Appetite 105 (2016) 549–556

Contents lists available at ScienceDirect

Appetite

journal homepage: www.elsevier.com/locate/appet

Removing energy from a beverage influences later food intake more than the same energy addition

K. McCrickerd [a, b], N.B. Salleh [a, b], C.G. Forde [a, b, c, *]

[a] Clinical Nutrition Research Centre, Centre for Translational Medicine, Yong Loo Lin School of Medicine, Singapore
[b] Singapore Institute for Clinical Sciences, Agency for Science, Technology and Research (A*STAR), Singapore
[c] National University of Singapore, Department of Physiology, Yong Loo Lin School of Medicine, Singapore

ARTICLE INFO

Article history:
Received 30 March 2016
Received in revised form
22 June 2016
Accepted 24 June 2016
Available online 26 June 2016

Keywords:
Energy compensation
Beverage
Preload
Satiety
Appetite
Calorie reduction

ABSTRACT

Designing reduced-calorie foods and beverages without compromising their satiating effect could benefit weight management, assuming that consumers do not compensate for the missing calories at other meals. Though research has demonstrated that compensation for overfeeding is relatively limited, the extent to which energy reductions trigger adjustments in later food intake is less clear. The current study tested satiety responses (characterised by changes in appetite and later food intake) to both a covert 200 kcal reduction and an addition of maltodextrin to a soymilk test beverage. Twenty-nine healthy male participants were recruited to consume three sensory-matched soymilk beverages across four non-consecutive study days: a medium energy control (ME: 300 kcal) and a lower energy (LE: 100 kcal) and higher energy (HE: 500 kcal) version. The ME control was consumed twice to assess individual consistency in responses to this beverage. Participants were unaware of the energy differences across the soymilks. Lunch intake 60 min later increased in response to the LE soymilk, but was unchanged after consuming the HE version. These adjustments accounted for 40% of the energy removed from the soymilk and 13% of the energy added in. Rated appetite was relatively unaffected by the soymilk energy content. No further adjustments were noted for the rest of the day. These data suggest that adult men tested were more sensitive to calorie dilution than calorie addition to a familiar beverage.

1. Introduction

Compensatory eating describes the adjustment of energy intake triggered by consumption of a food, such as a previous meal, beverage or snack (Booth, 1972). Central to this is the development of satiety (the process that inhibits further eating), which integrates pre-ingestive cognitive and sensory signals with post-ingestive nutrient effects (Blundell et al., 2010). The ability to regulate energy intake in response to calories consumed differs across individuals (Appleton, Martins, & Morgan, 2011) and foods. Food taste and texture (McCrickerd & Forde, 2016), form and volume (Almiron-Roig et al., 2013; De Graaf & Hulshof, 1996) and macronutrient content (Bertenshaw, Lluch, & Yeomans, 2008; Blundell & MacDiarmid, 1997; Westerterp-Plantenga, Rolland, Wilson, & Westerterp, 1999) have all been identified as some of the food-factors that influence satiety responses, characterised as changes in rated appetite sensations and further eating. In general, however, humans tend not to precisely compensate for increases in energy intake both in the short and longer term (Almiron-Roig et al., 2013; Levitsky, 2005; Levitsky, Obarzanek, Mrdjenovic, & Strupp, 2005; Rolls, Roe, & Meengs, 2006). In the context of an energy dense, palatable and varied food environment, insufficient compensation for increases in energy intake has been identified as one risk factor for the positive energy balance characterising the rise in obesity.

The extent to which a food or beverage leads to a decline in hunger and desire to eat and the inhibition of future eating has become a point of interest for researchers and members of the food industry who aim to reformulate foods and beverages to reduce energy intake and aid weight loss. One strategy is to design nutrient rich 'satiety-enhancing' foods that lessen the return of hunger after eating and inhibit future energy intake (Chambers, McCrickerd, &

* Corresponding author. Clinical Nutrition Research Centre, Centre for Translational Medicine, 14 Medical Drive #07-02, MD 6 Building, Yong Loo Lin School of Medicine, 117599, Singapore.
E-mail address: Ciaran_Forde@sics.a-star.edu.sg (C.G. Forde).

http://dx.doi.org/10.1016/j.appet.2016.06.030
0195-6663/

Yeomans, 2015). Such foods are often high in protein or fibre and have been shown to enhance satiety in short term acute studies (Chambers et al., 2015; Van Kleef, Van Trijp, Van Den Borne, & Zondervan, 2012). Yet to date many longer-term trials have failed to substantiate claims that these foods can promote adjustments to appetite and intake sufficient for weight loss when consumed over weeks or months (Halford & Harrold, 2012).

An alternative approach is to remove some of the energy from commonly consumed foods. These 'reduced calorie' products aim to dilute the energy density of the diet with minimal changes to the palatability and sensory experience of eating. Unlike satiety-enhancing foods, their capacity to reduce energy intake relies on the imprecise control of energy balance in humans, which predicts that the missing calories will not be fully compensated for later in the day. For example, though adults can make short term adjustments to food intake to account for energy removed when a single meal is skipped (Levitsky, 2002) or smaller portions are provided over several days (Foltin, Fischman, Emurian, & Rachlinski, 1988; Mattes, Pierce, & Friedman, 1988), these adjustments are often incomplete and energy intake remains reduced overall. Importantly, evidence suggests that this approach could support weight maintenance or loss in the longer term, at least for beverages: a recent meta-analysis of short and longer-term studies reports that consuming low/no-calorie sweetened beverages in place of sensory-matched caloric sugar-sweetened versions is linked to reduced daily energy intake and body weight if the replacement is sustained over weeks and months (Rogers et al., 2015).

It is possible that human eating may be more responsive to energy reductions rather than additions, in the short term at least. Firstly, in a recent meta-analysis Almiron-Roig et al. (2013) found that, contrary to their prediction, participants across a range of preload studies were better at adjusting subsequent food intake in response to lower-energy rather than higher-energy foods, independent of the time interval between the food preload and the later meal. Secondly, adults (De Graaf & Hulshof, 1996) and children (Cecil et al., 2005) increased their lunch intake after calories were removed from a pre-meal snack by replacing it with water, but showed less adjustment after energy was covertly added to the snack. It is possible that replacing a caloric snack with water or obviously skipping a meal encouraged compensatory eating because participants were aware that less food was consumed (Appleton, McKeown, & Woodside, 2015). Yet Appleton et al. (2011) noted that the accuracy of adjustment for a covert 361 kcal energy difference across two chocolate milkshakes (higher energy vs. lower energy) was improved when the energy manipulation was *experienced* as a reduction rather than an addition (achieved by reversing the order of consumption in half of the participants). This implies that energy intake adjustments might be more precise for calorie-reduced foods and less precise for more energy dense items.

To investigate this idea, the current study tested whether healthy male participants show different satiety responses to the same 200 kcal removed from or added to a mid-morning beverage, in the absence of cognitive and sensory cues for the energy difference. To our knowledge the extent to which adults adjust future eating for a disguised energy reduction, compared to the same energy addition has not been directly tested. We created three equally palatable, sensory-matched soymilk beverages varying only in their energy content: a calorie-reduced version, a calorie-added version, and a middle energy control, and tested their impact on subsequent changes in rated appetite, and adjustments to later food intake. The middle energy control was modelled on commercially available soymilks. If participants are equally insensitive to the energy additions and reductions they should demonstrate similar and minimal adjustments in subsequent eating behaviour regardless of the soymilk consumed. A secondary aim was to consider the consistency of individual's responses to the covert variations in soymilk energy across the test days.

2. Method

2.1. Design

A repeated-measures design was used to assess the influence of a covert reduction and addition of energy to a beverage on satiety responses (changes in appetite and energy intake at a later test meal and throughout the day). The satiating effect of three soymilk beverages varying in energy content (Medium Energy Control: ME; Low Energy: LE; High Energy: HE) was investigated over four test sessions. The ME control was always consumed on the first and last session (Days 1 and 4) and the order in which the participants consumed the LE and HE soymilk (Days 2 and 3) was counterbalanced across participants. This ensured that the LE and HE soymilks were experienced as an energy reduction and addition, and repeating the ME control at the end of the study allowed for a measure of consistency in responses and a check of order effects.

A previous study (McCrickerd, Chambers, & Yeomans, 2014b) found that a similar 200 kcal difference across two liquid preloads led to a significant adjustment in *ad libitum* lunch intake 60 min later (effect size: $\eta_p^2 = 0.20$; within-subject correlation: $r = 0.581$). Based on a more conservative effect size a minimum of 20 participants were required to detect a difference in lunch intake (at 95% power with a two-sided alpha <0.05 and $\eta_p^2 = 0.14$; using G*Power). We aimed to recruit 30 participants to account for any drop-outs or unusable data. The study was granted ethical approval by the Singapore National University Hospital Domain Specific Review Board in accordance with the Declaration of Helsinki.

2.2. Participants

Eligible participants were healthy non-obese males (predominately Singaporean), without food allergies or aversions to the study foods, and not currently dieting or using any medication that could influence appetite or energy metabolism. Potential participants attended a screening session after fasting for three hours, where they completed a brief questionnaire assessing their health and dietary habits and confirmed their weight had not changed more than ±5 kg in the last 12 months. Height and weight was recorded and body composition determined using air displacement plethysmography (BOD POD, Cosmed, Italy). Following screening, 29 eligible male participants were recruited into this study, who had a mean BMI of 23.0 (SD: ± 2.5; range: 18.0–28.6) and average age of 27.0 years old (SD: ±4.8; range: 21–37). Participants were told that the purpose of the study was to investigate the effect of consuming morning breakfast and a snack on mood.

2.3. Study food

2.3.1. Breakfast

Before each test day, participants were given a standard 498 kcal breakfast consisting of an Apple, muesli Bar (Nestle, Australia), cheese sandwich biscuits (Perfect Food Manufacturing Sdn Bhd, Malaysia) and a 100% Orange Juice Drink (Malaysia Dairy Industries Pte Ltd, Singapore).

2.3.2. Soymilk test drinks

The three soymilk test drinks were consumed in 456 ml portions containing 100 kcal (LE), 302 kcal (ME) and 500 kcal (HE). Ingredients consisted of almond flavoured soymilk (Marigold, Malaysia Dairy Industries Pte Ltd, Singapore: 200 g) and filtered water (LE = 264 g; ME = 224 g; HE = 264 g). Maltodextrin