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ORIGINAL COMMUNICATION

Energy density of foods and beverages in the Australian food supply: influence of macronutrients and comparison to dietary intake

TC Crowe[1]*, HA La Fontaine[1], CJ Gibbons[1], D Cameron-Smith[1] and BA Swinburn[1]

[1]*Centre for Physical Activity and Nutrition Research, Deakin University, Burwood, Victoria, Australia*

Objectives: The energy density (ED) of the diet is considered an important determinant of total energy intake and thus energy balance and weight change. We aimed to compare relationships between ED and macronutrient content in individual food and beverage items as well as population diet in a typical Western country.
Design: Nutrient data for 3673 food items and 247 beverage items came from the Australian Food and Nutrient database (AusNut). Food and beverage intake data came from the 1995 Australian National Nutrition Survey (a 24-h dietary recall survey in 13 858 people over the age of 2). Relationships between ED and macronutrient and water content were analysed by linear regression with 95% prediction bands.
Results: For both individual food items and population food intake, there was a positive relationship between ED and percent energy as fat and negative relationships between ED and percent energy as carbohydrate and percent water by weight. In all cases, there was close agreement between the slopes of the regression lines between food items and dietary intake. There were no clear relationships between ED and macronutrient content for beverage items. Carbohydrate (mostly sucrose) contributed 91, 47, and 25% of total energy for sugar-based, fat-based, and alcohol-based beverages respectively.
Conclusions: The relationship between ED and fat content of foods holds true across both population diets and individual food items available in the food supply in a typical Western country such as Australia. As high-fat diets are associated with a high BMI, population measures with an overall aim of reducing the ED of diets may be effective in mediating the growing problem of overweight and obesity.
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Introduction

The rise in the prevalence of overweight and obesity worldwide continues unabated with approximately 60% of adult men and women in Australian now overweight or obese (Dunstan *et al*, 2000). The development of overweight and obesity can be considered a multifactorial issue with genetic predisposition, physical inactivity, food availability, and inappropriate meal patterns all playing an important role. One factor thought to provide a significant contribution to overall energy intake is the energy density (ED) of foods (Poppitt, 1995). ED is defined by the amount of metabolisable energy per unit weight of the food. The two most important determinants of ED in foods are water and fat content. Fat is a major determinant of ED as its energy content is more than twice that of carbohydrate or protein with many high-fat foods being low in water and fibre also. The fat content of foods varies substantially, yet there is a remarkably close positive relationship between fat content and ED when a range of foods across the food supply are

*Correspondence: TC Crowe, Centre for Physical Activity and Nutrition Research, School of Exercise and Nutrition Sciences, Deakin University, Burwood Highway, Burwood, VIC 3125, Australia.
E-mail: tcrowe@deakin.edu.au
Guarantor: TC Crowe.
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analysed (Poppitt, 1995). Similarly, a close negative relationship is found between water content of foods and ED.

The ED of a diet as a whole is well correlated with the macronutrient composition, especially the fat content, with energy-dense diets tending to be high-fat diets. High-fat diets are associated with a high BMI while low-fat diets tend to result in a loss of body weight (Tremblay *et al*, 1989; Miller *et al*, 1990; Kendall *et al*, 1991; Sheppard *et al*, 1991; Astrup *et al*, 2000). It has therefore been proposed that, in general, foods that are high in fat tend to be energy dense and promote an excess energy intake (called passive overconsumption). Several short-term studies (Poppitt, 1995; Stubbs *et al*, 1996, 1998a; Rolls & Bell, 1999; Rolls *et al*, 1999a; Bell & Rolls, 2001) have systematically altered the fat content and ED of diets independently of each other and found that it was ED, not fat content, that promoted overconsumption. This suggests that ED mediates the effect that fat content has on energy intake and that other composition characteristics may also affect ED.

The number of food items available to consumers number in the tens of thousands. Each food item, whether eaten individually or as part of a complete meal, will contribute to the overall ED of a person's diet. A high-fat, energy-dense diet has the potential to promote overconsumption and lead to unhealthy weight gain. However, in addition to foods, beverages can make a significant contribution to an individual's overall energy intake. Unlike foods, the overall ED of beverages is much lower; however, relationships between ED and macronutrient content of such beverages is less studied. Energy taken in via beverages may not be as well 'registered' and compensated for as whole foods, at least when taken at the same time as eating the meal (Rolls *et al*, 1999b). Contrary to this, however, there is evidence to suggest that ingestion of a high volume of fluid 30 min prior to a meal may reduce energy intake from the subsequent meal (Rolls *et al*, 1998).

As ED is postulated to be an important factor in energy balance and hence weight regulation, the ED of the whole food and beverage supply should be considered when examining potential obesogenic factors in the environment. There is a strong positive relationship between fat content and ED seen when small samples of foods available in the food supply are analysed (Poppitt, 1995), but it is unknown if this relationship holds true for foods across the full range of foods available to a population and also for that population's overall diet. Furthermore, beverages can make a significant contribution to total energy intake yet no studies have examined if similar relationships exist between ED and macronutrient content for beverage items available to the population or beverages typically consumed by the population.

In the present study, we analysed the ED of a large cross-section of food items available to the Australian consumer in addition to analysing the typical diet of the population to examine if the relationships between macronutrient composition and ED are the same for food items as they are for overall diets. Further to this, we examined the relationships between ED and macronutrient content of available beverages (including fat-based, sugar-based, and alcohol-based beverages). An understanding of how individual food and beverage items can affect the overall ED of a person's diet has important implications in the development of dietary recommendations to help combat the epidemic of overweight and obesity in Western societies today.

Methods

Food and beverage items used in the analysis were sourced from the Australian Food and Nutrient Database (AusNut) compiled in 1999 by Food Standards Australia and New Zealand. The AusNut database is representative of most of the generic items available to the Australian consumer across all categories of food and beverage groups. All foods and beverages listed in the database were included for analysis unless the item was listed in a state that is not normally consumed (eg powdered foods that need reconstitution and liquid concentrates). In total, 3673 individual foods and 247 beverages (not including water) were included in the analysis. Foods were not grouped into product categories and no allowance was made for the likely frequency of consumption. ED and percent energy as carbohydrate, fat, and percent water by weight were calculated for each item based on the stated nutritional composition of each item.

Beverages were divided into three distinct groups based on the major macronutrient base of the drink. Groups were fat-based (either dairy- or soy-based), sugar-based (including fruit juices, sucrose-based carbonated drinks, and 'sports' drinks), and alcohol-based (including wines, beers, spirits, and premixed drinks). Beverages did not include liquid or semisolid products (such as salad dressings of yoghurt) that are usually eaten as part of a meal rather than drunk as a beverage.

Australian dietary intake data were sourced from the 1995 National Nutrition Survey (McLennan & Podger, 1998) which collected food and beverage intake data by 24-h dietary recall in 13 858 people over the age of 2.

Linear regression lines were calculated for ED *vs* percent energy as carbohydrate, fat, and percent water by weight for both the individual food and beverage items from the AusNut database and the average Australian dietary intake data of food and beverage items. Prediction bands were calculated to capture 95% of the data population. These bands were plotted and used to represent a large cross-section of Australian food and beverage items as well as the population dietary intake data. Significant differences between the ED of different beverage groups were determined by an independent *t*-test.

Results

The relationships for individual food items between ED and percent energy as fat, carbohydrate, and percent water by weight based on the AusNut food database are shown in Figure 1a–c. Identical graphical interpretation showing the relationships for population food intake between ED and percent energy as fat, carbohydrate, and percent water by weight based on the average Australian dietary intake are shown in Figure 1d–f.

There was a positive relationship between percent energy as fat and ED for both individual food items from the AusNut database and population food intake with close agreement between the slopes of the regression lines (Figure 1a and d, respectively; slope = 0.14 and 0.11, respectively; $r^2 = 0.29$ and 0.10, respectively). Similar analysis examining the relationship between ED and percent energy as carbohydrate showed a negative relationship for both individual food items and population food intake (Figure 1b and e respectively; slope = −0.04 and −0.045, respectively; $r^2 = 0.03$ and

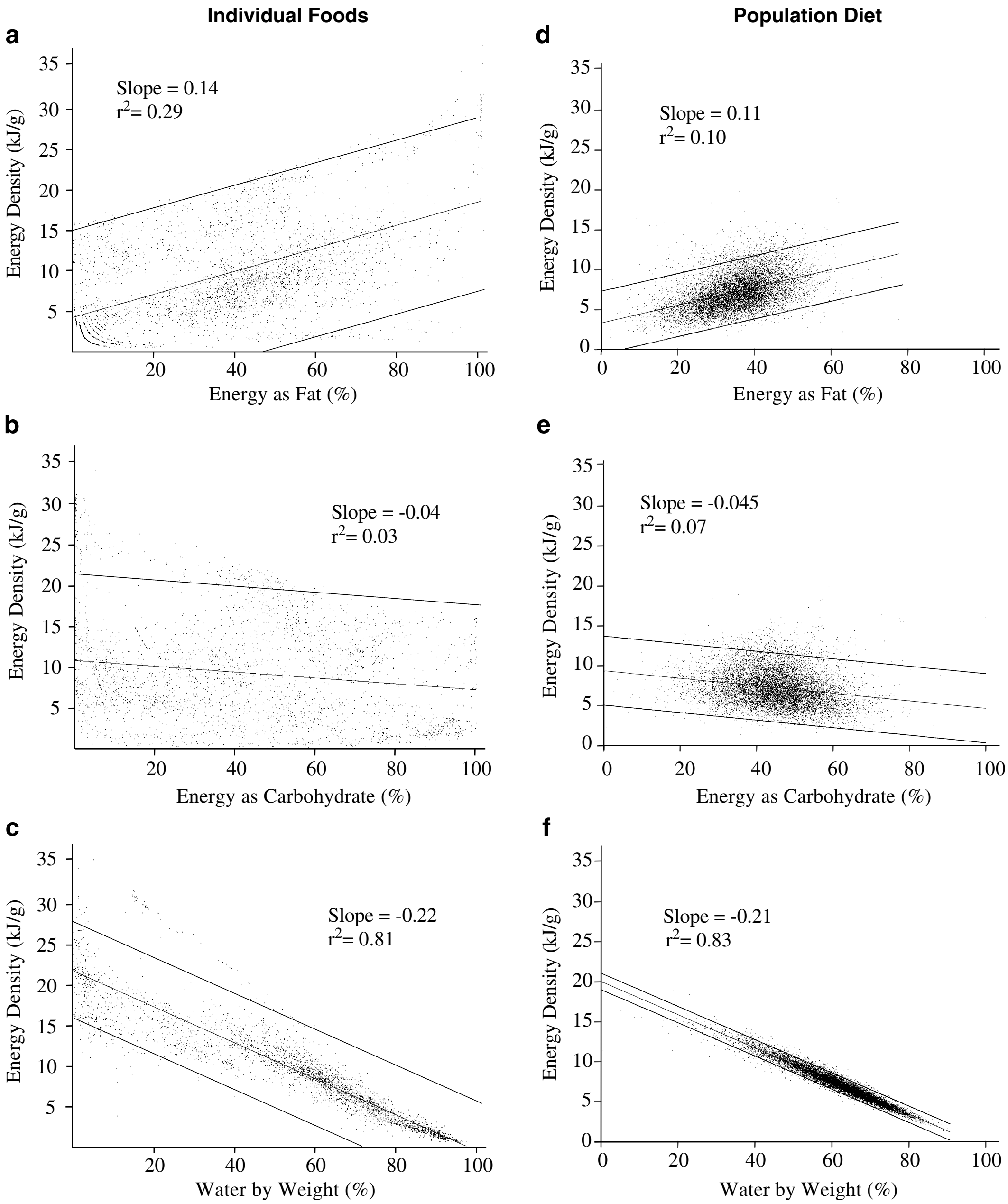

Figure 1 Relationship between ED and percent energy as fat (a), carbohydrate (b), and percent water by weight (c) based on all food items present in the Australian Food and Nutrient Database. Relationship between ED and percent energy as fat (d), carbohydrate (e), and percent water by weight (f) based on the average Australian dietary intake sourced from the 1995 National Nutrition Survey. For each graph, linear regression with 95% prediction bands is depicted (with the exception of (b) where only the upper 95% predication band is represented).

0.07, respectively). The strongest negative relationship was seen when percent water by weight was plotted against ED for both individual food items and population food intake (Figure 1c and f, respectively; slope = −0.22 and −0.21, respectively; r^2 = 0.81 and 0.83, respectively). Foods containing the highest amount of water were found to have the lowest ED and *vice versa*. In all cases, the 95% predication bands calculated for the food items showed a much greater range than the predication bands for the population food intake. All relationships shown in Figure 1 were found to be significant ($P<0.001$).

Table 1 lists the ED and macronutrient content of 247 beverages (listed in the AusNut database), classified into three different beverage types. Sugar-based beverages derived almost 90% of their energy from carbohydrate. Fat-based drinks, dominated by dairy and soy products, were significantly more energy dense ($P<0.01$) than sugar-based beverages with fat being an important contributor to total energy. Interestingly though, the major macronutrient contributor to total energy in fat-based beverages was carbohydrate (ie sugar). Alcohol-based beverages were by far the most energy dense beverages: almost double the ED of fat-based drinks and almost three times that of sugar-based drinks. Alcohol was the major contributor to the energy content of alcoholic beverages at 70.4%.

Graphs showing the relationship between ED and percent energy as fat and carbohydrate in beverage items are shown in Figure 2a and b, respectively. These graphs demonstrate a tendency for different beverage types to cluster together in terms of ED and macronutrient contribution, making it difficult to identify a true relationship that may exist between macronutrients and ED. By their nature, both sugar- and alcohol-based beverages are inherently low in fat, hence no relationship was found between fat content and ED for these beverage types as the fat content of the majority of these beverages was at most 5% of energy (Figure 2a). Fat-based beverages showed a positive relationship between ED and percent energy as fat (r^2 = 0.20; slope = 0.04); however, the degree of the slope was not as great as a similar positive relationship found between ED and fat content of food items and diets.

Similar analysis examining the relationship between ED and carbohydrate content of beverages once again showed a distinct clustering of the three different beverage types (Figure 2b). Sugar-based beverages were almost all composed of greater than 80% by energy of carbohydrate, which explains the tight clustering of these beverage types in relation to ED. A similar type of clustering in relation to ED was seen for fat-based beverages whose carbohydrate content mostly varied from 30 to 60%. Owing to the clustering effect seen for all beverage types, no relationship appeared to exist between ED and macronutrient content of fat-, sugar-, or alcohol-based beverages. Beverages grouped as alcohol-based showed no relationship between their alcohol content and ED (Figure 3).

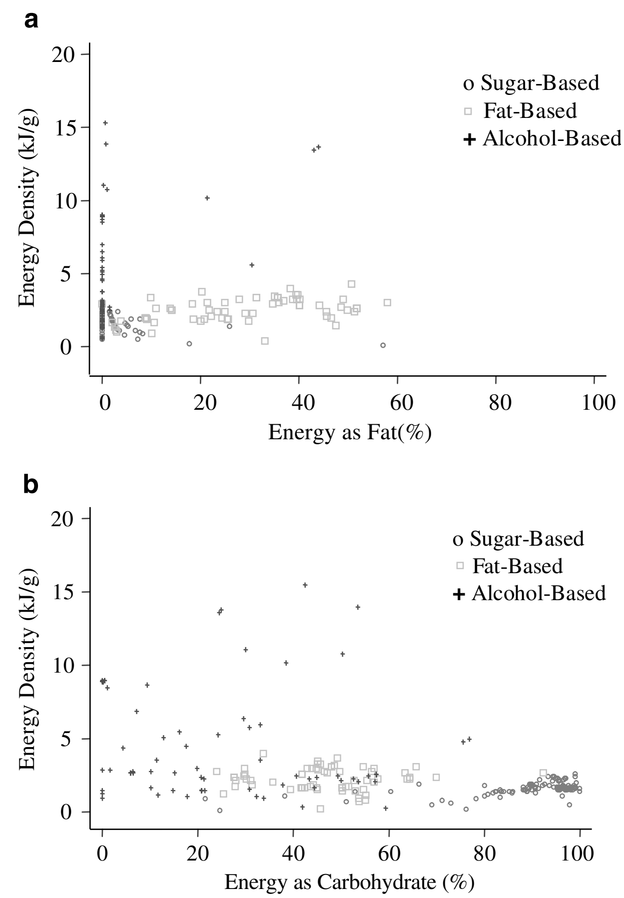

Figure 2 Relationship between energy density and percent energy as fat (a) and carbohydrate (b) from 247 beverages whose nutrient composition was listed in the Australian Food and Nutrient Database. Beverages were divided into three distinct groups based on the major macronutrient base of the drink. Beverage groups were sugar-based (○), fat-based (□), and alcohol-based (+).

Table 1 Macronutrient contribution to ED of different beverage groups

Beverage type	*Number of samples*	*ED (kJ/g)*	*CHO (% energy)*	*Fat (% energy)*	*Protein (% energy)*	*Alcohol (% energy)*
Sugar-based	112	1.6±0.1	91.0±1.0	2.0±0.6	3.4±0.5	—
Fat-based	65	2.6±0.1	46.6±1.4	28.1±1.9	25.2±1.17	—
Alcohol-based	70	4.6±0.5	24.9±2.5	2.1±1.0	1.7±0.3	70.4±2.8

Mean±s.e.m. energy density (ED) and macronutrient composition of typical beverage groups found in the Australian food supply. The ED of all three beverage types were significantly different to each other ($P<0.01$).

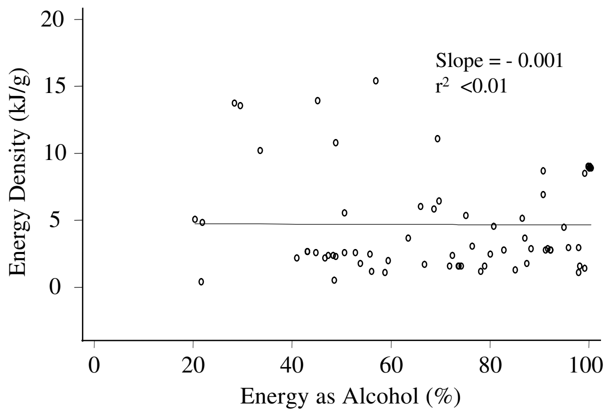

Figure 3 Relationship between energy density and percent energy as alcohol for alcohol-based beverages whose nutrient composition was listed in the Australian Food and Nutrient Database.

Discussion

This study examined the connection between ED and macronutrient composition and water content of a large cross-section of foods and beverages found in the Australian food supply and those eaten in the typical Australian diet. As ED is postulated to be an important factor in energy balance and hence weight regulation, the ED of the whole food and beverage supply should be considered when examining potential obesogenic factors in the environment. Previous studies have shown that the ED of foods is positively correlated to their fat content and negatively correlated to water content (Poppitt, 1995). In the present study, we analysed the ED of a large cross-section of foods and beverages available to the Australian consumer in addition to analysing the typical diet of the population to examine if the relationship between macronutrient composition and ED holds true over the entire range of foods and beverages likely eaten or drunk. For both individual food items and population food intake, there was a positive relationship between ED and percent energy as fat and negative relationships between ED and percent energy as carbohydrate and percent water by weight. In all cases there was close agreement between the slopes of the regression lines. Individual food items displayed a greater variability in the range of the 95% predication bands, which is explained by the fact that population food intake data are the mean of many individual food items; therefore the 95% predication bands are much narrower. Beverage items were clustered in fat-based, sugar-based, and alcohol-based groupings when macronutrient content and ED was analysed; however, there were no clear relationships between ED and macronutrient content for beverage items and beverage intake.

While previous metabolic studies have dissociated the separate effects of macronutrients and ED on energy intake, what we have shown is that in general for both individual foods and diets the simple relationship of high fat equals high ED holds true. Consumption of foods with a high ED may increase the risk of passive overconsumption and weight gain. As a general rule then, decreasing the fat content either of individual foods or the diet as a whole should decrease the ED of the diet. Studies performed in subjects who were fed a diet where the ED was varied while maintaining the macronutrient composition found that subjects ate a similar weight of food regardless of macronutrient composition thus promoting energy overconsumption on diets with a high ED (Stubbs *et al*, 1998a, b). Conversely, several studies have shown that if the amount of fat in the diet was varied while keeping the ED constant, subjects consumed a similar weight of food and hence energy intake remains unchanged (Stubbs *et al*, 1995; Bell *et al*, 1998; Rolls *et al*, 1999a; Bell & Rolls, 2001). These studies, however, involved diets that were highly constructed in terms of macronutrient composition and ED in order to create dissociations, hence do not reflect typical population diets. What these studies do suggest, however, is that the overall ED of the diet, strongly influenced by fat content, is probably a major contributor to total energy intake. As an example, based on the observed relationship between ED and percent energy as fat for the average Australian dietary intake, a five percentage point decrease in percent energy as fat of the diet will lower the ED by 0.55 kJ/g. If the total weight of solid food stayed constant at 1208 g/day for adults (McLennan & Podger, 1998), then this reduction in ED would correspond to 664 kJ less eaten per day.

Two important caveats to the positive relationship between ED and fat content come from a related study to the present one (La Fontaine *et al*, 2004). For foods with ‘low-fat’ claims and for high-fat vegetable-based dishes, there was no relationship between ED and fat content. Foods with ‘low-fat’ claims also had an ED higher than the average population diet ED thus could potentially contribute to excess energy intake. The lack of relationship between ED and percent energy as fat in ‘low-fat’ foods likely reflected their higher carbohydrate and lower water content. High-fat vegetable-based dishes had a low ED due to their water content and even high levels of fat in these dishes had little if any effect on ED.

Many Western countries have reported a decrease in fat consumption by the population in the face of a rising tide of obesity (Willet, 1998). Part explanation for this paradox is the strong evidence supporting low-fat diets as being the optimal choice for the prevention of weight gain and obesity, however, only when accompanied by intentional restriction of energy intake and maintenance of an adequate level of physical activity; two factors that are not being maintained in many Western countries (Astrup *et al*, 2000, 2002).

While many previous studies have focused on the link between ED and foods, beverages can also make a significant contribution to the total energy intake of an individual. In Australia, beverages contribute to 16.3% of the total daily energy intake for all persons (McLennan & Podger, 1998). In the analysis presented in this current study, sugar-based beverages had the lowest ED (1.6 kJ/g), while alcohol-based beverages, containing on average 26% less carbohydrate by weight, had the highest ED (4.6 kJ/g). Surprisingly, beverages classified as 'fat-based' (either dairy- or soy-based products; ED 2.6 kJ/g) had sugar as their main contributor to total energy content. The addition of sucrose to many dairy- or soy-based beverages (such as milkshakes or flavoured 'ready-to-consume' milk drinks) is the major reason for this finding. Moreover, for all beverages analysed, sucrose was the major contributor to energy from carbohydrate suggesting that beverage consumption needs to be taken into account when examining the impact of the dietary intake of sugar on energy balance.

Alcohol-based beverages were found to be the most energy dense of all beverages. However, the alcohol content of such beverages was a poor predicator of ED with no relationship seen between alcohol content and ED, which suggests that even 'low-alcohol' beverages can potentially be significant contributors to the total energy intake of an individual. In Australia, alcohol-based beverages contribute 3.7% to the total daily energy intake of the adult population (McLennan & Podger, 1998). Whether there is an association between alcohol intake and obesity is controversial (Hellerstedt *et al*, 1990; Lands, 1995; Prentice, 1995) although in terms of overall energy contribution, significant consumption of alcohol-based beverages has the propensity to increase total energy intake and hence contribute to obesity. As we have shown, relationships between ED and macronutrient content of beverages are more complex than that of individual foods or diets and thus analyses of beverages should be considered separately from foods when studying factors that can impact on the overall ED of a diet.

Foods with a high water content are invariably those foods with a low ED. There is evidence to suggest that eating foods with a high water content can significantly increase feelings of fullness and reduce subsequent energy intake from a meal (Rolls *et al*, 1999b). Furthermore, ingestion of a high volume of fluid 30 min prior to a meal may further reduce energy intake from the subsequent meal (Rolls *et al*, 1998). As the average ED of beverages is much lower than that of foods, increasing beverage consumption may be a way to help reduce total dietary energy intake. As a caveat to this point, beverages by themselves can be a significant source of energy in the diet and a major contributor to sugar intake, especially if a high volume of soft drinks and fruit juices are consumed.

In Australia, the rate of overweight and obesity is increasing. Between 1983 and 1995, BMI has increased by 1.7 U for men and 2.5 U for women with a corresponding doubling in the incidence of overweight and obesity (Cook *et al*, 2001; Booth *et al*, 2003). These described changes in the rates of overweight and obesity have a cause that is multifactorial and include genetic disposition, physical inactivity, food availability, and many other lifestyle factors. The role that ED plays in this matrix is presently unclear; however, it may prove to be a contributing factor to not only weight gain but also the ability of a person to maintain or lose weight.

This study has several limitations in its design — mostly to do with the methods of data collection. Population food intake data were collected by 24-h recall method that only gives an estimation of an individual's 1-day food intake. As diet may vary on a day-to-day basis, use of a 24-h recall method may introduce a greater degree of 'scatter' when analysis of macronutrients and ED are performed. For analysis of individual food and beverage items, no weighting was used for a probable frequency of consumption which may introduce bias into the analysis as certain foods or food groups may be over- or under-represented. Furthermore, while data are presented for both population food intake and individual foods, no direct comparisons between the two parameters are possible due to the differing nature of the data set.

We have shown that the positive relationship between ED and fat content of individual food items and population diets holds true in a typical Western country such as Australia. Separate from foods, beverages differ significantly in their ED and are inherently high in sugar and likely impact differently on satiety compared to solids, hence ED relationships need to be considered separately for foods and beverages. As high-fat diets have the potential to result in passive overconsumption and are associated with a high BMI, the selection of foods that are low in fat, and by virtue of the observed relationship — low in ED, may be a reliable strategy to help both manage and prevent weight gain. Population measures with an overall aim of reducing the ED of diets may be an effective measure in mediating the growing problem of overweight and obesity.

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