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A review of evidence supporting current strategies, challenges, and opportunities in regards to portion-size reduction

Eva Almiron-Roig, Ciaran G. Forde, Gareth J. Hollands, M. Ángeles Vargas, and Jeffrey M. Brunstrom

Affiliation: *E. Almiron-Roig and M. Ángeles Vargas* are with the Centre for Nutrition Research, University of Navarra, Spain. *E. Almiron-Roig* is with the Navarra Institute for Health Research (IdiSNa), Pamplona, Spain. *C.G. Forde* is with the Clinical Nutrition Research Centre, Singapore Institute for Clinical Sciences, Singapore. *G.J. Hollands* is with the Behaviour and Health Research Unit, University of Cambridge, Cambridge, United Kingdom. *J.M. Brunstrom* is with the School of Psychological Science, and the National Institute for Health Research, Bristol Biomedical Research Centre, University Hospitals Bristol NHS Foundation Trust, University of Bristol, United Kingdom.

Correspondence: *E. Almiron-Roig*, University of Navarra, Centre for Nutrition Research, Irunlarrea 1, 31008, Pamplona, Spain. E-mail: ealmiron@unav.es.

Although there is considerable evidence for the portion-size effect and its potential impact on health, much of this has not been successfully applied to help consumers reduce portion sizes. The objective of this review is to provide an update on the strength of evidence supporting strategies with potential to reduce portion sizes across individuals and eating contexts. Three levels of action are considered: food-level strategies (targeting commercial snack and meal portion sizes, packaging, food labels, tableware, and food sensory properties), individual-level strategies (targeting eating rate and bite size, portion norms, plate-cleaning tendencies, and cognitive processes), and population approaches (targeting the physical, social, and economic environment and health policy). Food- and individual-level strategies are associated with small to moderate effects; however, in isolation, none seem to have sufficient impact on food intake to reverse the portion-size effect and its consequences. Wider changes to the portion-size environment will be necessary to support individual- and food-level strategies leading to portion control.

Keywords: downsizing, eating behavior, eating context, obesity, portion-size effect.

INTRODUCTION

There is now convincing evidence that exposure to large portions of high energy–dense foods results in increased energy intakes, a phenomenon known as the *portion-size effect*[1–3] and observed across a variety of food types, environmental conditions, and study populations.[4] Because portion sizes have increased in recent years,[5–7] this phenomenon requires individuals to invoke personal coping strategies to avoid overconsumption.[8] Evidence for a potential association between increased portion sizes and obesity comes mostly from laboratory and field studies linking the consumption of large portion sizes with increased energy intakes across a variety of food types, age groups, and body weights.[2,4,9] In addition, a small number of studies indicate that serving smaller portions may help to reduce daily energy intakes[10–13]; however, the longer-term effects of reducing portions are less clear.[14] Although more observational studies are needed,[15] if reduced intakes can be sustained, then portion-reduction strategies might confer benefits at the population level.[3] Currently, little is known about how to support people to eat smaller portions, beyond education or the use of food labels, which have demonstrated limited success.[16,17]

The mechanism(s) underlying the portion-size effect remains unresolved. However, several processes have been proposed.[1,4,9,18] Factors that may contribute include ways in which the portion is served or presented (eg, meal and snack portion size and packaging cues, unit number and size, presence of segmentation cues, size of tableware, calibration marks on packaging or tableware); ways in which the portion is eaten (eg, plate-cleaning tendencies, bite size/eating rate, attention while eating), ways in which portion sizes are perceived (eg, "appropriateness" or portion-size norms, familiarity, expectation, awareness, and estimation biases), and other factors that interact to influence such perceptions (eg, palatability and energy density). In addition, external factors such as value for money and packaging information can also affect decisions about how much is purchased, self-served, and consumed.[3,9,18] Overall, consumers may rely on the amounts served or contained in a package as a simple heuristic to determine intake, balanced with consumption norms, taste, expectations, and/or prior experience.[19]

Recent robust meta-analyses (MAs) have shown that manipulations to portion size can have a strong impact on eating behavior.[2,3,20] However, much of this information has not been successfully translated to help consumers reduce self-selected portion sizes at the population level[21] Educational public health campaigns and observational studies suggest that portion sizes are still large, especially for high energy–density foods and caloric drinks.[6,15,22] It has been suggested that without modifying the environment in which consumers make portion-size decisions, on their own, educational initiatives are likely to have limited efficacy.[21] Another reason for the lack of progress may be that interventions that target weight loss or weight maintenance have tended to focus on successful body weight changes resulting from complex dietary, cognitive, physical activity, and/or pharmacological/medical manipulations, without specifically targeting portion size. This has also led to a general lack of understanding around the effects of reducing portion sizes on consumer perceptions and acceptance, meal satisfaction, satiety, and energy compensation, especially over long periods.

Although some portion-size interventions have shown promise, it remains unclear which type of intervention will work best, for whom, and in what contexts.[18,21,23] Based on the latest evidence, Vermeer et al[24] recommended more research on strategies for communication and marketing related to portion size, environmental portion-size interventions, educational interventions to deal with a "super-sized" food environment, increased regulation around portion-size labeling, and the use of nudging to stimulate healthier portion selections. These recommendations have been echoed by others, and actions ranging from doing nothing to eliminating choice have been proposed.[25,26]

Despite these efforts, practical and evidence-based population-wide guidelines around healthy portion control are still lacking. This review provides an update on current evidence supporting recommended strategies to reduce portion size across individuals and eating contexts. Initially, food-level strategies are considered, followed by individual-level and then population-wide approaches, including an assessment of their potential impact and challenges ahead.

METHODS

A narrative review was conducted to provide an overview of the key literature in this area, with additional searches to supplement authors' knowledge. Given the broad scope of this field, the decision was taken not to systematically identify and evaluate all associated literature.

Data searching process

First, MAs and systematic reviews (SRs) exploring the "portion-size effect," "portion size reduction," and "portion control strategies" were searched via PubMed plus the Cochrane Library. Initial searches were supplemented by an internal database of publications (years 1989–2018). Relevant MAs and SRs were selected based on title and abstract or from the full text when information in the abstract and title was unclear. Second, to capture recent developments, individual studies covering the same topics were identified from PubMed and the internal database and were selected if not included in any of the previous narrative reviews, SRs, or MAs. Searches were complemented with cross-referencing from the identified publications supplemented by the authors' specialist knowledge of the literature. For all searches, the following inclusion criteria were applied: English language; humans; portion control strategies based on food-, individual-, or population-level approaches; MAs covering related outcome measures (eg, on tableware size) when the set of studies examined differed; and individual studies related to individual characteristics that may be modulated to control portion size (even if the focus was not on portion size). For all searches, the following exclusion criteria were applied: MAs quantifying effect size of strategies of different categories altogether (ie, not specifying effect size for each individual strategy); and editorial/opinion piece. Confirmatory searches were performed using "portion size reduction," "portion size control" and "portion size labeling" as keywords in the Cochrane Library and PubMed databases during March–September 2018. A later MA[27] and 2 SRs[28,29] plus 1 cross-sectional study[30] were added during the revision period.

Data extraction process

Data were extracted by 2 investigators and disagreements discussed and agreed with a third author from the author team. Extracted data for both reviews and individual studies included strategy level (food, individual, or population), timeline, type of evidence, mediators, outcome measure, and effect size, plus, for reviews and MAs only, overall quality. For MAs, when numerical data were not reported or were presented in a different metric to standardized mean difference (SMD) or Cohen's *d*, the authors were contacted for information.

The following operational terms were used: *Timeline* of studies: defined as acute (1 d), short term (1 wk), medium term (2–3 wk), and long-term ($\geq$4 wk). *Type of evidence*: based on the American Dietetic Association Evidence Library criteria:[31] **A** = randomized controlled trial (RCT), cluster randomized trial, or randomized crossover trial; **B** = prospective or retrospective cohort study; **C** = nonrandomized controlled trial, nonrandomized crossover trial, case–control, time series, diagnostic, validity, or reliability study; **D** = non-controlled trial, case study, case series, cross-sectional, trend, before-after, or other descriptive study; **M** = MA or SR; and **R =** narrative review.

Mediators: variable reported as mediating the effect on the outcome measure. For instance, large portion size was identified as a mediator of increased energy intakes. *Outcome measure*s: any measure related to the portion-size effect and including actual, intended, or perceived intake as main outcome measures in terms of both energy and amount consumed and selected. Secondary outcomes were weight loss, impulsivity, portion-size perceptions or estimations, meal satisfaction, enjoyment, subjective appetite, eating behavior, cognitive (eg, memory), metabolic, and anthropometric outcome measures. *Effect size*: SMD or Cohen's *d*. This metric reflects how much more is consumed from a larger portion-size offering than, for example, a smaller or "control" portion size. A positive value for Cohen's *d* reflects the expected portion-size effect, with a larger mean difference reflecting a larger effect.[2] Magnitude of the effect size was based on Cohen's *d* criteria:[32] $d \leq 0.2$ small; $d = 0.5$ medium; $d \geq 0.8$ large.

Quality evaluation of the studies/reviews

Overall quality for the evidence from MAs, SRs, and narrative reviews was judged based on the summary assessments of the quality of the evidence that were reported in each review, including GRADE,[33] American Heart Association (AHA),[34] and US Preventive Services Task Force[35] evidence quality scores when available. These represent standardized, systematic approaches to assess quality or certainty of the evidence for an effect derived from a group of studies. The heterogeneity index (I^2) is also reported when available as a measure of inconsistency of effect estimates within these reviews (low $I^2 = 25\%$, medium $I^2 = 50\%$, high $I^2 = 75\%$).[36] For individual studies**,** the study evidence level[31] is reported as general guidance, whereas more detailed limitations are discussed in the text.

After applying the selection criteria, 72 publications were included in total. For 1 MA,[27] effect sizes could not be included in the figures due to different metrics and being unable to contact the authors. The results have been summarized in Table 1,[2,3,12–14,18,23–25,27,37–95] Table 2 (MAs results),[2,3,27,40,52,60,73,78] and Tables S1–S3 (*see the Supporting Information online*).

OVERVIEW OF STRATEGIES TO REDUCE PORTION SIZE

Food-level strategies

Food-level strategies for the reduction of portion size include reduced portion sizes of restaurant and manufactured meals and snacks; reduced pack and container size; packaging with portion size (calibration) markings;[3] portion size information on food packaging;[17,97] and modified serving and eating utensils.[3,40,41] In addition, emerging research in sensory science and related disciplines suggests that palatability and meal satisfaction might also play an important role in portion control[42,98] (see Tables 1 and 2 and Table S1 [*see the Supporting Information online*]).

Reduced meal/snack size offerings. Multiple sources of evidence suggest that providing smaller meals may be an effective way to reduce energy intakes.[2,3,8,12,99] A recent SR[3] suggests that, if sustained reductions to large portions could be achieved across the whole diet, average daily energy consumed could be reduced by up to 16% in UK adults (equivalent to 279 kcals per day) and by up to 29% in US adults (527 kcals per day). Given that portion control is particularly challenging, especially when dieting,[18] environmental cues that promote the self-selection of smaller portions should be given serious consideration. For instance, it may be helpful to reduce the size of offerings in restaurants and to provide commercially available portion-controlled meals[10,11,14] and snacks.[25,100] However, the positive benefits may be short-lived.[14] Although consumers may be willing to select reduced portion sizes when offered alongside regular counterparts,[23,101,102] sustained consumer acceptance of smaller portions is required.[103] This is particularly relevant for palatable foods, such as snacks and drinks consumed in social settings, as other factors such as perceived status,[104] context of eating (where and with whom),[105] palatability,[106] and expected satiation[107] may override otherwise good-intentioned health-oriented decisions. Importantly, from a health perspective, smaller offerings should not be financially penalized even if consumers expect a quantity discount because this may induce overconsumption.[108] However, this is rarely if ever the case—consumers are often expected to pay the same price for a smaller portion, and when price is reduced, this is rarely proportionate to the reduction in size.[109]

In response, it has been suggested that smaller portion sizes should be the default rather than an option in restaurants and work canteens (a form of dietary nudging).[24,25,110] However, when reduced portion sizes are offered, they need to be perceived as having sufficient energy content[12] and satiation power[12,46] to satisfy individual requirements. In addition, price may need to be considered as a mediator of some people's preferences for larger package and portion size[26] (the effects of linear vs nonlinear price are expanded in a later section).

The feasibility of producing and selling reduced portions requires careful consideration.[103] Reducing unit price poses a substantial risk to revenue that is unlikely to be matched by a reduction in ingredient costs. In terms of cost savings, changes to the cost of goods sold (COGS) per unit are often negligible, and, in some cases, moving to a smaller portion may create new ingredient, distribution, and operational complexities that actually increase costs. Therefore, savings made to COGS are unlikely to be sufficient to drive a profitable price-point when moving to a smaller portion. In restaurants, lowering the price point may increase the perceived value of a reduced-portion menu item but may also harm revenue and reduce consumer enjoyment of the meal. Relying on consumers to adopt a "less is more" mindset also poses a risk to repeat business and profitability and would require the adoption of a sector-wide portion-control strategy.[111] Although both chefs and restaurant owners have expressed concerns about how large portions influence intake, they are likely to regard individual dietary decisions as primarily the responsibility of their customers.[112,113]

In summary, reduced-size meal and snack offerings in food outlets and supermarkets offer potential as an environmental modification to induce healthier portion-size selections. However, more research is needed to understand the impact of these interventions in different types of foods, settings, and individuals. In addition, the feasibility and consumer acceptance of a market-wide reduction in portion sizes and the appropriate cost model that sustains both industry profitability and financial value for the consumer merit further scrutiny.

Package and container size. It is now well accepted that packaging and container format have a strong impact on what people regard as an appropriate amount to eat and then eventually consume, irrespective of actual volume and energy content.[38,114,115] A recent SR concluded that reducing pack size alongside meal portion size and tableware size could lead to significant reductions in intake in both adults and children.[3] However, the efficacy of this approach is predicated on the long-term acceptance of smaller portions. As shown in a later RCT, sustained effects of portion-size control strategies remain difficult to achieve.[14] Although prepackaged meals may aid greater weight loss over the first 3 months compared with portion-control training or standard advice, afterwards participants randomized to this intervention also showed more rapid weight regain. One possibility is that participants felt deprived while consuming these meals, leading them to select relatively larger meals after the intervention had terminated.

Unit size and unit number may also influence intake.[45] Studies show that number of packs in multipacks increases the likelihood of consumption.[115,116] A proposed theory is that compared with multipacks, a single large pack increases the period of deliberation before the pack is opened.[116] These effects also seem to depend on individual dietary traits—whereas the unit size of a multipack may not affect total consumption in normal-weight individuals,[115] it may in people who are overweight.[117] Alternatively, smaller packs may offer an opportunity to take a pause from eating, which may promote a memory for the number of packs consumed.[117] The pack-size effect may also be moderated by appetite, dietary restraint, gender, and a range of other individual differences.[38,39,45,75,100,118,119]

Dramatically reducing volume though may be counterproductive, because a lower threshold seems to exist for the portion-size effect. In other words, a marked reduction in portion sizes may actually increase consumption,[46] possibly because very small packs/containers encourage lapses in self-control.[116,120] In a recent qualitative study,[46] 16 British households were given bottles of 1500, 1000, 500, and 250 ml of sugary soft drinks to consume ad libitum. Consistent with the above hypothesis, families reported consuming a greater number of the smallest bottles and attributed this to their convenience, easier stockpiling, and a difficulty in keeping track of how many had been consumed.

The problem with packaging is likely to stem from visual biases that are inherent (ie, hardwired) in humans. Perceived size follows an inelastic power function of actual size (ie, with a power exponent smaller than 1).[44] In other words, perceived size grows more slowly than actual size.[121] Accordingly, as portions increase, their size is increasingly underestimated. In fact, people notice product downsizing much more easily than product supersizing. This is because estimating supersizing is an extrapolation from the reference size, whereas downsizing is an interpolation between the reference size and zero.[122] Some evidence indicates that better size estimation is found when individuals experience an emotional conflict toward hedonic food (for a comprehensive review see Ordabayeva and Chandon[4]). In addition, perceptual distortion also affects the impact of package size on portion selection. These dimensionality biases are particularly likely when packaging size changes in >1 dimension.[44] For example, people find it more difficult to estimate portion size when packaging changes in multiple dimensions (ie, height, width, and length) than when it changes only in height. The underlying reason is that people find it more difficult to integrate changes along 3 dimensions at once. Rather than multiplying percentage changes in height, width, and length, people often add these dimension when estimating changes in volume.[123] Leveraging this effect, downsized packaging may be less likely to be noticed by a consumer when several dimensions are reduced rather than just one.[124] In this regard, one such specific change, elongation (when the base of the package decreases while the height increases), has proved particularly successful. In a study using candles and soaps,[123] a 24% reduction in 1 dimension (height) was perceived as a 20% reduction, whereas the same reduction was perceived as only a 2% reduction when elongation (increasing the height while reducing the base) was applied.

Overall, the impact of packaging on portion-size estimation is strong and is, in part, influenced by perceptual biases that are inherent in human visual processing. Nevertheless, reductions in size that extend beyond the limits of these biases are unlikely to be effective because they will be readily detected by consumers. To achieve a greater immediate reduction in energy intake, reformulation may also be necessary, and in combination, this approach is more likely to yield successful outcomes because covert manipulations to energy density are less likely to be recognized than overt changes to the physical dimensions of products.

Portion size information on food labels and packaging. Similar to energy and nutrient labeling approaches,[125] portion-size information on food packaging (such as providing standardized information on portion sizes) has been proposed as a way to help consumers select appropriate portion sizes. A recent SR of 36 studies[28] concluded that nutrition and health information presented on food labels has varying impacts on portion sizes consumed, in part due to inconsistent reporting standards. The effects of labeled serving size information in particular and for nondiscretionary foods also remain unclear,[47] with the majority of studies being conducted in controlled conditions and very few being conducted in other contexts (eg, the home, restaurants, and on the go).

“Standardized portion sizing” refers to an attempt to establish reasonable single servings of foods and, in particular, those eaten frequently and that are known to increase the risk of chronic disease. For example, for snack foods and desserts, the standard portion might reflect the maximum recommended discretionary calories for the average adult trying to maintain weight (eg, 300 calories, according to US Department of Agriculture [USDA] guidelines).[26,126] However, implementing this guidance is nontrivial.[51] First, portion-size information is currently presented in a wide range of formats, including numerical—as part of the nutrition information back panel or the front-of-pack label (FOP)[127]—or as a suggested serving size—typically a food image on the FOP. Second, consumers find numerical information to be unclear, inconsistent, and difficult to visualize and interpret. In part, this may be attributed to the variety of formats in which numerical labeling can be presented—for example, per 100 g, per unit, per serving size, or other manufacturer-defined amounts not necessarily coinciding with public health guidelines.[128,129] Third, popular reference schemes (eg, in the United States and United Kingdom) are outdated because they reflect amounts that were customarily consumed before the current obesity epidemic.[26,38] Finally, certain formats provide contradictory information, such as depicted serving sizes on cereal packages[48] that actually promote overconsumption.[50]

In some countries, food packaging guidelines on portion sizes are voluntary and are issued by different industry bodies.[101] Given that consumers may distrust industry motives around portion size[130] and that visual information on the food package itself may be more impactful than text-based information,[131] the effectiveness of portion-size information delivered via food labels is difficult to predict. For example, 2 studies[49,97] explored the effects of mandatory changes in portion-size information provided by the US Food and Drug Administration Nutrition Facts Panel and found contradictory results. The first study concluded that, compared with existing labels, consumers who viewed labels with larger "suggested servings" believed they were portioning out more calories in a virtual online experiment, and when tested in the laboratory, this led to reduced consumption of a snack.[97] In the second study, a label indicating larger portion sizes led participants to serve 27%–41% more snack to themselves and to others, suggesting that the amended food label promoted overeating.[49] Confirming the importance of these labels, 78% of another group of 101 participants in this study claimed to understand that the Nutrition Facts label can be used as a guide to promote healthy portion control.[49]

Providing serving size recommendations reflecting smaller rather than larger portions may work better. In 1 study, 100 women were asked to taste and eat pizza ad libitum. Smaller meals were consumed when they were told that the pizza contained 4 servings as opposed to 2 servings (or no label), and the reduction was comparable to the effect of providing a smaller portion with no label.[17] Such information, however, needs to be specific. For example, providing only categorical size estimates (ie, "small," "medium," "large" portion) may be confusing because certain descriptors can result in a belief that less food has been consumed.[132,133]

Overall, the results of these individual studies suggest that portion-size information provided either as part of a nutrition label or at food outlets may be understood as normative information and has the potential to influence portion-size selection and intake. However, differences in study design have the potential to change the direction and magnitude of this effect (as suggested in a recent SR[28] and, in particular, when different reporting standards are used). Two of the aforementioned studies[40,41] (conducted in a basketball event and a school canteen) and 2 online studies[49,97] found that the food label or depicted portion size on a pack increased both the portion chosen and the perceived amount selected of a meal/snack. However, testing the same label formats in the laboratory resulted in smaller consumed portions of candy in 1 of the same studies.[97] Overall, controlled studies tend to find an impact of the format of portion-size labeling. However, these studies are overrepresented in comparison with field studies, which show varying effects.

For foods with packet labeling, recommendations include addressing the layout of the labels to correct serving-size inconsistencies, to reduce complex information, to avoid the need for serving-size calculations, and to consider consumer literacy and numeracy (eg, per 100 g or mL alongside serving size, household measures, and number of servings).[51,132] In terms of FOP label information, efforts should be made to present meaningful serving-size units that can be easily conveyed, and complicated layouts should be avoided.[132]

Modified tableware. Several studies, including various MAs,[3,40,52] have explored the effects of modified tableware. The first MA (involving 15 comparisons) found no effect of dishware size (plates and bowls) on energy intakes.[52] However, a wider review that included 19 comparisons of tableware reported a small-to-moderate effect on portion selection and intake after changing the size or shape of plates, bowls, cutlery, or glasses.[3] A more recent MA that involved 56 comparisons[40] concluded that the effect of modified tableware depends on how the portion size is determined—smaller plates lead to smaller meals, but only when the portion is self-served. The authors concluded that halving plate size led to a 29% reduction in the amount of food self-served and consumed.

However, participants may have been aware that they were being monitored, and it is possible that an awareness of the objective of the studies (demand characteristic) contributed to this effect.

Holden et al[40] also looked at the relative effects of manipulating area (eg, smaller plate) versus volume (eg, smaller bowl) and whether amounts consumed or selected depended on whether food was served from or eaten directly off the item. Manipulations to bowls and plates generated similar results when looking at consumption and selection studies together—that is, the effect of size reduction occurred irrespective of whether area or volume was manipulated (SMD of 0.24 for plates vs 0.51 for bowls, with overlapping confidence intervals) and of instrument purpose (using a consumption vs a serving plate). However, when explored separately, the effect of larger bowls on consumption was larger than for larger plates ($d = 0.47$ vs $d = 0.06$ for actual intake, and $d = 0.79$ vs $d = 0.49$ for intended intake, Table 2, see Holden et al[40]). Previous reviews have also concluded that manipulations to bowls has a stronger effect than manipulations to plates.[52,134] However, these results may be confounded by demand characteristics, and some observations were taken in the presence of distractors and/or with fixed portions.[40,134] Observations may also be further moderated by body mass index (BMI) because overweight participants are likely to select smaller portions for social desirability reasons.[95] A more recent study[135] considered the impact of different plate sizes on expected satiation and expected consumption in overweight and lean adults. The authors found that a smaller plate generated higher expected satiation and lower predicted intake, but only in lean participants. Age and gender do not appear to have a strong influence on tableware effects.[52]

Findings related to the manipulation of utensils are inconclusive. In an uncontrolled study, Geier et al[136] found that people passing by an apartment lobby consumed more free candy when a large spoon was placed next to the bowl compared with a regular spoon. However, an intervention[137] exploring fork size in adults showed that a small fork leads to larger meals in a restaurant setting (maybe because the small fork does not give diners the same feeling of making progress in satisfying their hunger as the large fork does, so they continue to eat for longer). In children the effects of spoon size appears to influence amounts self-served but not consumed.[138] A further study[139] found that using tongs (replacing spoons) reduced self-served portion sizes by 16.5% at a worksite salad bar, but only unit size items (eg, cherry tomatoes) were measured.

Studies looking at the use of bottles and glasses of varying shapes suggest that perceptual effects are likely to play a role in portion choice.[140,141] Overall, wider and shorter containers (as opposed to narrower and taller containers) lead to worse estimation of volume, more liquid poured, and more consumed.[142] Beyond the effect of container and participant characteristics, similar confounds identified for the tableware studies may apply. For instance, some studies were conducted at social events, whereas others were conducted under laboratory conditions, which may have affected the extent to which participants were aware that their food intake was being monitored.[40,143] Across these studies, different samples were recruited, including normal-weight adults, overweight children, and adults attending a weight-loss program. These groups are likely to have different eating habits and attitudes to food, which may explain variability in study outcomes.[144]

Results are more consistent when calibrated plates have been used.[41,53,54] Calibrated (also known as partitioned or portion-control) plates represent a more direct intervention for portion control than reduced-size utensils because they usually depict portion size information or provide a clear guide indicating how much of the plate should be allocated to individual food groups (some examples can be found online[145,146]).

Weight-loss interventions incorporating these tools have shown promising results, although in some successful cases[53,54] the tools have been deployed alongside dietetic counseling and other intervention components, making it difficult to isolate the role played by a portion-control tool. For example, in a study of patients with type 2 diabetes, a calibrated diet bowl for cereals and soups, together with a plate marked with sectors for 3 food groups, resulted in greater weight loss (2 kg) than in a control group over a 6-month period.[53] Similar results were achieved using a sectored plate and calibrated bowl as part of a dietetic weight-loss intervention over a 3-month period[54] and as part of a 6-month telecoaching intervention.[55] Differences by sex were observed in some studies, and in many cases the intervention failed to show efficacy beyond 3 months, suggesting lack of adherence. Only 2 studies have explored the effectiveness of a portion control plate on its own. In 1 study,[41] 29 people with obesity used a portion-control crockery dish and bowl (made of baked clay) and a calibrated glass at home. Over a 2-week period, participants reported that they found the plate easy to use and that it helped to control portions of starch and to increase portions of vegetables. In a second study,[56] 110 university students (of normal weight) self-served portions onto either a portion-control plate or a larger dinner plate and followed instructions based on 2 USDA guidelines (ratios or absolute amounts). Compared with the larger plate, the portion-control plate reduced self-served amounts in all conditions but did not promote increased intake of vegetables (portions remained below recommendations). Although both studies suggest a potential positive role for portion-control plates per se, their sustained benefit remains unclear. Together, these experiments highlight the need for more research and in different populations, including children and the elderly.

The use of other calibrated utensils (eg, glasses and serving utensils) has been explored, but to a lesser extent. In the study exploring the acceptability of the calibrated crockery plate,[41] a calibrated glass and bowl were also included. However, of these, participants perceived the glass as less helpful.[41] In the same crossover study, participants were also offered calibrated serving spoons for starch, protein, and vegetables, which they found equally acceptable and a helpful tool, both to reduce portions of starchy foods and to increase the selection of vegetables and salad. However, these data were self-reported, and their sustained effect on food choice and energy intake remains unclear.

The underlying mechanism(s) by which modified tableware impacts food intake also remains unresolved. One suggestion is that the perceived size of food portions becomes distorted by the size of the dish on which it is served. One example of this distortion is the Delboeuf illusion and is often illustrated using abstract circular shapes. Briefly, the size of a circle is perceived to be relatively larger if the gap between the edges of the circle and a second outer circle is small. Because the gap between food and the edge of a small plate is also small (relative to a larger plate), it is possible that distortions to food-portion estimation occur for the same reason.[147] Such illusions may bias both serving size and consumption and have the potential to promote overconsumption.[147,148] Similarly, for liquids, studies suggest that larger and curved glasses impair the ability to estimate volume[149,150] (participants consistently pour a larger volume into wider and shorter glasses than into narrower and taller ones and drink more slowly from a straight glass than a curved glass[141,151]).

As for calibrated plates and serving utensils, it is possible that these tools may prompt users to pay additional attention to self-served portions of individual meal components relative to the whole meal, mediated by visual information on the appropriate amount to be consumed. This may induce a recalibration of their normative beliefs about appropriate portion size (see below under individual-level strategies). Evidence has shown that this portion-norm recalibration is possible for meals consumed under laboratory conditions already at the first exposure, at least in lean individuals eating a specific meal (quiche).[13] An ongoing study is exploring whether a similar effect can be achieved in overweight individuals using a portion control plate and whether visual attention plays a role in this process.[152]

Age-appropriate tableware has also been advocated for children, including the use of smaller plates and plates with rims.[148] This suggestion is based on observations that adult-size plates encourage children to self-serve more of the foods they like, possibly by biasing their perception of physical size or by altering normative beliefs about appropriate portion size.[153] Nevertheless, it should be noted that the effect of serving food on smaller plates in children is not reliably demonstrated,[19] and although the presence of rims appears to reduce the Delboeuf illusion, there is little evidence that rimmed plates reduce food intake.[154]

Overall, the current evidence suggests that reducing the size of plates and especially bowls and providing taller and narrower glasses may help to reduce intakes of self-served portions. However, when amounts are preplated rather than self-served, then reductions in intake are less likely to occur. The use of calibrated utensils has yielded promising results, but more research is needed to demonstrate sustained changes in energy intakes.

Palatability, food satisfaction, and expected satiety. Recently the role of sensory attributes and, in particular, their contribution to food palatability and food satisfaction have been proposed as important determinants of food intake and satiety.[42,98,155,156] This view stems from research suggesting that food enjoyment directly impacts appetite and cravings, which, in turn, can impact portion selection, food intake, and body weight[157] and may motivate other health behaviors.[59,158] Recent studies also suggest that food satisfaction (defined as a generalized appreciation of food beyond just taste)[159] plays an important role in governing food intake,[98] to the extent that vividly imagining the sensory experience of preferred foods leads to the selection of smaller portions.[59] Indeed several studies have shown that enhancing the sensory properties of equally liked iso-energetic drinks and small portions of breakfast foods leads to increased satiety and reduced energy intakes.[57,155,160] Enhancing the expected palatability of a food also impacts selection and potentially consumption. For example, labeling the same vegetables with indulgent descriptors (eg, “zesty ginger-turmeric sweet potatoes”) increased the number of people choosing them and the total mass selected in a university canteen compared with basic (“sweet potatoes”) or healthy labels (“cholesterol-free sweet potatoes,” “wholesome sweet potato superfood”).[161] Merely increasing the portion size of low energy–dense foods (typically less palatable) and excluding high energy–dense (palatable) options is unlikely to be sustainable in the longer term because food satisfaction is a primary driver of food choice and intake.[19,162,163]

Recent functional magnetic resonance imaging studies have also shown that, compared with regular diets, monotonous diets induce stronger cravings for liked foods (which are typically energy dense), potentially leading to overeating (reviewed in Møller[98]) Although the effect of liking is relatively robust, it is difficult to modify because it relates to individual food preferences, which are highly heritable.[164,165] In addition, if the volume of these foods is reduced, then this may become obvious, promoting consumer dissatisfaction[166] and the potential for subsequent compensatory eating to occur.[167] Consistent with this hypothesis, the effect of lower energy density on subsequent food-intake compensation is reduced when visual and sensory cues are removed.[168,169] Therefore, sensory modification may provide a way to reduce energy intake without the need to reduce portion size—specifically, by lowering energy density while preserving palatability and by limiting compensatory eating behavior by maintaining satisfaction.

Despite palatability being regarded by many as a primary driver of food choice and energy intake,[162,163] other variables also merit consideration.[170] An important component of food satisfaction is food-related expectations.[159] Foods differ considerably in their expected satiety (the extent to which foods are expected to stave off hunger when compared on a calorie-for-calorie basis).[86] For example, 1 study showed that 200 kcal of pasta is expected to deliver the same satiety as 894 kcal of cashew nuts.[171] Related studies also show fine discrimination between foods—in 1 study simply changing the viscosity of a yogurt drink increased its expected satiety.[172] Although palatability is an important predictor of choice, expected satiety also plays a role, especially when smaller portions are offered.[173] Moreover, across typical lunchtime meals, variation in expected satiation (expected fullness) can be an even better predictor of portion selection (foods with low expected satiation are selected in larger portions) than variability in palatability.[174] Together, these findings illustrate opportunities to promote the selection of foods in smaller portions and to promote decisions that are not based solely on palatability.

Related studies have also shown that expected satiation is learned over time.[175] In particular, expected satiety and expected satiation are found to increase as food becomes more familiar.[176,177] This evidence for expected-satiation drift may benefit the development of reformulated lower-energy-dense products that are designed to reduce energy intake. Once an expectation has been acquired, it tends to remain stable, even after repeated exposure to a lower-energy-dense reformulated version of a similar product.[178]

In summary, recent research highlights palatability and food satisfaction as important determinants of food intake. In the future this understanding might be leveraged to inform the design of reformulated weight-management food offerings that are enjoyed by consumers and that maximize the reduction in energy intake that can be achieved in this context.

Individual-level strategies

The consumption of larger portions is governed both by the widespread availability of large portions and by financial incentives that promote their selection.[25] This section provides a review of individual-level strategies that might mitigate these pressures, including reducing eating rate and bite size, changing plate-cleaning tendencies, and manipulating portion-size norms and mindsets[18,78] (see Table 1 for overall summary and *see Table S2 in the Supporting Information online* for specific study details). It is also worth noting that, unlike food-level strategies, which are passive, the effectiveness of individual strategies, especially in the long-term, depends on active engagement by the person. Much of the evidence discussed below comes from laboratory studies where participants receive instructions and are able to alter their eating behavior (eg, eat more slowly, eat for health). Evidence of individuals actively sustaining such behaviors under free-living conditions is much scarcer.

Eating rate and bite size. Eating rate (eating speed) and bite size (amount loaded on the fork/spoon, or for liquids, amount sipped) are inherited, yet trainable, eating traits, which have been shown to be tightly linked with energy intake and energy balance[60,61,179] and are associated with BMI[180] and fat mass.[65] Among both adults and children, faster eating rates are produced by taking larger bite sizes that, in turn, are chewed less, leading to reduced oral exposure time.[181–183] Although faster eating rates have been shown to have a heritable component,[179] these behaviors are strongly influenced by food texture[181,184] and portion size.[64,185] Recent research indicates that larger portions induce larger bite sizes and quicker eating rates in overweight individuals,[64,185] resulting in a reduction in oral exposure time.[64] When food spends less time in-mouth this may reduce sensory-specific satiety (the decrease in pleasantness for a food previously eaten[186]), which may lead to the consumption of larger meals.[1] These findings are supported by a large body of literature suggesting that specific food-related perceptions play an important role in determining portion size,[4] alongside sociodemographic and psychological variables.[187]

Portion size and eating rate may also interact in other ways. A recent study with preschoolers showed that children who ate at a faster rate consumed more calories. However, of these children, those who also selected a larger portion consumed significantly more calories, indicating that portion size and eating rate combine to have an additive effect on meal size and food intake (McCrickerd et al, unpublished data). At the food level these variables can also be manipulated to moderate meal size. Manipulations to the texture of a food can encourage a slower eating rate, and this has been shown to moderate energy intake within a meal, as people tend to naturally take smaller bites and extend their chews per bite when texture is enhanced.[181,183] In a recent study, combining texture-based reductions in eating rate with smaller portion sizes produced a 11%–13% reduction in food weight and energy intake, compared with thinner versions of an ad-libitum meal.[57]

Although changes in eating speed have the potential to reduce meal size, in turn, this might generate a more rapid return of hunger. However, some research suggests that reductions in portion size do not increase perceived hunger.[12,66] Also, reducing energy intake by slowing eating rate does not appear to reduce perceived fullness at the end of a meal[60] and may indeed contribute to increased fullness in the intermeal period. In agreement with this, some studies have reduced the eating rate of a meal by increasing the number of chews per bite and demonstrated an increase in postprandial satiety per kilocalorie consumed, alongside higher GLP-1, PYY, and a longer suppression of ghrelin following extended chewing.[62,63,188–190] Studies where eating rate has been trained for a sustained period of time show effects on weight loss.[61,191] Whether reducing portion size in tandem with reductions in eating rate can support sustained decreases in energy intake without affecting hunger over longer periods has yet to be demonstrated. Similarly, whether reducing portion size leads to a concurrent reduction in eating rate over time remains unclear.

Overall, these findings suggest an opportunity to reduce the risk of increased energy intake from the portion-size effect by manipulating the rate of energy intake at a meal. In addition, manipulating these parameters may support reductions in energy intake by promoting greater feelings of fullness in the intermeal period.

Modulation of plate-cleaning tendencies. Plate cleaning refers to the tendency to consume everything on a plate during a meal. It is associated with increased body weight and has been proposed as a risk factor for overweight and obesity. It is also associated with being male and gaining higher educational attainment.[72] Although the methods for establishing these associations have been debated,[192] the prevalence of plate cleaning is often reported to be high (>90%).[70] Plate cleaners may be especially likely to overconsume when they receive large meals, and this may place them at greater risk of diet-related disease.[69] Plate cleaning does not seem to be influenced by exposure to larger portions, however, at least in women.[67] Given this, and the absence of a clear causal association between plate cleaning and adiposity, the implementation of public-health strategies to modify this behavior would not seem justified at present. On the other hand, the presence of leftovers might reduce perceived consumption and the motivation for later compensatory behavior.[69] Research has shown that providing a leftover box to take home has the potential to reduce the portion-size effect.[68] This simple approach may prove more successful than attempts to change plate-cleaning tendencies that may have been established during childhood.

Recalibration of personal norms. A *norm* is defined as a belief about what constitutes a typical behavior in a given situation and is found to influence how people usually behave.[193] It is now well established that portion-size norms influence food intake[73]—they represent beliefs and opinions on how much is considered appropriate, either personally (personal norms) or by others in a social context (social norms).[75] Personal norms for portion sizes are significantly larger in people with obesity than in normal-weight individuals. They also play a greater role in men, in restrained eaters (those attempting to restrict food intake to control body weight), and in those with higher liking for a food.[75] Exposure to large portions may induce an adjustment or recalibration of these normative beliefs about appropriate portion size.[76,110] Such processes may work via a mechanism of anchoring and adjustment to larger volumes, by which the size of a presented portion works as an anchor (reference for how much to eat) that strongly influences consumption and becomes the norm.[74] Studies have shown that, under controlled conditions where participants make hypothetical decisions, brief visual exposure to large portion sizes may induce a recalibration of what constitutes an appropriate portion size.[76] Whether the effects can shape the selection of unrelated foods and over long periods remains unknown. In response to some of these questions, Robinson and Kersbergen[13] recently conducted 3 experiments with lean adults (75–124 men and women) exposed to 2 portion sizes of a quiche-based meal that was presented in either a typical or a markedly reduced (but still acceptable) portion size over 1–7 days. In the short term (next day), exposure to the small portion (100 g, 220 kcal) produced a reduction in intake of 100 kcal in women and 207 kcal in men (both $P \leq 0.003$ vs. typical size portion). The same trend was observed after exposure over 7 days, but the reduction in intake was no longer statistically significant. Overall, these results highlight the modifiable nature of portion-size perceptions and suggest that normative portion-size judgements may be modifiable over very short periods but may be less likely to remain over longer durations. Further research is needed to establish whether beliefs can be modified in people who typically choose large portions and whether this approach offers promise as an intervention to aid weight loss.

Research has shown that parental portion size norms may also be important. Parents who serve their child based on their own beliefs about how filling a food is rather than on their child's appetite may be at risk of overserving and stimulating higher intake.[77] Consistent with this observation, parental beliefs about appropriate portion size predicts their child's BMI, whereas their children's beliefs about portion size do not.[194]

In summary, recalibration of personal portion-size norms toward smaller portions holds promise as a way to promote the acceptance of downsizing strategies. However, more evidence is needed before stronger conclusions can be drawn.

Cognitive strategies. Cognitive strategies, such as portion-size education, are common elements in many weight-loss interventions. However, very few interventions have investigated improved portion control as a main outcome.[18] Such strategies cover a range of approaches, including purchasing (eg, driven by impulse or cues such as promotions),[79] measuring skills, stockpiling, food exposure and unplanned eating, mindfulness and attention, out-of-home eating, and portion control self-efficacy awareness. Together, these strategies have been shown to be effective in decreasing BMI at 3 months[79] and in reducing body weight at 6 months, when deployed alongside an increase in physical activity.[80] However, they tend to involve intensive educational components that participants need to integrate into their daily routine. A recent RCT[14] examined the effect of portion-size training in 186 women, using either portion tools (food scales, measuring cups/spoons, and 2 image-based educational aids), pre-portioned packaged meals, or standard dietary advice. All participants were experienced dieters who regularly self-monitored their weight, diet, and walking and were offered regular contact with the investigators. Initially, participants receiving portion-control strategies showed greater weight loss. However, in the period following the intervention, these differences disappeared, and those who received a portion-control strategy were faster to regain weight.[14]

Other studies have considered the relative effectiveness of portion controls in people who adopt different dietary strategies. For example, studies have assessed people who adopt flexible, fixed, powerful, or powerless attitudes and those who eat attentively or unconsciously. Two individual differences are discussed below.

Psychological mindsets are defined as orientations that affect how consumers encode, interpret, and respond to information.[87] Mindsets can be interpreted as a lens through which individuals assess their environment and make decisions—for example, with a fixed (unchangeable) approach, a powerless approach, or a promoting approach. Mindsets can shape people's eating behavior, including their control of portion size, affecting how they respond to failure to adhere to a diet and how they start making changes to control portion size.[87] Mindsets may even influence hormonal responses to food exposure.[83] A recent fMRI study[84] has shown that manipulating a person's mindset to eat for health or pleasure at lunch, as opposed to fullness, can reduce the size of selected portions (using a virtual portion-selection task) and that this is correlated with activation of brain areas related to self-control. In contrast, asking the participant to select a portion size for fullness resulted in larger portion size selections and the activation of brain areas related to the processing of interoceptive signals (ie, being aware of being full).

A person's mindset around social status can also influence their valuation of calories, their selection of portions, and their food intake.[104,195] In 2 studies[81,196] participants received feedback that temporarily decreased their perceived social status. Subsequently, their calorie estimation and ability to detect energy differences in foods worsened, and their calorie selection, desire for the food, and intake at an ad-libitum meal increased. A third study[195] confirmed that inducing feelings of powerlessness via a virtual manipulation (online experiment), as well as through field interventions (banner displayed in a building hall), results in choosing larger portion sizes of free food. Overall these results suggest that if this type of mindset persists, then the psychological experience of low social status may reduce the efficacy of portion-size interventions.

Eating inattentively or while distracted (sometimes referred to as *mindless eating*) has also been associated with poor portion control.[18] One possibility is that distraction impairs the ability to accurately estimate amounts of food consumed and might influence the capacity to make deliberate decisions about how much to eat.[18,78] Memory and, in particular, food-related episodic memory has also been implicated in meal-size selection.[86] An MA by Robinson et al[78] suggests that distraction during eating increases meal size and that distraction also impairs "memory for recent eating" leading to greater intake at a subsequent meal (Table 2, Figure 1). Although a recent study failed to replicate this finding.[82]

Population-level strategies

Population-level strategies concern those that are either able to be directly applied simultaneously to or that are feasibly scalable to whole populations. Interventions to change human behavior can be broadly categorized as structural (ie, changing the environmental context in which an individual behaves) or agentic (ie, approaches targeting the individual and their knowledge or skills to make healthier choices). Although both may play a role in a successful public health strategy, the scalability of agentic approaches may be limited by the underlying resource that might be required to support their administration and execution. That said, some agentic interventions have been implemented effectively at scale,[197] including weight-loss and smoking cessation programs, whereas others, such as nutritional labeling, require only the provision of information. The sections that follow consider the potential impact of population-level approaches that target changes to the physical, sociocultural, economic, and political environments that influence food selection and consumption (see Table 1 and *Table S3 in the Supporting Information online*).

Physical environment. Changing aspects of physical environments ("nudging") has been proposed as a useful population-level strategy to improve patterns of intake.[29,198] Environmental cues fundamentally shape dietary decisions and behaviors, potentially outside conscious awareness,[26,199] so changes to the physical environment have the potential to confer benefits to health.[200] The Typology of Interventions in Proximal Physical Micro-Environments (TIPPME) intervention typology attempts to categorize specific ways in which the physical environment can be altered and includes size interventions, defined as "altering size or shape of products or objects," thus including food.[201] Food-level interventions that involve altering the size, shape, or presentation of foods could therefore be considered examples of nudges where they are scaled-up and administered at a population level. For example, reducing or limiting portion sizes represents a particularly feasible and scalable approach when applied to prepackaged or processed products that are manufactured and widely distributed to whole populations, but also in other environments where food is prepared from fresh on commercial premises (eg, restaurants).[90,91] Manipulations to food product order or proximity can also influence food choice and may represent another environmental approach[29]—for example, by moving larger portion sizes further away or making smaller sizes more accessible (Table 1). However, sustained environmental interventions are challenging; they require coordination between a range of stakeholders (eg, policy makers, food manufacturers, and restaurant owners), and they need to be regarded as acceptable by the public.[25] In particular, reductions in portion size are likely to face more resistance than other public health strategies, such as calorie labeling and banning soft drinks from schools.[202] Some of these issues are discussed in more detail below.

Educational and social environment. In general, educational and social marketing campaigns[22,37] have had a small impact on population behaviors. This may be because social norms about eating may be difficult to change. Social norms are implicit codes of conduct that provide a guide to appropriate action.[96] Social norms around eating impact both food choice and amounts consumed, perhaps by altering self-perceptions and/or the sensory/hedonic evaluation of foods.[73,96] An MA of 15 studies[73] showed that providing normative information suggesting that others make low-energy or high-energy food choices significantly increases the likelihood participants will make similar choices (both $p \leq 0.005$). Providing normative information about appropriate portion size might also be effective,[75] but this is yet to be demonstrated, and the effect this might have on subpopulations (eg, stratified by gender and BMI) remains unclear.

Economic environment. Increased sales translate into increased usage, caused by driving an increase in either the amount per serving (portion size) or the frequency of consumption,[203] or both. In many cases, the appeal of larger product sizes is enhanced when they cost relatively less than smaller product sizes by volume. Proportional pricing would eliminate this incentive and might discourage the purchasing of larger portions for that reason. Such a change could reasonably be applied on a large scale, although there is a lack of experimental evidence examining the effectiveness of this strategy in isolation. A recent MA[27] found strong evidence that changes in price can influence both healthy and unhealthy food choices, although there was high study heterogeneity (≥65%) (Table 1). In particular, subsidies for fruit and vegetables, healthy beverages, and other healthy foods (n = 22 comparisons) were associated with a 12% increase in intake per each 10% decrease in price. Taxation of fast foods, SSBs, and other unhealthy food and beverages (n = 15 comparisons) was associated with a 6% decrease in intake per each 10% increase in price. On the other hand, individual studies do not always show conclusive results. One intervention[204] considered the impact of value-size pricing and calorie information on fast-food choices in 594 US regular consumers. Value-size promotions (when the cost per unit is lower for the larger vs the smaller product) did not encourage the selection of larger (kcals) meals. In a second study[205] portion-size choices were assessed in both a Dutch worksite cafeteria and a fast-food restaurant. Similarly, in 2 different promotion conditions, value-size promotions did not lead to the selection of larger meals, but for overweight customers, the proportional (nonpromotional) pricing was beneficial (they tended to choose smaller portions). A third study[167] examined the impact of proportional pricing of small- and regular-portion meals across 26 Dutch worksite cafeterias. The smaller portion (cheaper) was hardly taken up and did not affect food choices. In a fourth study,[89] 245 mostly overweight US adults were randomized to an online menu choice task that enabled orthogonal contrasts across 4 different conditions—portion size (half vs full), calorie information (absent vs present), healthiness (healthy vs less healthy entrée), and price (linear vs promotional). In the presence of calorie information, removing the promotion led respondents to choose more calories from healthy entrées but had no impact on portion choice (participants preferred to stick to a full portion and to change meal content rather than switching to a smaller portion of the unhealthy dish, perhaps reflecting a portion-size norm).

Together, these results suggest that financial strategies have the potential to improve portion choice (especially increasing portions of foods and vegetables); however, they may have a weaker effect on portion control for other foods, especially when they go unnoticed or when their impact on cost is marginal. Moreover, using proportional pricing may interact with other factors affecting consumers' decisions, such as portion norms or motivation to lose weight. Generally, consumers are supportive of removing value pricing from restaurant food offers,[206] and given existing methodological limitations and overall lack of data, this topic merits further investigation.

Public health policy. Reductions in portion size might be implemented on a voluntary basis. However, historically this has proved largely ineffective. For example, the Public Health Responsibility Deal in the United Kingdom[207] encouraged industry entities to enter into voluntary public-private agreements with government to improve public health in the areas of food, alcohol, health at work, and physical activity. Subsequent evaluations suggest that this failed to effect a meaningful change in diet, and this was attributed to poor implementation and a reliance on ineffective means of changing behavior (such as only providing information, see Table 1).[93] This is unsurprising given that public health is not a central priority for many commercial enterprises and because competitive advantage may be lost if voluntary changes are made by some but not all organizations.[25] Therefore, regulatory and legislative approaches may be more effective (the removal of trans-fats illustrates this point[208]).

Based on the existing evidence, Marteau et al[25] proposed that some of the most effective policies may be those that target the availability and accessibility of large portion and package sizes in stores and cafés. This includes packaging cues (ie, demarcation or segmentation cues), size of tableware in self-service and served foods/drinks, and the removal of value pricing on large portions and package sizes. However, further high-quality evidence is needed before these and other policy changes are likely to be considered. To achieve this, researchers need to explore portion-size manipulations in real-world settings. This may be possible in small-to-medium-size environments (eg, restaurants[90–92,167]) but may be less feasible in larger-scale contexts (eg, large supermarket chains), especially when interventions involve financial incentives. Here, alternative sources of evidence may be needed, including natural experiments, longitudinal designs, and comparisons among geographic areas.

Overall impact of portion size strategies

This review has examined the existing evidence supporting strategies that are currently advocated for reducing portion size and meal size at the individual, food, and population level (summaries in Tables 1 and 2, Figures 1 and 2).

Pooled data from 7 published SRs, including MAs, show that across strategies (n = 22 MAs), the highest impact on consumption was for modifying bottle/glass shape or the size of the serving plate (Table 2, Figure 1). However, these were low-quality studies and included a very small number of comparisons ($k = 1$–3). The next most impactful strategies were modifying pack size, bowl size, removing distraction, and removing visual cues of foods eaten; however, k still ranged 4–16. The impact of modifying unit size, portion size offerings, eating rate/bite size, and normative beliefs about portion size tended to be of small to medium magnitude. The impact of the size of tableware (consumption plate, bowls mostly) was variable, with some utensils being more impactful than others and with study conditions also having an influence.[3,40,52] Bowl size was more impactful than plate size on both actual and intended intake (Table 2, Figure 1a,b), but this was affected by whether the study participants self-served their portion or not and whether they were aware of the manipulation.[40] Except for the serving plate comparison[40] and another analysis including 3 comparisons of bowl sizes,[52] the effect sizes of all tableware in general were of smaller magnitude than for other strategies, in particular for plates. The 4 more extensive MAs[2,3,40,60] ($k = 86$, $k = 24$, $k = 58$, $k = 27$) all showed medium effect sizes on consumption for portion size offerings, eating rate/bite size, and tableware size. Meta-analyses examining intended consumption showed a larger impact for size of bowls and other tableware than for portion size offerings; however, there was high heterogeneity, and the magnitude of the effects tended to be small to moderate, with the exception of bowl size (Figure 2).

To complement the data from MAs, a variety of RCTs, observational studies, and narrative reviews have been considered, and a wide range of mediators of portion-size choice and intake have been discussed (Table 1). A central limitation of these data is that, while in many studies increasing portion size leads to greater intake, there is a paucity of evidence showing that reducing portion size has the converse effect. In addition, whether changes in portion size are considered as reductions or increases depends on how the baseline is defined, and this varies across studies. This stems from the problem that, at present, there is no objective or widely agreed “appropriate” portion size that covers the range of foods and meals available to consumers.[128,129] This makes it difficult to compare the food portions used in different studies—in some cases they might be “larger than normal,” whereas in others the same or different foods might be “smaller than normal.”[144] Further, what people regard as a normal portion is likely to vary across individuals, and this variability might also be reflected in advice offered by health professionals and in government-sponsored schemes. In part, this uncertainty is also compounded by the increasing availability of larger portion sizes,[6,38,209,210] a change that has occurred in tandem over the same period that much of the associated scientific literature has developed.

Other limitations include a dominance of laboratory-based and acute, as opposed to medium or long-term, field studies and the presence of confounders that may affect portion selection and intake, such as participants being aware that food intake is being measured.[40,143] Studying the portion-size effect at the population level (where not everyone needs to reduce intake) is fundamentally different from testing interventions for weight loss. Also, aims in children differ from those in adults, and recommendations will likely vary.

A final limitation is that, assuming portion size reduction is an effective way to control population-level intakes, the extent to which reductions will be tolerated by consumers is unclear. From the current knowledge and consumer perspective[46,166] a portion-size threshold is likely to exist, at least for some products. Whether these thresholds undermine strategies to reduce portion size is also unclear.

Overall, the potential impact of some food-level strategies, such as reducing the size of commercially available meals and snacks and modifying packaging, is well documented. Also, food strategies are likely to be enhanced by individual-level strategies that modify eating behaviors (eg, eating rate, bite size), norms, and cognitive approaches. However, the impact of both food-level and individual-level strategies is likely to be small and will not be sustained unless implemented in combination with modifications to the environment, based on policy, financial, and marketing approaches.[14,21] Looking ahead, an important challenge is the need for methods to assess the feasibility of implementing downsizing strategies at a large scale[18,144] and across multiple sectors, including food retailers and manufacturers, restaurant owners, chefs, and the general public.

The challenges in developing effective portion reduction strategies reflect a limited understanding of cognitive and physiological determinants of portion control. In particular, it remains unclear how various food-level and individual mediators interact over long periods to influence behavior and energy balance. Several questions should be given high priority, such as those related to food-level cues, which may help inform the design of better interventions at other levels. Studies that integrate individual participant-level differences with an assessment of food-related characteristics, meal eating behavior, and cognitive processes are needed.[4] In controlled studies participant demand characteristics are a particular problem,[143,211] and efforts should be made to incorporate assessments of everyday consumer behaviors outside the laboratory and over long periods. In addition, studies that identify population segments who respond best to different interventions are needed so interventions can be targeted to where they are the most effective.

Quality of evidence

A total of 72 publications were reviewed, including 8 MAs[2,3,27,40,52,60,73,78] and 1 umbrella review.[93] For the majority of the MAs, the quality of evidence was rated as low to moderate, when assessed through official systems (eg, GRADE, AHA). Meta-analyses showing larger effect sizes tended to include more heterogeneous studies, studies of lower quality, or those that involved a smaller number of comparisons. Therefore conclusions from these studies need to be treated carefully.[3] For evidence not formally graded but assessed qualitatively, the quality of individual studies was generally described as neutral to positive, based on study design, blinding, publication bias, and whether participants were aware of the study purpose. Methodological differences are likely to affect study quality and the extent to which findings can be extrapolated to different eating contexts. For example, meals are complex, and they vary greatly across studies, which might otherwise account for different outcomes across settings and populations.

CONCLUSIONS

A wide range of portion-reduction strategies and potential targets have been reviewed, ranging from food-level approaches (strongest potential effects for modified commercial portion sizes and packaging, and some types of tableware) to individual-level (training of eating habits and recalibration of consumption norms), to population approaches (policy strategies involving structural changes in food production and distribution). For some (especially food- and individual-level strategies), there appears to be acceptable evidence of a small to moderate effect. However, in isolation, none is likely to have a sufficiently large impact on population intakes to reverse the portion-size effect. In addition, although significant progress has been made in this field, much of the underlying evidence is provided by studies exploring the effects of large, rather than small, portion sizes and from observations drawn from acute interventions conducted in small-scale laboratory settings. Wider changes to the portion-size environment will be necessary to support effective individual- and food-level strategies. In particular, appropriate changes are needed that enable consumers to be satisfied with “less” at an appropriate price point in a way that sustains the profitability of smaller portions for food manufacturers and retailers.

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Supporting Information

The following Supporting Information is available through the online version of this article at the publisher’s website.

Table S1 **Overview of current evidence on the impact of food-level strategies on portion size awareness, amount selected, or intake**

Table S2 **Overview of current evidence on the impact of individual-level strategies on portion size awareness, amount selected, or intake**

Table S3 **Overview of current evidence on the impact of population-level strategies on portion size awareness, amount selected, or intake**

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Figure 1 Effect sizes reported in meta-analyses of strategies to reduce actual intake by strategy category (a) and decreasing magnitude of effect size (b). Each bar depicts the overall effect size ± 95% confidence interval for each strategy and corresponds to a separate analysis. Bars representing meta-analyses extracted from the same publication are filled with the same shade. A positive effect size represents an increase, and a negative effect size, a decrease in actual intake. The code after each strategy on the *X* axis (eg, ZLA) corresponds with the code for each meta-analysis in Table 2. Afshin et al's meta-analysis[27] could not be included due to differential metrics being reported. Quality of the evidence is indicated as follows: + = very low or low quality of evidence; ++ = moderate quality of evidence; no sign = quality of the evidence not systematically graded. *Abbreviations:* CI, confidence interval; SMD, standardized mean difference.

Figure 2 Effect sizes reported in meta-analyses of strategies to reduce intended intake, by strategy category**.** Each bar depicts the overall effect size ± 95% confidence interval for each strategy and corresponds to a separate analysis. Bars representing meta-analyses extracted from the same publication are filled with the same shade. A positive effect size represents an increase, and a negative effect size, a decrease in actual intake. The code after each strategy on the *X* axis (eg, ZLA) corresponds with the code for each meta-analysis in Table 2. Quality of the evidence is indicated as follows: + = very low or low quality of evidence; ++ = moderate quality of evidence; no sign = quality of the evidence not systematically graded. The number of comparisons included in each meta-analyis are indicated with *k*. *Abbreviations:* CI, confidence interval; SMD, standardized mean difference.

Table 1 **Overview of current evidence on the impact of food-, individual-, and population-level strategies on portion size awareness, amount selected (intended intake), or actual intake**

Reference	Evidence level[a]				Mediators	Overall magnitude of effect or impact[b]	Timeline of studies
	M	A	B–D	R			
FOOD-LEVEL STRATEGIES							
PS offerings							
Zlatevska et al (2014)[2] (**27**), Hollands et al (2015)[3] (**55**)	√				Larger and smaller PS offerings, PCMs	Small, moderate or large for acute effects on actual and intended intake (eg, actual intake: 9%–13% less meal/protein; 87% more vegetables)[90]; small for longer-term effects on selection (eg, incomplete implementation of intervention[91])	Acute, medium, and long term (3, 12 mo)
Rock et al (2016),[43] Rolls et al (2017),[14] Lewis et al (2015),[12] Robinson and Kersbergen (2018),[13] Reinders et al (2017),[90] Hollands et al (2018)[91]		√					
Berkowitz et al (2016)[92]			√				
Ordabayeva and Chandon (2016)[44]				√			
Pack and unit size/number							
Hollands et al (2015)[3] (**55**)	√				Larger, medium, and smaller packs/ containers, unit size, unit number	Small to moderate effect on actual and intended intake	Mostly acute studies (some medium term)
Brogden and Almiron-Roig (2011),[38] Almiron-Roig et al (2013),[39] Van Kleef et al (2014)[45]		√					
Van Kleef et al (2014),[45] Mantzari et al (2018)[46]			√				
Ordabayeva and Chandon (2016)[44]				√			
Food label							
Brown et a l(2018)[28] (**32**), Bucher et al (2018)[47] (**5**)	√				Larger and smaller PS info on label, PS contextual info on label, type of meal, larger PS image on pack, taste, nutrition, and health information	Unknown (limited evidence) or varied effect (from increased to decreased consumption) on actual intake; no effect of health or taste information on portion-size selection (confounding effect of general health interest)	Mostly acute laboratory studies (some cross-sectional and field studies)
Almiron-Roig et al (2013),[39] Tal et al (2017),[48] Dallas et al (2015),[49] Neyens et al (2015)[50]		√					
Tal et al (2017),[48] Benson et al (2018)[30]			√				
Ordabayeva and Chandon (2016),[44] Klieman et al (2018)[51]				√			
Tableware							
Robinson et al (2014)[52] (**8**), Hollands et al (2015)[3] (**58, 3**), Holden et al (2016)[40] (**20**)	√				Larger and smaller dishes, bowls, and glasses; wider	Small, moderate, or large for dishware on intended	Acute, 3, 6 mo

Pedersen et al (2007),[53] Kesman et al (2011),[54] Huber et al (2015),[55] Almiron-Roig et al (2016)[41]		√			and shorter glasses; portion-calibrated plates, bowls, and glasses; knowing study purpose	and actual intake (tends to disappear beyond 3 mo) Large impact on intake for bottles/glasses	
Hughes et al (2017)[56]			√				
Sensory effects, expectations McCrickerd et al (2017)[57]		√			Sensory and ED manipulations, aesthetic and symbolic value of food, perceived sensory pleasure, satiety	Small effect on actual intake (around 10%)[57]. Impact on intended intake seen also in virtual experiments[59]	Acute studies
Cornil and Chandon (2016),[58] Cornil and Chandon (2016)[59]			√				
McCrickerd and Forde (2016)[42]				√			
INDIVIDUAL-LEVEL STRATEGIES ***Eating rate/bite size*** Robinson et al (2014)[60] (**22**)	√				Modifications in eating rate, bite size, chewing rate	Small to medium effect on actual intake (45 g reduction in PS in 12 mo RCT)[61]	Acute, 12 mo, or cross-sectional
Ford et al (2009),[61] Li et al (2011),[62] Zhu and Hollis (2014),[63] Almiron-Roig et al (2015),[64] McCrickerd et al (2017)[57]		√					
Fogel et al (2017)[65]			√				
Plate cleaning Rolls et al (2002),[66] Sheen et al (2018),[67] Zuraikat et al (2018),[68] Krishna & Hagen (2018)[69]		√			Effects of gender, BMI; presence of leftovers on plate-cleaning tendency	Null to small effect on actual intake (PS effect blunted by 47 g or 71 kcal for each 100 g of additional food eaten in a meal)[68]	Acute, cross-sectional
Fay et al (2011),[70] Hinton et al (2013),[71] Robinson et al (2015)[72]			√				
Portion-size norms Robinson et al (2014)[73] (**5**)	√				Gender, BMI, PS anchors, perceived impulsivity, perceived appropriateness, food-related emotional conflicts, personal and social norms, parental influence, knowing purpose of the study, stakeholder priorities	Moderate effect, seen mostly for intended intake	Mostly acute (1 study short term)
van Kleef E et al (2014),[45] Marchiori et al (2014),[74] Lewis et al (2015),[75] Robinson et al (2016),[76] Robinson and Kersbergen (2018)[13]		√					
Ordabayeva and Chandon (2016),[44] McCrickerd and Forde (2016),[77] Marteau et al (2015),[25] Robinson et al (2013)[95]				√			
Cognitive strategies Robinson et al (2013)[78] (**19**)	√						

Poelman et al (2015),[79] Young et al (2015),[80] Rolls et al (2017),[14] Sim et al (2018),[81] Whitelock et al (2018)[82]		√			PC strategies, physical activity, takeaway consumption, perceived deprivation, psychological mindset, premeal planning, previous food experience, episodic memory, food environment	Null to large effect on intended and actual intake (inconclusive effects for role of attention on later food intake)[78,82]	Acute, 3, 6, and 12 mo
Crum et al (2011),[83] Hege et al (2018)[84]			√				
Brunstrom (2011),[85] Brunstrom (2014),[86] Rucker and He (2016),[87] Steenhuis and Poelman (2017)[18]				√			
POPULATION-LEVEL STRATEGIES ***Physical environment*** Bucher et al (2016)[29] (**18**)	√				Positional changes (distance, order) affecting immediate food intake or choice at individual level	Positive effect on food choice from closer position of foods; however, compensatory behavior detected in some studies	Acute RCTs except for 1 long-term (9 mo) longitudinal study
Educational and social environment Robinson et al (2013)[73] (**5**)	√				Information about healthy/less healthy eating habits of others, individual traits (BMI, gender), program adherence	Moderate effect of intake norms on food choice; low impact of public health campaigns on intakes for healthy/less healthy foods	Acute and long term
Croker et al (2012)[37]		√					
UK Department of Health (2016)[94]			√				
Higgs (2015),[96] The Marketing Society (2010)[88]				√			
Economic environment Afshin et al (2017)[27] (**30**)	√				Price reductions (subsidies) and increases (taxation)	Price reductions on healthy foods increased intake by 12% and price increases of unhealthy foods decreased intake by 6% for each 10% change in price[27]; small overall effect when price incentive unnoticed, incentive too small, other concurrent factors (eg, calorie information given)	Acute, medium, and long term
Haws and Liu (2016)[89]		√			Promotional price and calorie label		
Steenhuis and Vermeer (2009),[23] Vermeer et al (2014)[24] Steenhuis and Poelman (2017)[18]				√	Financial incentives in cafeterias and restaurants		
Policy[c] Knai et al (2015)[93] (umbrella review of **17 reviews**)	√				Synchronized action from policy makers, industry, and the public, involving structural changes beyond information or awareness raising	Potentially moderate impact on selection and consumption if implemented at scale	Acute, medium, and long term
Marteau et al (2015)[25]				√			

Meta-analyses with overlapping studies are included if the total number of studies differs. Individual studies are included only when not included in previous reviews or meta-analyses. Studies including experiments addressing >1 strategy are included under each of the corresponding strategy categories.

Timeline defined as acute (1 d), short term (1 wk), medium term (2–3 wk), long-term (≥4 wk). Number of publications included in meta-analyses are shown in parentheses and bold type. Quality of the evidence is presented in Table 2 (for meta-analyses only). Full details of all studies are given in Tables S1–S3 (*see the Supporting Information online*).

Abbreviations: A, highest evidence level category (see footnote *a*); B–D, second to fourth evidence level categories (see footnote *a*); BMI, body mass index; ED, energy density; M, meta-analysis or systematic review; PCM, portion-controlled meal; PS, portion size; R, narrative review or analysis paper; RCT, randomized controlled trial.

[a]Type of evidence based on American Dietetic Association Evidence Library criteria[31]: A = randomized controlled trial, cluster randomized trial, or randomized crossover trial; B = prospective or retrospective cohort study; C = nonrandomized controlled trial, nonrandomized crossover trial; case–control, time series, diagnostic, validity, or reliability study; D = noncontrolled trial, case study, case series, cross-sectional, trend, before-after, or other descriptive study; M = meta-analysis or systematic review; R = narrative review.

[b]Effect based on Cohen´s *d* criteria[32] for meta-analyses: Small, $d \leq 0.2$ small magnitude or clinical relevance (even if significant); Medium, $d = 0.5$ medium magnitude or clinical relevance; Large, $d \geq 0.8$ significant effect of clinical relevance. For individual studies not reporting effect-size metrics, the effect was judged by the magnitude of changes reported.

[c]Includes analysis or review papers where portion-size reductions are studied/reviewed and presented in a policy or population health context.

Table 2 **Effect size of strategies to reduce amount selected or consumed from the meta-analyses identified in this review**

Strategy / intervention	Reference (code)	Impact on actual intake			Impact on intended intake			Effect size magnitude[a]	Quality of evidence
		ES (95% CI)	k	I^2	ES (95% CI)	k	I^2		
FOOD LEVEL									
PS offerings (larger)	**Zlatevska et al (2014)[2] (ZLA)**	0.45 (0.38–0.52)	86	65%	0.18 (0.05–0.31)	13	41%	Small to medium	Moderate
	Hollands et al (2015)[3] (HOL)	0.37 (0.26–0.48)	58	NA	0.30 (0.09–0.50)	5	NA	Small to medium	Moderate (GRADE)
Pack and unit size or number (larger)	**Hollands et al (2015)[3] (HOL)**								
	Pack size	0.54 (0.27–0.80)	10	NA	NA	NA	NA	Medium to large	Moderate (GRADE)
	Unit size	0.33 (0.07–0.58)	9	NA	NA	NA	NA	Small to medium	Moderate (GRADE)
Modified tableware	**Robinson et al (2014)[52] (ROB4)[b]**								
	All smaller tableware	−0.18 (−0.35 to 0.00)	15	77%	NA	NA	NA	Small	Not formally or systematically assessed, but limitations noted

	Smaller plates only	−0.06 (−0.24 to 0.11)	11	64%	NA	NA	NA	Small	
	Smaller bowls only	−0.61 (−0.94 to −0.29)	3	69%	NA	NA	NA	Medium to large	
	Hollands et al (2015)[3] (HOL)								
	All larger tableware	0.29 (0.07–0.51)	12	NA	0.51 (0.21–0.81)	7	NA	Small to medium	Moderate (GRADE)
	Shorter and wider water bottle	1.17 (0.57–1.78)	1	0%	NA	NA	NA	Large	Very low quality (GRADE)
	Shorter and wider soft-drink bottle/glass	1.47 (0.52–2.43)	3	90%	NA	NA	NA	Large	Low quality (GRADE)
	Holden et al (2016)[40] (HLD)								
	All larger tableware	0.35 (0.29–0.41)	27	NR	0.51 (0.46–0.56)	29	NR	Small to medium	Not formally or systematically assessed, but impact of being aware of study purpose tested
	Larger plates only (area)	0.06 (−0.06 to 0.18)	10	NR	0.49 (0.27–0.71)	7	NR	Small to medium	
	Larger bowls only (volume)	0.47 (0.39–0.55)	16	NR	0.79 (0.57–1.01)	10	NR	Medium to large	
	Larger plater only (volume of serving utensil)	1.15 (0.15–2.15)	1	0%	0.33 (0.22–0.44)	12	NR	Large (actual intake), small to medium (intended intake)	
INDIVIDUAL LEVEL									
Eating rate/bite size (quicker/larger)	**Robinson et al (2014)[60] (ROB2)**	0.45 (0.25–0.65)	24	92%	NA	NA	NA	Medium	Not formally or systematically assessed, but no major limitations noted (from assessing blinding, randomization, participant awareness of aims, confounding, publication bias)
Portion-size norms	**Robinson et al (2014)[73] (ROB3)**								Not formally or systematically assessed, but no major limitations noted (from assessing participant awareness of aims, assessing awareness of aims, control/comparator type, method limitations, publication bias)
	High intake norms	0.41 (0.20–0.63)	11	47%	NA	NA	NA	Small to medium	
	Low intake norms	−0.35 (−0.59 to −0.10)	8	56%	NA	NA	NA	Small to medium	
Cognitive strategies	**Robinson et al (2013)[78] (ROB1)**								Overall "high quality evidence"
	Distraction on immediate intake	0.39 (0.25–0.53)	14	70%	NA	NA	NA	Small to medium	Moderate
	Distraction on later intake	0.76 (0.45–1.07)	6	0%	NA	NA	NA	Large	Moderate
	Enhancing memory of foods eaten on later intake	−0.40 (−0.68 to −0.12)	6	0%	NA	NA	NA	Small to medium	Moderate
	Removing visual cues of amounts eaten on immediate. intake	0.48 (0.27–0.68)	4	59%	NA	NA	NA	Medium	Not formally or systematically assessed
	Enhancing attention on immediate intake	−0.09 (−0.42 to 0.25)	2	0%	NA	NA	NA	Small	Moderate
POPULATION LEVEL									
Economic environment	**Afshin et al (2017)[27] (AFS)[c]**								
	Taxation (per each 10% increase in price)	−6.01% (−7.83 to −4.20)	15	65%	NA	NA	NA	Small to medium	Moderate (Class II AHA, Grade B USPSTF)
	Subsidy (per each 10% reduction in price)	12.42% (10.16–14.68)	22	99%	NA	NA	NA	Small to medium	Strong (Class I AHA, Grade A USPSTF)

Meta-analyses with overlapping studies are included if the total number of studies differs. I^2 for analyses including a single comparison ($k = 1$) has been assumed as 0 when not reported. Intended intake includes portion-size selection. Effect sizes are indicated as standardized mean differences

(SMD), Cohen's *d*, or % change, based on each publication. ES > 0 indicate increases and <0 decreases in intake for the listed strategy. For details of individual studies, *see Tables S1–S3 in the Supporting Information online*.

Abbreviations: AHA, American Heart Association; CI, confidence interval; ES, effect size; GRADE, Grading of Recommendations Assessment, Development, and Evaluation; NA, not applicable; NR, not reported; USPSTF, US Preventive Services Task Force.

[a]Magnitude of effect size based on Cohen's *d* criteria[32] for meta-analyses: small, $d \leq 0.2$ small magnitude or clinical relevance (even if significant); medium, $d = 0.5$ medium magnitude or clinical relevance; large, $d \geq 0.8$ significant effect of clinical relevance.

[b]For laboratory studies, overall effect size for all tableware was −0.06 (95%CI, −0.24 to 0.11; $k = 11$; $I^2 = 64\%$) and for field studies was −0.47 (95%CI, −0.84 to 0.09; $k = 4$; $I^2 = 86\%$).

[c]Taxation was explored for fast foods, sugar-sweetened beverages, and other unhealthy food and beverages. Subsidies were explored for fruit and vegetables plus other healthy food and beverages.