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Effects of food form on appetite and energy balance

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ABSTRACT

The sensory properties of food influence food choice, digestion and metabolism. The properties arising from a food's form, in particular, can alter nutritional outcomes through multiple mechanisms operating at cognitive, orosensory, gastric and intestinal levels of food processing. Expectations regarding a food's form can influence satiety, sensory ratings of products, digestive processes and post-absorptive metabolism. In the oral cavity, the structure of food influences mastication efforts affecting appetite and energy and nutrient bioavailability in the GI tract. In the GI tract, the physical form of food influences gastric emptying, intestinal transit time and nutrient absorption. Hence, the physical form of food holds important implications for ingestive behavior and health outcomes.

1. Introduction

Consumer surveys consistently reveal that the sensory properties of foods are the primary determinant of food choice (IFIC., 2013). Although cost, convenience, nutritional value, sustainability and other properties are also important, for the overwhelming majority of consumers, acceptable "taste," the vernacular term, but more correctly, "flavor," is required for repeated purchases and consumption. However, sensory properties of food hold nutritional implications beyond just hedonic impressions.

Sensory systems are signaling systems. They convey information from the external and internal environments to the central nervous system. The function is to inform the organism about potential dangers and opportunities so that appropriate behavioral and physiological responses can be initiated to optimize survival. To facilitate the process with respect to feeding, associations between sensory properties and post-ingestive consequences may be learned so that repeated sensory exposures can elicit rapid, reflexive, appropriate responses. For example, sweetness becomes predictive of carbohydrate ingestion and stimulates insulin release (Härtel, Graubaum, & Schneider, 1993; Just, Pau, Engel, & Hummel, 2008; Teff, Mattes, Engelman, & Mattern, 1993). The magnitude of the first phase of insulin secretion attributable to sweetness, the cephalic phase insulin response (CPIR), is significantly correlated with the post-prandial insulin response (Teff et al., 1993). Although causality has not been established, the sensory signal likely modulates the overall response, so the organism is not threatened by marked hypo- or hyperglycemia after an ingestive event. Blocking the CPIR leads to greater peak post-prandial plasma glucose concentrations and a prolonged elevation of circulating glucose (Calles-Escandon & Robbins, 1987; Lorentzen, Madsbad, Kehlet, & Tronier, 1987; Steffens, 1976). Many other examples of cephalic phase responses to oral stimulation could be cited such as bitterness evoking CCK release with implications for gastric emptying and appetite (Jeon, Seo, & Osborne, 2011; Sternini, 2007), saltiness moderating renal sodium clearance and possibly blood pressure levels (Akaishi, Shingai, Miyaoka, & Homma, 1991), or fat taste influencing circulating triglyceride concentrations and cardiovascular disease risk (Mattes, 1996b, 2011).

Association of an item's sensory properties with the post-ingestive consequences of consuming the item is an associative learning process that can influence dietary behavior. Such associations can be explained by the flavor-consequence (Yeomans, 2009) and flavor-nutrient (Yeomans, 2012) learning models. When the sensory profile is paired with a positive experience, future exposures to the sensory stimulus can evoke an appetitive response. Conversely, when the sensory profile has been linked to a negative

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experience (e.g., gastric distress) the stimulus is likely to be avoided when next encountered. Importantly, this form of learning permits decision making prior to sampling of a food or beverage as is common under customary dining conditions. Inherent hedonic impressions of sensory properties (e.g., positive and negative responses to sweetness and bitterness, respectively) and cultural norms modify associative learning, but dietary experience can transcend and dominate behavioral practices (Booth, Lee, & McAleavey, 1976; Brunstrom, Shakeshaft, & Scott-Samuel, 2008; Hardman, McCrickerd, & Brunstrom, 2011; Tepper, Mattes, & Farkas, 1991).

Additionally, sensory properties stemming from a food's or beverage's composition and structure can directly modify nutritional outcomes. Textural attributes are an example. The perceived brittleness of food may alter chewing responses (Frecka, Hollis, & Mattes, 2008) with subsequent implications for the bioaccessibility of energy and nutrients from the food (Mandalari et al., 2008). Thus, the sensory properties of foods and beverages hold important nutritional implications at multiple levels.

Claims that sensory properties are linked to energy intake/balance raise questions about the fundamental issue of whether a "Calorie is a calorie." Why would energy from one source have different implications than energy from another? This issue is prominent in consideration of the role of energy-yielding beverages on energy intake where it is often stated that beverages are especially problematic for weight gain (Mattes, 2006). Though it is true that the amount of energy stored or released when different chemical bonds are formed or broken is consistent, the behavioral and more organ- and whole-body level responses to foods or beverages varying in sensory properties are functionally different. In fact, this is the basis of all energy-restrictive diets predicated on properties not reflected by bomb calorimetry values alone. The literature is replete with claims that selected nutrients, foods and diets hold special properties that may be harnessed for therapeutic purposes. For example, there are reports that protein (Johnstone, 2013; Westerterp-Plantenga, Lemmens, & Westerterp, 2012) or fiber (Clark & Slavin, 2013) are especially satiating and capsaicin (the compound in red peppers responsible for their irritancy) can increase energy expenditure (Ludy & Mattes, 2011; Yoshioka et al., 1995). Low energy dense foods (Pérez-Escamilla et al., 2012), whole grains (McKeown, Hruby, Saltzman, Choumenkovitch, & Jacques, 2012) and fruits and vegetables (Whigham et al., 2012) are reported to aid weight management. Diets that evoke low glycemic responses (Jones, 2013) or exclude animal products (Orlich & Fraser, 2014) also purportedly facilitate weight loss or maintenance. Thus, many properties of foods and beverages, including their form, are, justifiably or not, widely held as especially nutritionally meaningful and amenable to manipulation for designated purposes (e.g., weight management, reduction of chronic disease risk).

The perception of flavor (of foods and beverages) arises from an amalgamation of all the sensory properties. However, flavor is primarily defined as a combination of the gustatory, olfactory and trigeminal sensations perceived during ingestion (ISO, 2008). Expectations regarding the perceived flavor of foods can affect food acceptance (Cardello, 1994). Although much attention is focused on appearance, taste and odor, food form is also a critical determinant of acceptability. Foods expected to be creamy (e.g., custard, ice cream) or crispy (e.g., crackers, chips) must be so or they will be rejected. Similarly, foods not expected to be slimy, greasy or gritty will be similarly avoided if presented in these forms. Consequently, physical properties warrant careful consideration in product development, diet prescriptions and policy recommendations. Food form can exert effects at different phases of ingestion and thus warrants comprehensive evaluation. Definitive evidence of food form effects is limited because researchers often fail or are unable to match energy, macronutrient content, weight, volume, palatability, and other food properties that could influence findings (Mattes & Rothacker, 2001; Tucker & Mattes, 2013). Nevertheless, the present article will review the importance of food form on energy balance at the levels of cognition, orosensory stimulation and gastrointestinal processes.

2. Cognitive effects of food form

Associative learning generates expectations regarding the consequences of consuming the same and related foods, and these expectations comprise the cognitive effect of food. Examples of cognitive effects include: the color of a food influencing the identification of its flavor (for a review, see (Spence, Levitan, Shankar, & Zampin, 2010)), increased salivation at the sight or thought of familiar foods (Wooley & Wooley, 1973), the weight of a container influencing the expectation of fullness the food would provide if consumed (Piqueras-Fiszman & Spence, 2012), or the effects of messaging about the healthfulness of items and both the endocrine response to their ingestion (Crum, Corbin, Brownell, & Salovey, 2011) and total energy intake (Provencher, Polivy, & Herman, 2009). Cognitive effects may overwhelm physiological cues as demonstrated by work showing ratings of hunger after consumption of preloads are better correlated with expected than actual energy content (Wooley, 1972).

In terms of food form, there are strong expectations that solid foods will be more satisfying – in terms or satiation and satiety – than beverages matched on energy (Cassady, Considine, & Mattes, 2012; DiMeglio & Mattes, 2000; Flood-Obbagy & Rolls, 2009). Semi-solid, iso-energetic and nutrient-matched products are also expected to be more satiating than a liquid product (Hogenkamp, Mars, Stafleu, & de Graaf, 2012), and higher viscosity products appear to facilitate the process of learned satiation more so than lower viscosity stimuli (Mars, Hogenkamp, Gosses, Stafleu, & de Graaf, 2009). Following ingestion, the expectations associated with solids and higher viscosity semi-solids are generally supported (de Wijk, Zijlstra, Mars, de Graaf, & Prinz, 2008; Leidy, Apolzan, Mattes, & Campbell, 2010; Martens, Lemmens, Born, & Westerterp-Plantenga, 2011, 2012; Mattes & Campbell, 2009; Mattes & Rothacker, 2001; Mourao, Bressan, Campbell, & Mattes, 2007; Tournier & Louis-Sylvestre, 1991). In addition, subtle changes in viscosity of beverages can be perceived as well, with thicker beverages expected to be more satiating and inducing greater satiety than thinner beverages (McCrickerd, Chambers, Brunstrom, & Yeomans, 2012). Changing expected satiation and satiety values held by individuals has proven difficult, at least in laboratory-based settings, in many (Hogenkamp, Brunstrom, Stafleu, Mars, & de Graaf, 2012; Hogenkamp, Mars, et al., 2012; Hogenkamp, Stafleu, Mars, Brunstrom, & de Graaf, 2011; O'Sullivan, Alexander, Ferriday, & Brunstrom, 2010), but not all studies (Wilkinson & Brunstrom, 2009).

While solids are generally reported to be more satisfying than beverages (for a review, see (Tucker & Mattes, 2013)), soups do not follow this pattern. They hold greater satiating powers than solids (Clegg, Ranawana, Shafat, & Henry, 2013; Kissileff, Gruss, Thornton, & Jordan, 1984) as well as greater satiety effects (Flood & Rolls, 2007). The reasons for this are not yet clear and a variety of explanations have been proposed (Clegg et al., 2013; Viskaal-van Dongen, Kok, & de Graaf, 2011). Some suggest a cognitive component to explain differences in satiety between soups, beverages, and solids. Soups are perceived as nutritious, while beverages are usually consumed to allay thirst (Mattes, 2005). Hence, expectations regarding the satiation and satiety value of soups may partly explain these effects.