents varying in body fat [15], outcomes were also compared between lean and obese individuals.

2. Methods

Participants were recruited by public announcements. Respondents completed a screening questionnaire and those who met the stipulated initial eligibility criteria were asked to participate in a screening visit. This entailed first providing voluntary consent. Then, height was measured with participants in bare feet with a Holtain stadiometer. Fasting-state body weight (gown only) was measured to the nearest 0.1 kg after the participant had voided. Fasting-state whole body density was determined by whole body plethysmography (BodPod®, Life Instrument, Inc., Concord, CA). Body composition was determined by tetrapolar bioelectrical impedance analysis (RJL Systems, Detroit, MI). Eligibility was based on the following criteria, 18–50 years of age; body mass index 18–25 or 30–35 kg/M^2; good health; not initiating or terminating the use of medications reported to affect appetite or body weight during the proposed study period; stable activity level (no deviation > 1×/week at 30 min/session); no eating disorder (score < 20 of the Eating Attitude Test (EAT-26) [38]); no allergies to test foods; not glucose intolerant or diabetic (based on fasting blood glucose between 70 and 99 mg/dl); no history of GI pathology; and self-reported consumer of breakfast and lunch. Eligible volunteers were scheduled for three test days.

2.1. Testing sessions

The trial was of a randomized, controlled, cross-over design (see Fig. 1 for timeline). On three occasions separated by approximately a week, subjects reported to the laboratory at their customary lunch time having consumed the same typical breakfast (for them). They refrained from eating and using oral care products for at least 3 h prior to arrival at the laboratory. Sessions started with ratings of appetitive sensations on a visual analog scale. The session continued if self-reported hunger was rated greater than "strong" and a finger prick blood test revealed that plasma glucose was <110 mg/dl (OneTouch® Glucometer, LifeScan, Inc.).

For each of the three trials, a catheter was placed in an arm vein and the catheter was kept patent for the next 4 h. On a given test day, participants chewed nothing or chewed grape-flavored soft or hard chewing gum (approximately 5 g) for 5 min and then removed and stored the gum. This pre-chew was to negate selected differences in orosensory properties (e.g., physical form and sweetness) between the soft and hard versions prior to testing. Ten minutes later, a breath sample was

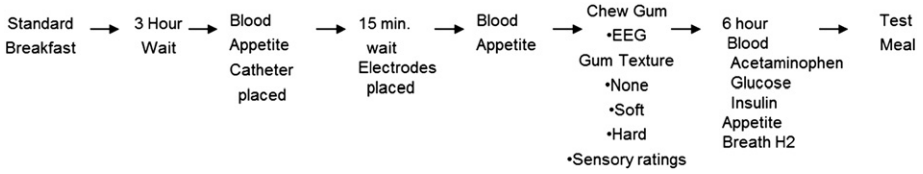

Fig. 1. Timeline of study activities.