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Food portion sizes: trends and drivers in an obesogenic environment

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Abstract

The prevalence of overweight and obesity in children and adults has increased worldwide. A strong environmental factor contributing to the obesity epidemic is food portion size (PS). This review evaluates the current evidence linking food PS to obesity, examines the effects of PS on energy intake (EI), and discusses the drivers of food PS selection. The leading causes of the rise in PS include globalisation, intensive farming methods, the impact of World War II, due to shortage of staple foods, and the notion of 'waste not, want not'. Large PS of energy-dense foods may stimulate overconsumption, leading to high EI levels. However, the studies have not shown a cause-and-effect relationship, due to confounding factors. Important mechanisms explaining the attractiveness of larger PS leading to higher EI levels are value for money, portion distortion, labels on food packaging, and tableware. Consumers depend on external rather than internal PS cues to guide consumption, irrespective of satiety levels. Further research is recommended on food consumption patterns to inform policymakers and provide information and insights about changes in diet.

Key words: energy density: energy intake: food portion sizes: obesity: trends

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Introduction

Obesity and overweight levels have risen continuously worldwide over the past two decades, with 39% of adults currently considered to be overweight and 13% obese[1]. In England, 27% of men and 29% of women are obese. About two-thirds of adults are overweight or obese, with prevalence higher in men (68%) than women (60%). Notably, obesity is up to 9% more prevalent in deprived areas than in those less deprived[2,3]. Adult obesity is defined as having a body mass index (BMI) of 30 kg/m^2 or above. By 2025, one-fifth of adults are expected to be obese[4].

Biological and physiological factors are the main drivers affecting food intake. However, extrinsic cues such as food portion size (PS) and food visibility are often used to regulate food intake[5]. Hormones that control appetite, such as leptin and ghrelin, are crucial in determining food intake. Their fasting levels are different between normal weight and overweight individuals[6]. Food PS represents an environmental factor contributing to the obesity epidemic[7,8] which has changed the food environment[9], with exposure to large food PS encouraging greater consumption and subsequent excess energy intake[10,11]. Food PS is defined as the amount of food served available for instant consumption in a single eating event[12]. It is well documented that standard PS in foods and drinks has increased in the past two decades[13–16]. This review aims to (a) review the current evidence linking food PS to obesity, (b) review the effects of food PS on energy intake (EI) and (c) discuss the main drivers of food PS selection.

Overview of evidence on current trends in portion size

Portion size

PS guidance has been developed in the UK[17,18], the USA[19,20], the Netherlands[13] and Denmark[21]. The PS for home-cooked meals as specified in a Danish cookbook has increased over the past century[22]. A French study stated that the increase in the PS trend is 25% smaller compared with the USA[23], where a fivefold increase since the 1970s is noted[24], indicating a trend towards larger PS. This has continued worldwide over the last 40 years[25], introducing new larger-sized portions in popular and energy-dense foods, such as pre-packed snacks[26], white-bread products, macaroni[27], cakes, popcorn[28], soft drinks[29] and alcoholic beverages[30].

The evolved emphasis on 'super-sized' portions[30], share packs, king-size packs and duo packs[13] initiates overeating[31]. Consequently, consumers are attracted to the 'value for money' offered[32,33], consuming higher amounts than the national recommendations[34–36], even up to eight times larger[24], and increasing the bite-size mechanism (increased bite-size consumption when the PS is larger)[37,38]. This was first documented

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in young children (3–5 and 8–9 years old)[39,40]. Furthermore, in existing dietary guidance, the terms PS and serving size (the quantity recommended to be consumed on a single eating occasion)[31] have been deemed to be confusing, and consumers feel challenged when deciding on the appropriate amount of food to consume[41]. Accounting for the constant change in PS and evident international differences[42], continuous international monitoring is vital[33], as adults between 18 and 65 years old are mostly affected by these changes[14,34].

In Britain, the leading causes of the rise in PS include globalisation, intensive farming methods, the impact of World War II, due to shortage of staple foods, and the notion of 'waste not, want not'[18]. UK PS guidance has been considered outdated, contributing further to this phenomenon[43,44] and leading to a distorted perception of appropriate PS[45]. This increase has been noticed in restaurants[33,46], fast-food restaurants[47], take-out shops[19], supermarkets[14,24] and in-home recipes[22,48].

The UK Government provides advice on healthy eating and the daily consumption of key food groups as part of a healthy balanced diet as part of the ongoing calorie reduction strategy[49,50]. Nevertheless, guidance on the consumption of the appropriate PS of each food group and key foods within food groups is limited[51], compounding consumers' confusion[52].

Current trends in food portion size from National Survey Data

The UK National Diet and Nutrition Survey (NDNS) has previously presented inconsistent trends in PS over 15 years[17]. Savoury food PS appears to have increased, while that of potatoes/chips, desserts, and some fruits and vegetables has decreased[15]. Examining PS from numerous sources, namely NDNS data, past publications and manufacturers' information between 1987 and 2006, an increase in PS was identified in confectionery products and fast foods, while PS in other foods decreased[15,17]. For example, the PS of McDonald's Big Mac changed from 204 g in 1993 to 216 g in 2006. Similarly, the PS of the McChicken sandwich was 159 g in 1993 in comparison with 170 g in 2006[15,53]. Since the 1986/1987 NDNS, lifestyle changes, such as a broader food culture and less preparation time, have resulted in a wider range of food being available in the UK, alternating the trends[54]. Furthermore, perhaps this increase was driven by changes in the *British Agricultural Policy*, which introduced the *Common Agricultural Policy* in the 1950s, encouraging intensive farming methods and more cost-effective food production[55]. This resulted in an excessive amount of cheap, readily available food[56] that consumers became accustomed to[57]. Additionally, in Ireland, the North-South Ireland Food Consumption Survey between 1997 and 2001 and the National Adult Nutrition Survey between 2008 and 2010 suggested significant increases in the PS of white bread, wholemeal/brown bread, milk, meat and poultry, and significant decreases in potatoes/chips and sliced ham. No significant change over time was identified in yoghurt, cheese, processed potato products, butter/spreads and ham/bacon[58]. In contrast, the USA showed a continuously rising trend in PS for the majority of the food groups[16] regardless of age and sex according to the Continuing Survey of Food Intake by Individuals conducted by the US Department of Agriculture[20]. The latest NDNS data indicate that over 11 years (2008/2009–2018/2019), there was a 7% increase in consuming five-a-day, but only in women aged 19–64 years old. A reduction in mean consumption of red and processed meat across all age groups was noted. For the same timeframe, in sugar and chocolate confectionery, a reduction of 8% and 10%, respectively, was noted among those aged 11–18 years old[59].

To summarise, consumption of numerous food groups has increased over time, emphasising large PS and value for money[32,33]. The increase in PS is due to globalisation[18] and possibly from changes in government policies leading to the production of inexpensive food[56]. However, consumers may be confused as to what constitutes a standard PS. Research is required to identify foods that may be over- or under-consumed and to examine potential impacts on overall dietary adequacy.

Effects of portion size on energy intake

Adults and portion size

Observational studies. Numerous studies have identified that EI increases with exposure to larger PS, showing a potential risk factor for overweight and obesity[60]. The increase in consumption rates due to larger PS is up to 25% during lunch, and up to 45% for snacking[24]. Longitudinal and cross-sectional studies have proposed a positive association between the consumption or occurrence of eating outside the home and increased BMI or weight gain[61–64]. Representation of an appropriate amount to consume is structured by PS encountered in various places, such as supermarkets, restaurants, marketing images or the home[65]. Nevertheless, the wide diversity in the characteristics of the food sector within the data leads to disagreement. Some associations were not identified[66,67], or they were identified only in women[64] or only in men[68,69]. Furthermore, serving the same food amount at various junctures established a notable consistency in the food type and the amount consumed, especially in individuals who learn the PS they need to feel satiety ('previous experience/expectation mechanism'). The choice of PS may be influenced by prior experiences[33]. For instance, the PS chosen and consumed at a later time depends on prior experiences with the degree of fullness produced by a food, in both adults[33] and children[70].

Recent data from the Kantar Market Research Group revealed that during the coronavirus disease 2019 (COVID-19) pandemic eating patterns changed considerably globally, highlighting an increase in sugar, sweeteners, herbs, seasonings, olive oil and alcohol purchases for home consumption, whereas other purchases such as health and beauty products declined[71]. This speculates that the population worldwide, including the UK, was treating themselves to food. A recent scoping review indicated that the lockdown had positive (increased consumption of fresh produce and home cooking) and negative impacts (unhealthy snacking, mental health issues, physical inactivity and weight gain) on dietary practices globally[72]. A study commissioned by the UK Food Standards Agency (FSA) identified the same beneficial changes in eating habits in households an increase in unhealthy snacking[73,74]. The latter was indicated in another UK study[75] and the European Institute of Innovation and Technology[76]. Furthermore, it is indicated

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that the existing food security issues experienced in Brexit[77,78], post-Brexit[78] and the COVID-19 pandemic[73,74,77,79] have changed the consumption patterns, highlighting a change in food trends.

Experimental studies. Various experimental studies have shown a potential long-term association between fast-food or takeaway consumption, and high EI[60,80,81], independent of individuals' satiety levels[82]. This suggests that adults ignore both hunger and satiety signs in the presence of external cues, such as large PS[83,84], especially when eating out with others[80,85]. It is proposed that individuals learn to eat in the absence of hunger as children and continue to adulthood with this eating behaviour[39,86], indicating a major determinant of food consumption[14,87]. Indeed, continuous exposure to more than 6 months of high-energy lunch consumption led to a significant increase in EI and weight gain[88]. A recent scoping review of randomised-controlled trials (RCT) and quasi-experimental studies highlighted a significant effect in lowering food consumption when offered a single smaller package compared with a larger one[89]. A systematic review and meta-analysis of RCT indicated a moderate to large reduction in daily EI when comparing smaller with larger PS[90]. A meta-analysis of RCT and cross-over trials (COT) indicated that the association between PS and food intake is not linear in population groups[10]. Furthermore, a Cochrane review of seventy-two RCT indicated that doubling a PS leads to an increase of approximately 35% in energy consumption, mostly noticed in men and non-overweight individuals[11].

Studies have indicated that individuals determine the food amount consumed according to what they are accustomed to eating. This is related to frequent exposure to large portion consumption (unit size) over time[80,91]. This is called the portion size effect (PSE) or portion size response[92] (more food is offered, more is consumed)[12] and is documented in naturalistic environments, such as offices and restaurants[82,93]. A Cochrane review of RCT identified a consistent PSE on EI in adults consuming more food when offered in larger-size versions[11]. Furthermore, a systematic review and meta-analysis of RCT of PSE indicated that consuming larger PS was related to higher daily EI (295 kcal; 95% CI: 202, 388 kcal)[94]. A study has attempted to identify mechanisms of the PSE on food intake, indicating the importance of the dual-process theory[95]. It has been proposed that the mind has two thinking systems: system 1 (intuition) and system 2 (reasoning). A research dialogue stated that system 1 is heuristic, with a preference for a dominant option that stands out based on appeal. However, when there is no dominant option, consumers may have difficulty making a decision. As a result, system 2 is activated, selecting the alternative according to their goals by comparing the attributes and values[96]. Consumers use the latter to make decisions based on time constraints, processing capacity, desired level of accuracy, and fatigue[96]. An independent relationship of other factors, such as nutritional status[27,84], sex[27] and posterior compensation[29,97] was observed. More research is required to address the reasons that individuals do not comply with the satiety cues in their eating environments[80].

Larger effects on PS consumption have been identified in men[26,86,98] compared with women. Additionally, if larger PS was combined with higher energy density (ED) (the amount of energy in each weight of food), stronger effects were observed on total daily EI[65]. Moreover, the effects of PS can persist for several days as evidenced at 2[26,86], 4[99] and 11 d[97]. The larger PS of high-energy-dense foods has the greatest impact on EI, up to 279 kcal/d, especially in pre-packed foods. COT have suggested that ED directly influences *ad libitum* EI and provides an independent effect on the macronutrient composition of food[100]. Table 1 summarises studies' evolution over time, indicating the relationship between PS and EI, including ED in adults.

To summarise, studies with similar design and methodology indicate a hypothetical association between large PS and obesity[26,27,83,84,86,92,97–99]. However, it is difficult to determine whether an independent risk factor exists, due to confounding factors. Further research is needed due to the controlled environment of the above studies, where social interactions and food-related reminders were non-existent and blinding bias was absent[101,102]. Exploring the exact relationship between high EI, energy-dense foods and PS in real-life settings is needed to draw stronger conclusions[83]. Longer-duration studies are required in real-life environments to establish whether a cause-and-effect relationship exists between PS and daily EI[88,103].

Children and portion size

A recent narrative review demonstrated that parents make food-related decisions for their children based on their own consumption patterns, their own gut feelings and their understanding of their appetites[104]. Due to the routine nature of food provision, parental choices regarding their child's PS may be made automatically or as part of a complex process influenced by several interconnected factors, such as the child's weight status, other family members and the parents' own mealtime experiences as children. Parents might also base their judgements on PS on the amount of physical activity their children engage in; larger portions are served to youngsters who are thought to be more active[104]. Furthermore, although research suggests that customised nutritional advising systems are superior to general, one-size-fits-all approaches in improving health indices, these findings have been observed in adult populations[105]. Below are reviewed the observational and experimental studies.

Observational studies. Studies have indicated that large PS is positively associated with obesity in young children aged 1–5 years old[106,107]. In the UK between 1997 and 2005, adolescents consumed an increased amount of PS and EI from snacks (drinks, crisps, savoury snacks) and breakfast cereals[108]. Moreover, PS is positively associated with BMI percentiles in boys from 6 to 11 years old and children from 12 to 19 years old[109]. For pre-schoolers, 4–6 years old, EI is regulated by natural hunger-driven eating behaviours. However, environmental cues, such as large PS, can disturb this self-regulation[110]. In infants (11 months and younger) the relationship between ED and average PS is negative, proposing that as ED decreases, food intake downregulates correspondingly. In contrast, no

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Table 1. Shows studies researching the relationship between portion sizes (PS) and energy intake (EI) and/or energy density (ED) in adults

Author, year	Study design/duration	Study size	Food type	Outcome
Bell *et al.*, 1998[175]	Within-subjects, repeated-measures design, with two different PS. 3 d sessions.	Adult women aged 20–45 years old ($n = 18$).	Pasta salad: low ED (0·33 kcal), medium ED (0·67 kcal), high ED (1·33 kcal/g). PS: 150 g, 300 g.	Consuming low ED salads reduced meal EI (7% in small PS and 12% in large PS). Consuming the high ED salads increased EI (8% in small PS and 17% in large PS).
Wansink and Park, 2001[28]	Random 2 groups × 2 between-subjects design with two different PS. 2 movie sessions.	Moviegoers aged 11–89 years old ($n = 151$; 56% men, 44% women).	Popcorn PS: medium container (120 g) and large container (240 g).	Increased popcorn intake (53%) was significant when served a larger container.
Rolls *et al.*, 2002[27]	Within-subject cross-over design, with four different PS. Lunch – 1 d/week × 4 weeks.	Adults aged 21–40 years old ($n = 51$; 26 men, 25 women).	Macaroni and cheese (1·63 kcal/g). PS: 500 g, 625 g, 750 g, 1000 g.	Increased EI when served a larger PS respectively: 12% (64 kcal), 19% (105 kcal), 30% (161 kcal).
Diliberti *et al.*, 2004[82]	Between-subjects, parallel-group intervention, with two different PS. 10 d over 5 months.	University campus, cafeteria visitors ($n = 180$; 78 men, 93 women).	Baked pasta with cheese sauce: 27% carbohydrate; 54% fat; 19% protein; ED: 1·7 kcal/g. Standard PS: 248 g (422 kcal). Large PS: 378 g (633 kcal).	Increased EI when served a larger PS: 43% (172 kcal). Overall extra EI of entire meal: 25% (159 kcal).
Kral *et al.*, 2004[83]	Within-subject cross-over design, with three different PS and three different ED. 1 d/week × 6 weeks.	Women aged 20–45 ($n = 39$).	Italian pasta bake (25% fat, 60% carbohydrate, 15% protein; ED 1·25–1·75 kcal/g). PS: 500 g, 700 g, 900 g.	Statistically increased food intake (20%) when served a larger PS compared with the smallest PS. Combined effect with ED: 56% more EI when served the largest higher ED portion compared with the smallest lower ED portion (225 kcal).
Rolls *et al.*, 2004[26]	Within-subject cross-over design with three different ED salads and two PS. Lunch – 1 d/week × 7 weeks.	Women adults aged 19–45 years old ($n = 42$).	Salad PS: 150 g, 300 g; with ED: 0·33 kcal, 0·67 kcal, 1·33 kcal.	Consumption of low ED salads reduced meal EI (by 7% – small PS and 12% – large PS). Consumption of high ED salads increased EI (by 8% – small PS, and 17% – large PS). Meal intake was decreased when a large PS of the lower ED salad was consumed.
Rolls *et al.*, 2004[98]	Within-subject cross-over design, with five different PS. 1 d/week × 5 weeks.	Adults aged 20–45 years old ($n = 60$; 26 men, 34 women).	Potato chips (5·4 kcal/g). PS: 28 g, 42 g, 85 g, 128 g, 170 g.	Snack significantly increased EI when served in a larger PS (143 kcal). Largest versus smallest PS: women – 184 kcal more, and men – 311 kcal more.
Rolls *et al.*, 2004[92]	Within-subject cross-over design, with four different PS. Lunch – 1 d/week × 4 weeks.	Adults aged 20–45 years old ($n = 75$; 38 men, 37 women).	Deli-style sandwich, (2·4 kcal/g). PS: 6 in, 8 in, 10 in, 12 in.	EI increased significantly with a larger PS. Largest versus smallest PS: women – 159 kcal (31%) more, and men – 355 kcal (56%) more.
Wansink and Kim, 2005[7]	Random 2 × 2 between-subjects design, with two different PS. 1 movie session.	Adult moviegoers ($n = 158$; 57·6% men, 42·4% women).	Fresh and stale popcorn. PS: medium container (120 g) and large container (240 g).	Increased food intake when served a larger PS, for fresh (45·3%) and stale (33·6%) popcorn.

Table 1. (*Continued*)

Author, year	Study design/duration	Study size	Food type	Outcome
Wansink *et al.*, 2005[84]	Randomised parallel-group design, with two different PS. One eating time session.	Adults aged 18–46 years old (*n* = 54; 72% men, 28% women).	Self-refilling versus normal bowls of soup.	Increased EI (73%, 113 kcal) when served a larger PS without an accurate visual cue.
Flood *et al.*, 2006[29]	Cross-over design with repeated measures, with two different PS. Lunch – 1 d/week for 6 weeks.	Adults aged 18–45 years old (*n* = 40; 20 men, 20 women).	Beverages served varied in type (water, Cola, diet Cola, water). PS: 360 g, 540 g.	Increasing beverage PS significantly increased the weight of beverage consumed, regardless of the beverage type. EI increased by 10% for women and 26% for men when there was a 50% increase in the PS.
Rolls *et al.*, 2006[86]	Randomised cross-over design, with three different PS. ×2 consecutive days × 3 weeks.	Adult undergraduate students (*n* = 32).	Same two daily menus/week with a variation of PS of foods/beverages in a given week: 100%, 150%, 200%.	Increasing PS by 50%: EI increased by 16% (women: 335 kcal/d; men: 504 kcal/d). Increasing PS by 100%: EI increased by 26% (women: 530 kcal/d; men: 812 kcal/d).
Fisher *et al.*, 2007[114]	Within-subject experimental design, with two different PS. 1 d.	African American women and children aged 5 years old (*n* = 59; 28, 31 Hispanic, 24 boys, 35 girls).	ED: crackers (4·62 kcal/g), chicken (1·73–2·42 kcal/g), rice (0·8 kcal/g), macaroni and cheese (1·51 kcal/g), cereal (4·0kcal/g), apple juice (0·47 kcal/g) in reference and larger PS.	Statistically significant difference between doubling the PS of entrées and snacks in 1 d for both women and children. Increased EI from foods by 21% (180 kcal) in women. Total EI in the large PS was 6% higher in women.
Jeffery *et al.*, 2007[87]	Within-subjects, randomized cross-over design with 2 different PS lunch boxes. 5 d/week × 4 consecutive weeks.	Adults employed at a county medical centre, aged 18–40 years old (*n* = 19).	Lunch boxes: main course (sandwich or salad), side dish (fruit or vegetable salad, chips or bread), dessert (bar or cookie), and drinks (water, Sprite or Coke). Small PS: 750 kcal. Large PS: 1500 kcal.	Lunch EI: 332 kcal/d higher in large PS lunch box than in small PS lunch box. 24 h EI: 278 kcal/d higher in large PS lunch box than in small PS lunch box.
Raynor and Wing, 2007[176]	Random 2 groups × 2 between-subjects design with two different PS and units. 3 d period.	Adults aged 18–30 years old (*n* = 28; 12 men, 16 women).	Potato chips, cheese crackers, cookies, candy. Small versus large PS; small versus large unit.	Increased EI when served a larger PS; 81% (2246 kcal). No effect on package unit size.
Rolls *et al.*, 2007[169]	Cross-over design with repeated measures within-subjects of three different plate sizes. Study 1: 1/week × 3 weeks. Studies 2, 3: 1/week × 2 weeks.	Adults aged 20–45 years old (*n* = 119, 60 men, 59 women). Study 1: *n* = 44; Study 2: *n* = 30; Study 3: *n* = 44.	Same foods/amounts served at each meal with different plate sizes: 17 cm, 22 cm, 26 cm. Studies 1, 2: macaroni and cheese; ED: 1·60 kcal/g. Study 3: a selection of 5 different foods; ED: 1·60–1·71 kcal/g.	Plate size has no significant effect on EI. EI was statistically different using the smallest and largest plates were 21 g, 4 g and 11 g, respectively (~34 kcal).
Rolls *et al.*, 2007[97]	Within-subject cross-over design, with two different PS. 11 consecutive days.	Adults aged 20–40 years old (*n* = 23; 13 men, 10 women).	Full daily menu. PS: 100%, 150%.	EI increased with larger PS (423 kcal/d), for all food categories except fruit and vegetable.
Kelly *et al.*, 2009[99]	Randomised within-subject cross-over design with two different PS. Two separate 4 d periods.	Adults aged 18–65 years old (*n* = 43; 21 men, 22 women).	Variety options for breakfast, lunch and dinner for both PS: standard and large.	Mean EI over 4 d was significantly higher on the large PS (men increased EI by 17% and women by 10%). Larger PS may be a significant factor contributing to excess EI and adiposity.

Table 1. (*Continued*)

Author, year	Study design/duration	Study size	Food type	Outcome
Stroebele *et al.*, 2009[177]	Randomised two-period cross-over design with two different unit sizes.	Adults aged 18–65 years old ($n=59$; 18 men, 41 women).	Unit size: standard size packages (187–368·5 g) versus 100 kcal packages (19·2–26 g).	Week 1: total grams of snacks differed significantly between the two groups; 302·5 g of 100 kcal snack-packs versus 675·5 g of standard size packages.
	Snacks for 1 week.			Week 2: not a statistical difference (71·4 g) due to the lower consumption of snacks from standard size packages.
Burger *et al.*, 2011[37]	2 × 2 repeated measures, within-subject design.	Adults aged 18–60 years old ($n=30$; 15 men, 15 women).	Condition 1: pasta dish in small portion (410 g)/visible.	Entrée EI increased by 26% (220 kcal) and mean bite size increased by 2·4 g/bite in large PS.
	×4 occasions separated by >4 d.		Condition 2: past dish in small portion (410 g)/blindfold.	The blindfolded condition resulted in a 12% (122 kcal) decrease in entrée intake; but no portion by visual cue interaction was found.
			Condition 3: pasta dish in large portion (820 g)/visible.	
			Condition 4: pasta dish in large portion (820 g)/blindfold.	
Hermans *et al.*, 2011[85]	3 × 2 between-subjects design with three different PS.	Adult women x̄ age 20·85 ($n=85$).	Macaroni mash in different PS:	Participants consumed more food when offered a larger PS. More food was consumed when the eating companionate consumed more.
	~1 h session.		Standard: 500 g Small: 250 g Large: 750 g	
Marchiori *et al.*, 2011[178]	Between-subjects design with two different PS.	Adult undergraduate students ($n=33$; 4 men, 29 women).	Condition 1: 10 normal-sized red candies and 10 normal-sized cherry candies.	Reducing the size of candies resulted in a decrease in EI (60 kcal) compared with the other group.
	1 d.		Condition 2: candies cut in half; 20 half-sized red ribbon candies (2 g each) and 20 half-sized cherry; shaped candies (2·5 g each).	
Marchior *et al.*, 2012[152]	Between-subjects design with three different conditions.	Adult undergraduate students ($n=88$; 26 men, 62 women).	Condition 1: M&Ms medium PS (200 g) in small container size.	Participants in condition 1 consumed significantly fewer M&Ms than participants in conditions 2 and 3.
	22 min TV show.		Condition 2: M&Ms medium PS (200 g) in large container size.	Intake of larger container increased by 129% (199 kcal).
			Condition 3: M&Ms large PS (600 g) in large container size.	
French *et al.*, 2014[88]	Randomised controlled trial with three different conditions.	Adults aged 18–60 years old ($n=233$; 32·6% men, 67·4% women).	Variations existed in food types in each energy condition.	Lunch EI was significantly higher in the 800 and 1600 kcal groups compared with the 400 kcal group.
	Weekdays lunch box × 6 months.		Energy sizes: 400 kcal, 800 kcal, 1600 kcal.	Total EI was significantly higher for the 1600 kcal group compared with the 400 and 800 kcal groups.

Table 1. (*Continued*)

Author, year	Study design/duration	Study size	Food type	Outcome
Lewis *et al.*, 2015[141]	Cross-over design with three different PS.	Adults aged 18–60 years old ($n=33$; 15 men, 18 women).	*Ad libitum* lunch (pasta, minced beef, tomato sauce, mixed vegetables, grated cheese): 8275 kJ men; 6350 kJ women.	EI at lunch did not vary:
	1 d.		Control group: 3310 kJ men; 2540 kJ women.	Control group: 2930 kJ.
			20% reduction group: 2650 kJ men; 2030 kJ women.	20% reduction group: 2853 kJ.
			40% reduction group: 1990 kJ men; 1520 kJ women.	40% reduction group: 2911 kJ.
			Meals EI: 35% fat, 18% protein and 47% carbohydrates.	
Haynes *et al.*, 2020[160]	Randomised cross-over design with three conditions.	Adults aged 18–60 years old ($n=30$; 15 men, 15 women).	Manipulated main meal component of lunch/dinner in conditions: smaller-than-normal (339 kcal), small-normal (543 kcal), and large-normal (747 kcal).	Daily EI was significantly lower in the small-normal condition (95 kcal/d).
	×3 5-d periods.			Daily EI was significantly lower in the smaller-than-normal than the small-normal condition (210 kcal/d).
Haynes *et al.*, 2020[179]	Two cross-over experiments, with three different PS.	Adults (study 1: $n=45$; 22 men, 23 women; study 2: $n=37$; 18 men, 19 women).	Study 1: pasta with tomato sauce; large-normal PS (336 g; 1284 kJ), small-normal PS (252 g; 962 kJ) and smaller-than-normal PS (168 g; 644 kJ).	Study 1: small but significant increase in additional intake when served the smaller-than-normal compared with the small-normal PS ($\bar{x}$ difference 161 kJ).
	Lunch – 1 session/each condition.		Study 2: chicken curry with rice; large-normal PS (423 g; 2117 kJ), small-normal PS (325 g; 1628 kJ), and smaller-than-normal PS (228 g; 1138 kJ).	Study 2: small but significant increase in additional intake when served the smaller-than-normal compared with the small-normal PS ($\bar{x}$ difference 149 kJ).
				Smaller PS was associated with a significant reduction in total meal intake.
Gough *et al.*, 2021[102]	Mixed design with a within-subjects independent variable of the environment (standard lab, real-life), and a between-subjects independent variable of two different PS, for both studies.	Study 1: adults aged 21–71 years old ($n=60$, 16 men, 44 women).	For both studies: Butterkist cinema-style sweet popcorn (5·26 kcal/g) in a clear bag.	PS effect on food intake did not differ between the standard laboratory and the semi-naturalistic laboratory ($d=0{\cdot}50$ versus $d=0{\cdot}49$).
	×2 weekdays sessions; ~40 min.	Study 2: adults aged 19–63 years old ($n=59$, 20 men, 39 women).	PS: 100 g (small) or 200 g (large) serving of popcorn.	

PS, portion sizes; EI, energy intake; ED, energy density.

association has been noted in toddlers (1–2 years old)[111]. Evidence from a systematic review in the USA supports the positive relationship between ED and weight gain throughout life[112]. Overall, PS is consistently positively associated with both EI and children's weight[100]; nevertheless, these data cannot determine causality[31].

Experimental studies. Most experimental studies have taken place in the USA and have established that when children aged 3–6 years old doubled the PS of their main meal it resulted in an increase of EI by 40%[39,113–115], where the main food given was macaroni and cheese[39,113,115] or a selection of foods, including macaroni and cheese[91]. Vegetables, mainly carrots, were offered alongside the food[30,113–115]. The average PS consumed by 2-year-olds appears to have remained stable over the last 20 years, while PS increased[80]. This supports the hypothesis that 3-year-old children self-regulate their intake according to hunger and satiety rather than food cues[113,116]. As children grow, internal cues, such as satiation, are less effective on food intake, while external factors are more influential, such as watching TV[80,117]. Nevertheless, studies in a controlled environment have validated the significant positive effect of larger PS on EI in 2-year-old children[40,114,115]. It is not known what the results would be in a free-living environment.

Few short-term studies have examined the impact of a reduction in children's PS with a positive effect in reducing the EI in age-appropriate PS[118,119]. No change in EI was noted when the PS of an entrée was decreased by 25%[120]. While studies are limited, they provide evidence that children from an early age are vulnerable to PS cues. Children increase the PS by eating more, but the evidence is weak to determine if they compensate for this at following eating points[120], such as in adults[99,100]. No available data exist to investigate the long-term effects of PS in children[31]. A study in a controlled environment indicated that computerised manual PS selection can be observed in children between 5 and 11 years old and the correspondence between manual portion selection and actual intake improves with age. This highlights that the relationship between children's cognitive development and PS may help to develop age-appropriate PS[121].

COT have indicated that reducing the ED of an entrée reduces children's total EI[120,122,123]. However, manipulation of the ED of a single snack did not significantly affect children's EI at a single eating juncture[124]. Additional research revealed that the EI effect could be continued when the ED of multiple meals were manipulated over 2 d[120]. Also, reduction of ED has a positive effect on adiposity in the longer term, particularly when individuals, both children, and adults, are receiving positively focused messages about weight control[125]. Table 2 summarises studies' evolution over time, indicating the relationship between PS and EI, including ED in children.

A great deal of evidence from COT positively associates ED, adiposity and PS in children[120,122–124]. Studies strongly support that 5-year-old children respond to increasing PS[113–115]. While a direct causal link between obesity and PS has yet to be determined, consumption of large PS of ED foods promotes obesity-eating behaviours in children[31,100]. More research is required on influencing PS education and downsizing strategies for parents/carers, thus helping children to consume age-appropriate PS[126,127]. This could identify a possible EI reduction strategy that has still not been demonstrated[128]. Additional strategies are required to help children to recognise and respond appropriately to internal signals and resist environmental influences on PS[126].

Drivers of portion size selection

Portion distortion

Consumers' inability to estimate PS and permanent exposure to larger versions contributes to a positive association of perceiving large PS (visual norm) as appropriate amounts consumed on a single eating occasion[21]. This is called 'portion distortion'[28] and refers as well to consumers who do not realise that the PS mostly exceeds the serving size[34]. Figure 1 helps to illustrate this. This is mostly noted in young individuals where a possible contribution to increasing both EI and waistlines was identified[33].

Labels on food packaging. Serving size guidance is voluntarily included on food packaging across the European Union (EU)[129], and is mandatory in the USA[130]; however, consumers prefer household measure guidance[131], such as a portion control cup[5], rather than referring to food labels for managing PS[106]. Household measures result in positive behavioural changes, particularly in staple foods such as cereals, rice and pasta[5]. Consumers refer mostly to quality, quantity, brand, price and sell-by date, and less to ethical and sustainable food labels[132], therefore preferring visual impressions of packages and PS[133]. This leads to 'awareness and estimation bias'[33] as they fail to identify and understand the quantity information or representation of food[134] in the packages, particularly if it is obtainable in non-metric units[135]. A study that looked at the differences between suggested serving sizes in energy-dense foods indicated a lack of clarity in serving size guidance' emphasises. This clearly indicates the need for effective and meaningful guidance on pre-packed foods[44]. Contrarily, consumers with medical issues such as food allergies have reported problems with confusing and contradicting information on the food labels[136,137], readability of the label[136], lack of harmonisation between the different countries, and the position of the labels in the food package[138,139]. A literature review conducted by FSA and Food Standards Australia New Zealand highlighted the same issues[140]. Men experience more difficulties in estimating appropriate PS[141]. However, other studies show that perceived healthiness of the food[142], the ED[143] and the BMI[144] may also contribute to shaping appropriate PS perceptions.

Different food labelling laws between countries add to consumers' confusion. Clear information is provided in the consistent EU approach (EU Regulation No. 1169/2011) and retained regulations in the UK for the food labels on the pre-packed products[145]; however, there is no harmonised approach for front-of-pack (FoP) labelling[146]. A decade ago, the UK Government announced via a press release new consistency guidelines based partially on previous research[115] stating that different FoP labels could hinder consumer understanding and discourage use[147]. Although nutrition labels on pre-packaged

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Table 2. Shows studies researching the relationship between portion sizes (PS) and energy intake (EI) and/or energy density (ED) in children

Author, year	Study design/duration	Study size	Food type	Outcome
Rolls *et al.*, 2000[113]	Within-subject cross-over design, with three different PS.	Children aged 3–5 years old ($n = 32$; 14 boys, 18 girls).	Macaroni and cheese (250 g: 29 g carbohydrate, 16 g fat, 13 g protein). ED: 1·4 kcal/g.	Children 5 years old: consumed more food when served large PS than the small PS.
	1 meal/week × 3 weeks.		PS: small, medium, large.	Children 3 years old: PS did not significantly affect food intake.
			3 years old PS: 150 g, 263 g, 376 g. 5 years old PS: 225 g, 338 g, 450 g.	EI higher in children 5 years old (39%).
Wansink and Park, 2001[28]	Random 2 groups × 2 between-subjects design with two different PS. 2 movie sessions.	Moviegoers aged 11–89 years old ($n = 151$; 56% men, 44% women).	Popcorn PS: medium container (120 g) and large container (240 g).	Increased popcorn intake (53%) was significant when served a larger container.
Fisher *et al.*, 2003[39]	Within-subject cross-over design, with two different PS.	Children aged 3–5 years old ($n = 35$; 17 boys, 18 girls).	Main entrée macaroni and cheese; ED 3·7 kcal/g.	By doubling the age-appropriate entrée portion, EI at lunch was increased by 25% (<4 years old) and 15% (≥4 years old), respectively.
	1 meal/week × 4 weeks.		Small PS: 125 g, <4 years old; 75 g, ≥4 years old.	When serving themselves, children consumed 25% less entrée than when served a large PS.
			Large PS: 250 g, <4 years old; 350 g, ≥4 years old.	
Fisher, 2007[40]	Between-subjects design with a within-subject component with three different PS.	Children aged 2–3; 5–6 and 8–9 years old ($n = 75$; 44 boys, 31 girls).	Macaroni and cheese entrée and choc cookie PS:	Age effect in the large PS was not significant.
	1 meal/week × 3 weeks.		Children 2–3 years old: 200 g, 2 cookies; 22 g, total: 811 kcal.	Entrée consumption in large PS was 29% greater and meal EI was 13% greater.
			Children 5–6 years old: 250 g, 3 cookies; 33 g, total: 933 kcal. Children 8–9 years old: 450 g, 3 cookies; 33 g, total: 1219 kcal.	
Fisher *et al.*, 2007[114]	Within-subject experimental design, with two different PS. 1 d.	Children aged 5 years old ($n = 59$; 28 African American women, 31 Hispanic, 24 boys, 35 girls).	ED: crackers (4·62 kcal/g), chicken (1·73–2·42 kcal/g), rice (0·8 kcal/g), macaroni and cheese (1·51 kcal/g), cereal (4·0 kcal/g), apple juice (0·47 kcal/g) in reference and larger PS.	Statistically significant difference between doubling the PS of entrées/snacks in 1 d for both women and children. Increased EI from foods by 23% (180 kcal) in children. Total EI in the large PS was 12% higher in children.
Fisher *et al.*, 2007[115]	2 × 2 within-subject factorial design, with two different PS.	Children aged 5–6 years old ($n = 53$; 25 boys, 28 girls).	Macaroni and cheese entrée PS: 250 g or 500 g.	The larger, more ED entrée provided 76% more energy to children, and the meal provided 34% more energy overall.
	×1 d/week × 4 weeks.		ED: 1·3 kcal/g or 1·8 kcal/g.	
Leahy *et al.*, 2008[120]	Within-subject cross-over design, with two different PS. 1 meal/week × 4 weeks.	Children aged 3–5 years old ($n = 61$; 30 boys, 31 girls).	Pasta entrée with cheese and tomato-based vegetable sauce PS: 300 g (ED: 1·2 kcal/g) or 400 g (ED: 1·6 kcal/g).	Decreasing ED of the entrée by 25% significantly reduced EI by 25% (63 kcal) and EI at lunch by 17% (60·7 kcal). A 25% reduction in the entrée PS did not significantly affect total food intake or EI at lunch.
Leahy *et al.*, 2008[122]	Within-subject cross-over design, with two different ED.	Children aged 3–5 years old ($n = 26$; 10 boys, 16 girls).	Manipulated meals: 1·32 kcal/g in the lower ED condition, 1·77 kcal/g in the higher ED condition.	In the lower ED condition, energy consumption decreased significantly by 389 kcal (14%).
	2 d/week × 2 weeks.		Manipulated beverages: 0·42 kcal/g in the lower ED, 0·60 kcal/g in the higher ED condition. Non-manipulated meals 40% of EI; ED: 1·41 kcal/g. Non-manipulated beverages: 0·50 kcal/g.	

Table 2. (*Continued*)

Author, year	Study design/duration	Study size	Food type	Outcome
Leahy *et al.*, 2008[123]	Within-subject cross-over design, with two different ED. 1 meal/week × 6 weeks	Children aged 2–5 years old (*n* = 77; 37 boys, 40 girls).	Macaroni and cheese entrée: higher ED, 2 kcal/g, lower ED –30%. *Ad libitum* consumption: broccoli, applesauce and milk.	Decreasing ED of the entrée by 30% significantly reduced EI by 25% (72 kcal) and total lunch energy intake by 18% (71·8 kcal). Significantly higher consumption of the lower-ED entrée.
Spill *et al.*, 2010[180]	Within-subject cross-over design, with three different PS. ×1 lunch/week × 4 weeks.	Children aged 3–5 years old (*n* = 51, 22 boys, 29 girls).	Raw carrots PS: 30 g, 60 g, 90 g.	Meals' total vegetable consumption statistically increased as the carrot's PS increased. Doubling the PS of the first course increased carrot consumption by 47% (12 g). Tripling carrots PS did not lead to an extra increase in intake.
Looney and Raynor, 2011[124]	2 × 2 within-subject factorial design, with two different PS. 1 snack/week × 4 weeks.	Children aged 2–5 years old (*n* = 17; 7 boys, 10 girls).	Snack offered with unsweetened applesauce (lower ED food, 0·43 kcal/g) and chocolate pudding, made with 2% milk (higher ED food, 1·19 kcal/g). Small PS: 150 g (lower ED; 64·5 kcal; higher ED; 178·5 kcal). Large PS: 300 g (lower ED; 129 kcal; higher ED; 357 kcal).	No significant main effect of ED on snack intake. Increased EI when snacks are offered in larger PS, regardless of ED.
Savage *et al.*, 2012[119]	Within-subject cross-over design, with six different PS. 1 meal/week × 6 weeks.	Children aged 3–6 years old (*n* = 17; 7 boys, 10 girls).	Macaroni and cheese entrée PS: 100 g (ED: 1·02 kcal), 160 g (ED: 1·15 kcal), 220 g (ED: 1·16 kcal). 280 g (ED:1·19 kcal), 340 g (ED: 1·30 kcal), 400 g (ED: 1·31 kcal).	Increasing PS, statistically increased entrée intake (61%) from the smallest ED to the highest one. Decreased intake of other foods served together, including fruits and vegetables. Children consumed more ED lunch as PS increased.
Smith *et al.*, 2013[95]	Within-subject cross-over design, with various PS. 1 meal × 3 consecutive days.	Chinese children aged 3–6 years old (*n* = 171; 93 boys, 78 girls).	Children 4 years old: 105 g (small PS –30%) versus 150 g (reference) versus 195 g (large PS +30%) of rice (50%)/vegetable (25%)/protein (25%) mix. Children 6 years old: 182 g (small PS –30%) versus 261 g (reference) versus 389 g (large PS +30%) of rice (50%)/vegetable (25%)/protein (25%) mix.	Significantly less food consumption when served in small PS. Large PS: 6-year-old children increased food intake; 4-year-old children decreased food intake in comparison with the reference portion. PS affects food intake in children 4 to 6 years old. As PS increases, older children eat more food than younger children.
Smethers *et al.*, 2019[181]	Within-subject cross-over design with two different PS. 2 periods.	Children aged 3–5 years old (*n* = 46; 30 boys, 16 girls).	Different daily menus were served. PS: normal (100%) and large (150%). Menus: EI in the 100% portion condition– 1627 kcal/d; for the 150% condition – 2450 kcal/d.	Increasing the PS by 50%; increased statistically consumption by 143 g/d (16%) and EI increased by 167 kcal/d (18%).

PS, portion sizes; EI, energy intake; ED, energy density.

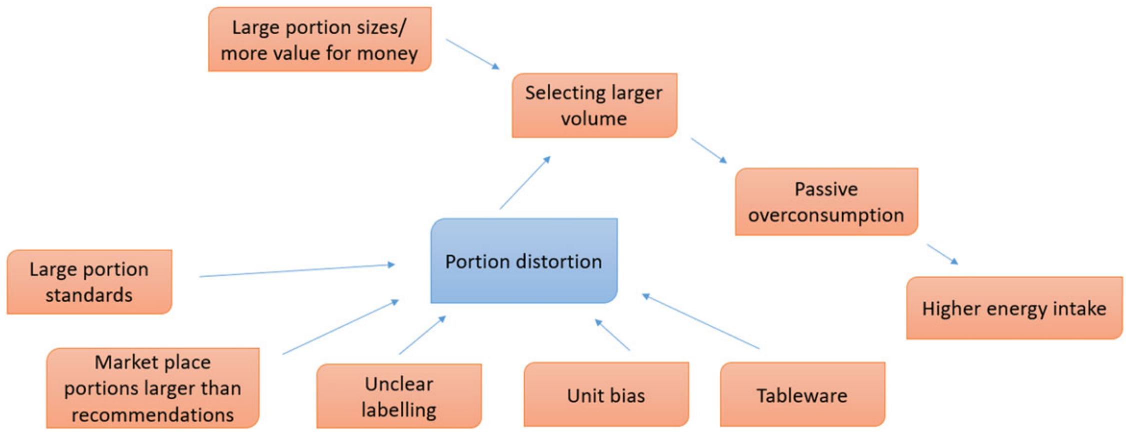

Fig. 1. The underlying factors causing portion distortion.
Steenhuis IH and Vermeer WM (2009) Portion size: review and framework for interventions. *Int J Behav Nutr Phys Act*, 6, 1–10 [adapted]. *Copyright © 2009, Steenhuis and Vermeer; licensee BioMed Central Ltd.*

food products are cost-effective at the population level, governments need to maximise their potential, by identifying new layouts and different types of information content to ensure that nutrition information is available and comprehensible for consumers' benefit(148,149). The food industry is pressured to reduce the PS and calories as part of the ongoing strategy to reduce childhood obesity(50). However, this leads to further issues, as consumers want value for money(150). Furthermore, a scoping review, including experimental and observational studies, indicated that food package labelling for serving size is unclear(151). Specifically, consumers believe that the labelled serving size set by the manufacturer is the government recommendation(151). Occasionally, the serving sizes are considered to be unrealistically small; resulting in consumers' overestimating not only to the number of servings in one package but also the caloric content(19,34,152). Most consumers interpret the package size as a single serving size when it contains multiple servings(151). Likewise, using terms such as small, medium and large leads to confusion in interpretation and differences(153). Regrettably, visual perception is not reliable in indicating the package size or the PS because of biases, which are highlighted in Table 3(133). Additionally, more emphasis towards dietary guidelines as well as the nutritional composition of the products sold may be warranted(154). For instance, consumers widely know the number of PS of fruits and vegetables they need to consume every day. However, it remains unclear if they consider the consumption frequency and quantity of ultra-processed foods, such as confectionery and biscuits, when the EatWell Guide does not quantify how many portions of each food group should be consumed, unlike other food-based dietary guidelines(154,155).

Unit bias. The unit bias model suggests that one serving is appropriate to consume at once, irrespective of the size(93). However, it is argued that segmentation bias is more applicable to use as individuals consume less food when it is divided into smaller units(156). A study supports that the anchoring effect works as a reference point for PS, as consumers eat a specific amount of the food. This means that PS acts as an influential anchor for determining the amount to consume, and succeeding adjustment processes do not negate the effect of that anchor(9).

The package size or the unit creates a 'consumption norm', operating for most individuals(10), which arguably is not appropriate according to the nation's food recommendations(93,157). The 'clean your plate' notion is encouraged, especially when the food is free; yet, in public settings, it promotes the bias to finish it, as the appropriateness mechanism is activated(116). The PS sets a norm and dictates the amount consumed; therefore, PS and not hunger leads to food consumption(33,93). This is associated with human evolution, involving psychological and physiological mechanisms protecting against low adiposity(158,159). Consequently, consumers could be sensitive to detecting food inadequacy in terms of smaller than normal PS(160).

Tableware

The shape or size of tableware may influence the food selection and consumption(11,161) of a PS served in restaurants and in-home(82,162). The visual cue mechanism directs the PS intake, such as the plate emptiness degree, possibly activating meal termination(37). The rim width of the plate could influence the PS selection(163). Thus, after choosing a large PS, passive overconsumption occurs (mindless eating), since individuals unintentionally prefer palatable and high-energy-dense foods(100,164). Similar PS appear larger when served on a small plate (Delboeuf illusion), therefore controlling individuals' judgements differently(165,166). If using larger bowls or plates, individuals tend to serve themselves more food, such as vegetables(167,168), so the EI is not reduced(169,170). However, a meta-analysis of COT presented no dependable effect of tableware on food intake(171).

COT propose that some drivers of PS selection remain unclear. However, their crucial role in body weight regulation remains evident. Food labels are difficult for consumers to interpret, leading to confusion. Well-conducted studies are required to provide solutions to consumers concerning appropriate PS(172–174).

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Table 3. Shows the summary of package and portion size (PS) estimation biases

Bias	Findings	References
Affective	Size estimations are more sensitive to changes in package and PS when consumers experience an emotional conflict towards food (e.g. desire to eat appetising food conflicts with perceptions that it is unhealthy).	Balcetis and Dunning (2010)[182]. van Koningsbruggen *et al.* (2011)[183]. Cornil *et al.* (2014)[184].
Dimensionality	Size estimations are less sensitive when packages or portions change in three spatial dimensions than when they change in one dimension. This occurs as people, rather than using a multiplicative model to compound changes in multiple dimensions, use an additive model.	Chandon and Ordabayeva (2009)[185]. Ordabayeva and Chandon (2013)[186].
Labelling	Estimation of portion size and package is lower when labels inform the consumers about the small size of the food, healthy ingredients, the product description on top left or left, versus bottom right, right or bottom of the front of pack package.	Wansink and Chandon (2006)[187].
		Chandon and Wansink (2007)[188,189]. Deng and Kahn (2009)[190]. Chernev and Gal (2010)[191]. Aydınoglu and Krishna (2011)[192].
Underestimation	Due to an inelastic power function of actual size, PS and package sizes are underestimated. This is more noticeable for large sizes than for small ones.	Krider *et al.* (2001)[193]. Chandon and Wansink (2006, 2007)[188,194]. Cornil and Chandon (2015)[195,196].

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Conclusion

PS has increased significantly over recent decades worldwide, potentially associated with a significant rise in the prevalence of obesity. The available evidence demonstrates that the large PS of energy-dense foods may stimulate overconsumption, leading to high EI levels. However, a cause-and-effect relationship has yet to be shown, due to confounding factors. Nonetheless, studies have mostly taken place in lab environments for a short period in the USA. Although food labels assist consumers, frequently their interpretation is difficult. Studies show that consumers rely on external rather than internal PS cues to guide consumption, irrespective of satiety. Further research on food consumption patterns as well as consumer insights would help to inform the inclusion of clear and consistent information on PS into national dietary guidelines.

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None.

Authorship

This review was conducted as part of the dissertation module in the MSc Food Regulatory Affairs by Maria Papagiannaki who helped formulate the research question, conducted the literature search, interpreted the findings and wrote the review. Dr Maeve Kerr formulated the research question and provided guidance on the review. Dr Maeve Kerr has a track record of publications in the area of food portion size and obesity, having published nine articles in this area of research (four review articles; five original papers).

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