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Review

Mechanisms underlying the portion-size effect

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HIGHLIGHTS

- We review candidate explanations for the portion-size effect.
- One strong candidate is that a given portion suggests an appropriate amount to eat.
- The data require variations on a simple "appropriateness" explanation.
- Explanations based on visual cues are also considered.
- Portion size may affect bite size and consequently oral exposure and intake.

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ABSTRACT

The portion-size effect (PSE) refers to the fact that people eat more when served larger portions. This effect is neither obvious nor artifactual. We examine the prevailing explanations (or underlying mechanisms) that have been offered for the PSE. The dominant candidate mechanism is "appropriateness"; that is, people accept the portion that they are served as being of an appropriate size and eat accordingly. Because people do not necessarily finish the portion that they are served, variations on the basic appropriateness mechanism have been suggested. We also consider some evidence that is inconsistent with an appropriateness explanation, including the appearance of the PSE in children as young as two years of age. We also examine other mechanisms that do not rely on appropriateness norms. Visual food cues may assist in assessing appropriateness but may also drive food intake in a more mindless fashion. Larger portions induce larger bites, which may increase intake by reducing oral exposure time and sensory-specific satiety. We consider further research questions that could help to clarify the mechanisms underlying the PSE.

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1. Introduction

The "portion-size effect" (PSE) refers to the empirical phenomenon whereby variations in portion size (sometimes in the form of an experimental manipulation) produce corresponding variations in food intake (i.e., larger portion sizes increase intake and smaller portion sizes reduce intake). Rozin et al. [55] assert that "probably the single most important determinant of meal intake is how much is served" (p.450). There is substantial evidence for the reality and power of the PSE, although it is neither ubiquitous nor omnipotent. Two significant reviews of the PSE have been published within the past decade [3,59]. These reviews discuss the nature, extent, and limits of the PSE, and their availability obviates the need for another review (at least for a few years) and allows us to proceed with only a cursory summary of the main findings before addressing our particular concern — the narrower issue of *why* the PSE occurs. Many discussions of the PSE have avoided the issue of underlying mechanisms entirely; and most of the remainder have speculated about underlying mechanisms without achieving much closure. In this paper, we will tackle the "mechanism" issue head-on; and although we may not reach a definitive conclusion, we will move the yardsticks toward that goal line. Recently, English et al. [18] provided a review and analysis of "mechanisms of the portion size effect." Their paper, with a distinctly different emphasis than our review, also failed to reach a definitive conclusion. It should be read as a complementary document.

1.1. Preliminary issues

Before summarizing the literature we must address some preliminary questions and issues. First, what do we mean by "portion size"? For some researchers (e.g., [44]), "portion size" means "the amount of food consumed," whereas for other researchers (e.g., [49]), "portion size" refers to "the amount of food served," irrespective of the amount consumed. To avoid a tautology ("people eat more when they eat more") we will adopt the latter definition and insist that "portion size" refers to the amount served rather than the amount consumed.

Second, we must address a methodological concern — namely, the possibility that the portion-size effect is a methodological artifact. Specifically, if people eat the entire portion that is served to them, then they will necessarily eat more when served a larger portion than when served a smaller portion. Such an artifact might arise if people lacked any sort of satiety mechanism, or if they were simply hungry enough (or liked the food enough, or the portions were small enough) to eat all the food provided to them, even in the "large portion" condition. If such were the case, the portion-size effect would not be of much interest. Researchers have been aware of this interpretive threat, however, and have taken steps to mitigate it. For instance, in the "small portion" condition, researchers will serve an initial small portion but often make available a further easily accessible supply or reservoir of the food, so that participants can take (and eat) more if they so choose (e.g., [49]). Thus, in the "small portion" condition, participants' intake is not limited to the amount initially served (the small portion). In the "large portion" condition, participants are typically served more than they can (or at least, do) eat, so it is not the case that they are simply eating the entire portion and therefore eating a very large amount. (In fact, in most studies even the small portion is large enough so that most participants do not finish it [e.g., [49]]. This consideration is important inasmuch as finishing one's initial portion and then supplementing it may well be quite a different phenomenon from simply eating more of an initial portion; so the fact that the small portion is rarely finished removes some potential interpretive complications.) Finally, some researchers (e.g., [13]) eliminate from the data analysis all participants who finish their initial portion ("plate cleaners"); even with these participants eliminated, the portion-size effect usually emerges.

Portion size has been manipulated in various ways, in what amount to various different paradigms. The most recognized approach is to present research participants with larger or smaller portions of a particular food. Pasta, an amorphous food, is the paradigmatic example [49], but the same principle applies when the researchers present participants with a single sandwich that varies in size [52]. An alternative approach is to vary the number of items presented; for instance, Nisbett [43] presented research participants with either one or three sandwiches as the initial portion, with all sandwiches being the same size. Finally, some researchers (e.g., [40]) present the same amount of food to each participant, but cut the food so that there are, say, twice as many items in one condition than in the other, but those more numerous items are only half the size. Such a manipulation technically does not affect the size of the portion, but some researchers have argued that the number of items offered is as important as (and maybe more important than) the size of the items. In our analysis of underlying mechanisms, we must remain cognizant of the various alternative approaches to manipulating portion size.

1.2. Summary of the literature

To overgeneralize only a little, the literature based on studies in which the initial portion served is manipulated tends toward a clear conclusion: larger portions lead to greater intake, although the proportional increase in actual intake is almost always less than the proportional increase in manipulated portion size (which is often arbitrarily large). Zlatevska et al. [73] meta-analysis found that, on average, for adults, a doubling of portion size results in a 35% increase in intake. Some studies (e.g., [16], Study 1; [37]) have failed to find a PSE, and there may be other failures sitting in file drawers, but the reality and power of the PSE are not in dispute. Evidence of its strength may be found in the PSE's resistance to attempts to reduce or eliminate it. Marchiori and Papies [38] had participants engage in a mindfulness meditation exercise intended to combat the PSE, but the PSE was unaffected (a 60% increase in intake in the condition in which portion size was tripled) (see also [9]). Practicing chefs are well aware of the PSE [11], confirming its real-world power. The PSE operates even if the food is less than highly palatable (e.g., [74]) or when diners cannot see what they are eating (e.g., [57]) or when people are exposed to portion-size manipulations lasting for weeks [32] or even months [25].

Some aspects of the PSE are surprising and may bear on any attempt to explain the phenomenon. For instance, despite the substantially greater intake in the "large" condition, research participants tend to report no more satiety at the end of the meal than do participants in the "small" condition. This finding has been for the most part ignored but bears on the cogency of one of the possible mechanisms. Also of potential explanatory relevance is Rolls et al.'s [47] finding of a strong PSE for 5-year-old children, but no indication of a PSE in 3-year-old children. We will now turn to an examination of proposed mechanisms underlying the PSE. Those wishing more detail about the PSE's range and limits (and some of the moderating factors that come into play) are again referred to the reviews by Benton [3] and by Steenhuis and Vermeer [59]. New empirical studies involving the PSE appear on a continuing basis.

2. Mechanisms of the PSE

As Kral [35] has noted, "although the profound effects of portion size on energy intake are well documented, the mechanisms by which portion size affects energy intake are poorly understood" (p.103). As recently as 2014, Marchiori, Papies, and Klein argued that "no research has provided conclusive evidence regarding *why* people overconsume when more food is served" (p.109).

This bleak characterization notwithstanding, a number of potential mechanisms have been suggested. In their review, Steenhuis and Vermeer [59] identified two mechanisms underlying the PSE: value

for money (i.e., larger portions represent a better economic value) and "portion distortion" (i.e., larger portions have become normative). Considering the first (value for money) explanation, there is no denying that consumers believe (usually accurately) that they are getting more for their money when they purchase and consume larger portions (see [65], for a version of this argument), but there are some problems with this interpretation of the PSE. For one thing, in most laboratory studies of the PSE, there is no economic benefit to eating more when presented with a larger serving; the food is provided free of charge. Of course, clever research participants might calculate that if they eat more during the experimental session, then they will save money later on, because they will be less hungry later on and therefore require less food (and incur less expense). The research on the PSE, however, provides no indication that eating more during the experimental session suppresses subsequent intake; people tend not to "compensate" for a larger or smaller meal by following it with a smaller or larger meal (e.g., [51,58]), and thus there are no savings (caloric or economic) from eating a lot in the lab. Indeed, if research participants wanted to get "the most for their money" (or get the most for nothing), they would eat as much as possible in all conditions; but the PSE research makes it clear that people in the small portion conditions eat less than do those in the large portion conditions, even when we eliminate those few participants who eat everything that they have been offered. There is no obvious economic explanation for this consistent pattern. Moreover, in many of the portion-size studies, participants' awareness of their eating is assessed and indicates that they are not aware that they have overeaten (e.g., [67]), so this does not appear to be a deliberate strategy on the part of the participants. The "portion distortion" (normative/appropriateness) mechanism is one that makes more sense to us, but it is by no means the only plausible mechanism; and as we shall see, it ignores certain aspects of the data.

2.1. Appropriateness

The most prevalent explanation for the portion-size effect is that people consider the portion that they are served to be appropriate, an indicator of how much to eat. If people are served a relatively small portion, they consider it appropriate and eat accordingly; and if they are served a relatively large portion, they likewise consider it appropriate and eat accordingly. This explanation presupposes that people's food intake is not principally dictated by hunger and satiety sensations [29] and that people, in the absence of other guidance, use portion size as a guide. This "normative" explanation is usually associated with Brian Wansink and his colleagues. "The size of a serving bowl [or of a portion] may provide a consumption cue that implicitly suggests an appropriate amount to eat" [66, p.1728]. According to one summary, Wansink and van Ittersum [68] suggest that "portion size influences consumption norms. People are flexible in the amount they can eat, and portion size is likely to help them define the size of a reasonable meal. A supersized portion is likely to result in an upward shift of the consumption norm, particularly for people who do not pay much attention to how much they are eating" [60, p.70]. Smith and Ditschun [75], in their review of environmental influences on food intake, more or less endorse Wansink's view. We too [29,31] have championed a normative approach to understanding food intake in humans. This view has also been articulated by Rolls and her group, who have suggested that "people have the expectation that the amount of food served to them by others is appropriate" [49, p.1211].

Judgments of appropriateness extend across a wide range of portion sizes, with the result that widely discrepant portion sizes are all considered appropriate (but see [10], who argue that small packages are viewed as providing an appropriate serving whereas large packages "clearly contain more than a single serving" [p.382] and are therefore not consumed in their entirety). People appear to assume that whoever determined the portion size selected that particular size not at random but rather after some deliberation about what a suitable amount to serve would be. (Condrasky et al. [11] found that in most restaurants, it is the executive chef who decides how large portions will be.) There are probably limits beyond which most people would deem a particular portion size preposterously small or large and refuse to accept that portion size as appropriate, but the limits of appropriateness have not been explored in any detail. Marchiori et al. [39] found that "portion size effects have been shown with implausible anchors [i.e., initial portions]" (p.113). Diliberti et al. [13] found that smaller (standard) and larger (150% of standard) portion sizes were perceived as equally appropriate (4.4 and 4.6 on a scale from 1 = "way too small" to 7 = "way too large"; in other words, both portion sizes were perceived as close to just right), suggesting that both portion sizes were perceived as appropriate. Looked at another way, increasing the portion size by 50% did not render it any less appropriate. Further, there was no difference in retrospective estimates of amount eaten in the two conditions, supporting the notion that people are not monitoring their intake in any absolute way, although perhaps they are monitoring their intake in relation to the size of the portion (e.g., they may know that they have eaten half the portion). Finally, Kerameas et al. [33] found that participants who were served 90 g of cookies thought that it was appropriate to eat more than did participants who were served 30 g of cookies, and that perceived appropriateness mediated the effect of portion size on food intake.

One might ask what would happen if experimental participants were told that the portion size that they were served was not determined by a supposedly rational human but instead by a random-number generator or perhaps by a dart-throwing monkey. Would people reject the portion as inappropriate in size and fail to show the PSE? Marchiori et al. [39] manipulated whether experimental participants were given "discounting" information (i.e., information that the portion-size anchors had been selected at random) and found that knowing that the anchors were generated randomly did not reduce the PSE. We suspect that people become so accustomed to deferring to the presumed suitability of a given portion that they continue to defer even when the sensibleness of the portion becomes objectively doubtful.

In Marchiori et al.'s [39] "anchoring" interpretation of the PSE, the initial portion serves as an anchor – in effect, a tentative proposal of how much should be eaten – subject to possible adjustments based on hunger, palatability, and other considerations. In our view, the anchoring hypothesis does not differ significantly from the appropriateness hypothesis; indeed, Marchiori et al. concede that "anchors such as the portion size may become influential as they serve as relatively easy indicators of what might be an appropriate consumption amount" (p.109). They explicitly describe the appropriateness interpretation as consistent with their anchoring interpretation.

Some data appear to directly threaten the "appropriateness" interpretation of the PSE. Ueland, Cardello, Merrill, and Lesher [76] served people identical portions that were presented explicitly as 50%, 100%, or 150% of a normal portion. Being served a portion that was allegedly larger or smaller than a normal (and presumably appropriate) portion had no effect on overall intake, which might be seen as conflicting with an "appropriateness" interpretation of the PSE. In our lab (unpublished), we likewise presented (identical) portions of a main course that were labeled as small, average, or large, with no effect on (a) intake of the portion itself or (b) intake of a subsequent dessert. Rather than providing a challenge to the appropriateness interpretation, we suggest that a likely explanation for these findings is that the portion sizes themselves connote appropriateness, overriding experimenter-provided labels.

2.1.1. Fractional portions

Portion size may provide an indication of how much is appropriate to eat, and people do eat more as the portion expands. However, it is also important to point out that people often do not eat the entirety of

what they are served, suggesting that eating the entire portion is considered inappropriate, at least for them. Perhaps people restrict themselves to a specific fraction (e.g., half or three-quarters) of what they are served, with the result that they end up eating more when served a large portion that when served a small portion, even though they do not eat the entire portion in either case. This "fractional" version of the normative explanation probably works better than does the "unqualified" version (in which the appropriate amount to eat is the entire portion), but it raises interesting (and as yet unanswered) questions about what fraction of the entire portion is considered appropriate, how people arrive at this fraction, whether different people use different fractions, whether people leave not a fraction but a certain amount, and so on and so forth. Further, it is interesting to speculate about how conscious people are of these judgments. People behave "as if" they are calibrating their intake to the supplied portion, but the precise cognitions that accompany these eating episodes remain largely unexplored. Cavanagh et al. [9] found that participants failed to acknowledge that their food intake was influenced by portion size. Likewise, Wansink et al.'s [67] participants showed no awareness that the portions in their soup bowls were larger or smaller. We thus have some inkling of what people are *not* thinking, but not much inkling of what they *are* thinking (or whether they are thinking about their meal at all).

A variation on the "fractional" explanation was proposed by Burger et al. [8]. They suggested that people stop eating when they have consumed enough so that their plate achieves a certain degree of "emptiness." "Thus, when a large amount of food is offered, more would have to be consumed before the specific amount of plate space/residual food is reached and signals meal termination" (p.546). These researchers, however, found that the PSE was unaffected by whether the participants could see their plates or not – in some cases they were blindfolded – which would appear to rule out any explanation based on visual observation of the plate being sufficiently empty, although tactile evidence of emptiness could presumably substitute for vision.

A complementary mechanism of the PSE is contained in the "unit bias heuristic" proposed by Geier et al. [26]. Unit bias refers to people's tendency to eat one unit of food, irrespective of its size (within limits). As Nestle [42] puts it, "most people seem to view a soft drink as a soft drink, no matter how big it is" (p.40). (This same principle was exploited in the original conception of "supersizing." People are more likely to purchase one double-sized bag of popcorn than two single-sized bags, even holding price-per-gram constant.) People consider eating a given amount of chocolate more appropriate when it is presented as one larger piece than as five smaller pieces [62]. Geier et al. concede that exclusive control of intake on the basis of unit bias is "an unlikely state of affairs" (p.522), but the operation of unit bias may well account for some and possibly a substantial amount of the variance in intake. Geier et al. endorse the notion of appropriateness norms, but argue that "the norm of eating 'one' is not arbitrary" (p.524). Others have challenged the "unit bias" interpretation of the PSE. Koh and Pliner [34], for instance, suggest that "one plate of food" is not a "unit" of particular power. In Koh and Pliner's study, in which additional pasta with tomato sauce was available, some people helped themselves to a second serving but there was no difference in the amount eaten by those who took only one versus two servings. In other words, some people took two smaller servings while others took one larger serving. Raynor and Wing [45] manipulated portion size and unit size orthogonally and found an effect for portion size but not for unit size. Kerameas et al. [33] served participants either 30 g of cookies (one 30-g cookie or 3 10-g cookies) or 90 g of cookies (one 90-g cookie or 3 30-g cookies), and found that (a) participants were highly unlikely to eat precisely one cookie, regardless of condition and (b) although people did eat more when served one large cookie than when served three smaller cookies, the PSE (i.e., people eating more when served 90 g rather than 30 g, irrespective of whether the serving was one large cookie or three smaller cookies) was the most powerful effect.

2.1.2. Development of the appropriateness norm

The study by Rolls et al. [47] found a PSE for 5-year-olds but not for 3-year-olds. This finding might be seen as supporting an "appropriateness norm" interpretation of the PSE, on the premise that 5-year-olds, but not 3-year-olds, may have developed an appreciation of (or subjugation to) social norms. Any normative interpretation of the PSE would have to require that the effect emerges at some point during childhood, in concert with the development of norm-governed behavior.[1] "These findings suggest that, as children grow older, they become less responsive to internal hunger and satiety cues and more reactive to environmental stimuli" [15, p.476].[2] Vartanian et al.'s [63] meta-analysis confirmed this pattern.

Before we invest more effort into understanding the shift toward more "normative" eating between the ages of 3 and 5, we must acknowledge some indications that the PSE, or at least its precursors, may be evident even earlier. Ello-Martin et al. [17] note that "the average portions of foods consumed by 2-yr-olds have remained stable over a 20-yr period, although many commercially available products have increased in portion size during this time" (p.236S); this observation is meant to suggest that 2-year-olds do not show a PSE. Still, Fox et al. [24] found that whereas up to the age of 12 months infants showed quite good within-meal energy regulation, beyond the age of 12 months this precise regulation deteriorated, presumably opening the door for the intrusion of environmental effects, including the PSE. Fisher [20] found a PSE in children as young as 2 years of age. Fisher et al. [23] also found a PSE in both younger and older children, although they entertain "the possibility that the magnitude of developmental differences in children's responsiveness to portion size may become more pronounced with increasing age and exposure to environmental influence" (p.1169). This evidence of the PSE (or something like it) in 1- and 2-year-olds challenges the notion that the PSE is based on a developing social concern with propriety, something that is notably absent in such young children. Maybe the PSE reflects the operation of some other underlying mechanism. Are we prepared to accept the proposal that 2-year-olds behave in a norm-governed fashion? And if not, then perhaps responsiveness to norms is not a prerequisite for the operation of the PSE. Fisher and Kral [22] argue that "children [are] relatively unaware of the increases to entrée portion size" even while showing the PSE. Again, it is difficult to specify how conscious people (adults or children) are of portion size and their response to it. In any case, it is difficult to reconcile a norm-based explanation for the PSE with the presence of the PSE in 2-year-olds.

2.1.3. Unsettled issues regarding appropriateness

Whether or not toddlers adhere to appropriateness norms is only one puzzle currently facing proponents of the appropriateness interpretation of the PSE. One may also ask whether the appropriateness of a particular portion is fixed or malleable, and whether there are degrees of appropriateness. Ferriday and Brunstrom [19] found that people were willing to "tolerate" (i.e., consume without reluctance) portions much (almost 40%) larger than their ideal portion size. So it would appear that whatever norm is implicit in the notion of an ideal portion size, people are prepared to have that norm overridden by whatever norm is imposed by a larger portion. In other words, a perfectly appropriate (i.e., ideal) portion may be supplanted by a different, larger portion, which is also treated as "tolerably" appropriate.

Scheibehenne et al. [57] found that "people with super-size portions in the dark consumed more food compared to those in the light, where visual cues helped people to regulate their intake more and stop eating

[1] Bloom [4] notes that "disgust kicks in at roughly the age of three or four," presumably because children at that age have developed a distinction between what is appropriate to eat and what is not (see Rozin & Fallon [54] for a more extended discussion of the ontogeny of disgust).

[2] Do children become more "normative" in general as they age or is the shift from internal to external cues specific to eating and a function of explicit learning experiences in eating situations, such as being instructed to clean one's plate?

sooner" (p.712). Scheibehenne et al. suggest that visual cues act as a brake on intake, possibly because visual cues are crucial to the assessment of appropriateness: "Non-visual cues do not provide as accurate input as visual cues [do] for estimating food quantities and satiety and thus for stopping consumption" (p.713). Still, we must recall that Burger et al. [8] found that whether or not one could see one's plate had no effect on the PSE. At best, the presence of visual cues may explain why people in various large-portion conditions do not eat as much as they might, but it does not explain why they eat more in the first place. Certainly, the elaboration of any appropriateness interpretation of the PSE will require more attention to exactly what cues people use to establish and monitor appropriateness.

Some perplexing issues are raised by Nisbett's [43] finding that overweight participants displayed a PSE when offered either one or three sandwiches as an initial portion whereas normal-weight participants ate the same number of sandwiches irrespective of initial portion. Bauer [2], commenting on Nisbett's study, argues that overweight people are more concerned with avoiding inappropriate (eating) behavior than are normal-weight people; put differently, overweight people are highly concerned with behaving appropriately and therefore ate what the experimenter gave them and no more or less. Normal-weight people, by contrast, are unconcerned about eating appropriately and therefore ate strictly on the basis of hunger. It is probably prudent to remember that whereas normal-weight individuals did not show a PSE in Nisbett's study, they almost always show a PSE in other studies. Rolls for instance, has repeatedly found equivalent PSEs in overweight and normal-weight participants (e.g., [13,21,49]). Nisbett's overweight-versus-normal-weight difference is difficult to explain and perhaps should be regarded as anomalous.

Logically, it would appear to be easier to induce people to eat larger portions if the food is amorphous than if it is countable. With a countable food, it is easier to keep track of how much one has eaten. Nisbett, as we have seen, found no PSE, at least for normal-weight participants. Kerameas et al. [33], however, found that although people did eat less when their portions were subdivided into smaller, discrete units, this "segmentation" effect was much weaker than was the overall PSE, with (overwhelmingly normal-weight) participants who were served larger portions eating much more than did those who were served smaller portions, irrespective of segmentation/countability. It seems prudent to avoid putting too much emphasis on the distinction between countable and amorphous food until such time as a clear empirical difference emerges.

2.2. Other possible mechanisms

Although "appropriateness" has dominated speculation about the mechanism underlying the PSE, other mechanisms have been suggested. Here we discuss the two that have received the most attention in the literature: visual cues and bite size.

2.2.1. Visual cues

The role of visual cues in the PSE and in eating more generally requires clarification. One version of the role of visual cues involves a fairly primitive visual mechanism, reminiscent of the "seefood diet" – "If I see food, I eat it" – by which the mere sight of food triggers eating, and the more food that is present or visible, the more is eaten. This version does not explain why people stop eating before they consume everything on their plate, but neither does a non-fractional appropriateness explanation (and neither does Schachter's [56] "external cue" hypothesis, which dictates that [fat] people eat until all the food cues are gone).

Another approach suggests that people use visual cues as an element in the calculation of how much they should eat. For instance, Scheibehenne et al. [57] emphasize the importance of visual cues for the *termination* of eating (i.e., people stop eating when they *see* that they have had enough), although Burger et al. [8] found that the presence or absence of visual cues did not affect the magnitude of the PSE.

Wansink et al. [67] surreptitiously manipulated soup bowls so that in one condition the bowl imperceptibly refilled itself as the participant ate, resulting in a 73% increase in intake (with no increase in reported satiety) in the "imperceptibly refilling" condition. Presumably participants who saw that bowl remaining relatively full inferred that they had not eaten all that much. In effect, their eyes were deceiving them into overeating. This study, while raising various questions [27], nevertheless suggests that visual cues may play an important role in the PSE.

Rolls et al. [50] manipulated the size of the plate on which a constant portion was served. Some previous research (e.g., [69]) had suggested that a larger plate would make a given portion look smaller and thereby increase intake, but Rolls et al. found no difference as a function of plate (and spoon) size. A recent meta-analysis [46] likewise found weak and inconsistent effects of plate size on intake.

On balance, it must be conceded that the studies reviewed in this section are far from conclusive with respect to the precise role of visual cues in the PSE. It remains to be determined whether visual cues drive eating in a relatively mindless fashion or whether they contribute to the cessation of eating by assisting in the calculation of how much food is enough. English et al. [18] speculate about an "anchoring effect" by which the size of the portion affects judgments of appropriate intake, noting that "visual perceptions are easily biased…and this can affect our ability to judge amount consumed," but "whether this impacts actual intake is still unclear." In this context, it is worth distinguishing the situation that we have been considering, in which the experimenter serves a somewhat arbitrarily large or small portion to experimental participants, from the situation in which participants select their own portion. In the self-serve situation, people tend to eat most of what they serve themselves [6], whereas in the experimental situation, they often leave large amounts uneaten. In both cases, however, larger initial portions lead to greater intake. In the self-serve situation, we may well ask why participants selected the particular portions they do. Portion selection may reflect, for instance, variations in estimations of the satiating power of the available food (e.g., [6,7]) or (contra Brunstrom), the palatability of the food. This interesting question is independent of the PSE, however.

2.2.2. Bite size

Another possible mechanism, more sensory than normative, has emerged from Fisher's work. Fisher et al. [23] measured the number of bites that the children in their study took in the various conditions. Strangely, it turns out that increases in intake in the large-portion conditions were not associated with more bites of food; rather, the difference was attributable entirely to an increase in the *size* of bites, and that increase occurred only when children ate the large portion after the reference ("normal") portion, not in the reverse order. Fisher [20] again found that the PSE was "mediated" by significant increases in bite size in the large condition. More specifically, children in the large condition took larger bites, and the children who ate the most in the larger condition took more of these larger bites. The mediation of the PSE by bite size has not been explained by Fisher and her colleagues, who leave it to the reader to wonder why children take larger bites when encountering larger portions. Whether bite size mediates the PSE in other samples remains uncertain, because bite size is so rarely measured. Burger et al. [8], like Fisher et al., observed larger (but not more) bites in the large-portion condition. Almiron-Roig et al. [1] found a bite-size increase of 0.22 g for every 100 g increase in portion size. Dodd et al. [14] note that obese eaters tend to take larger bites, and also that they tend to select larger meals, but Dodd et al. do not connect these two phenomena in such a way as to suggest that it may be that larger portions induce larger bites. Finally, Stunkard et al. [61] did not observe larger bite sizes in the large-portion condition than in the normal-portion condition; however, obese participants did take

larger mouthfuls – perhaps equivalent to larger bites – than did normal-weight participants in the large-portion condition.

Is it possible that the PSE arises because larger portions induce larger bites which in turn eventuate in greater intake? One possible mechanism for larger bites producing greater intake involves sensory-specific satiety, which refers to the fact that as people consume more of the same food during a given eating episode, their liking for that food declines (e.g., [36]). If they switch to a different type or flavor of food, they tend to eat more than if they continue to eat the same food. "During the course of a meal the pleasantness of foods which have been eaten declines whereas the pleasantness of those foods not eaten remains relatively unchanged. Such changes in palatability affect the amounts of particular foods that will be eaten during the remainder of the meal" [53, p.116]. In effect, sensory-specific satiety means that people will tire of food as they eat more of it, or as they experience its sensory properties more extensively.

Sensory-specific satiety varies as a direct function of oral exposure time: the more time a given morsel of food spends in the mouth, the more opportunity there is for sensory-specific satiety to develop. Larger bites tend to translate into less oral exposure time (i.e., a given unit of food spends less time in the mouth), which in turn could mean that there is less opportunity for sensory-specific satiety to arise, which in turn should mean increased intake [48]. There is ample evidence (a) that larger bites are normally associated with reduced oral exposure time and (b) that reduced oral exposure time conduces to greater intake [5,12,71]. Zijlstra et al. [72] concluded that "greater oral sensory exposure to a product, by eating with small bite sizes rather than with large bite sizes and increasing [oral processing time], significantly decreases food intake" (p.269). (Note that this finding coincides with the diet recommendation to take small bites and chew one's food thoroughly.) Mishra et al. [41] (lab study) observed greater intake among participants using large forks than among participants using small forks; although these authors do not refer to oral exposure time, they do assume that larger forks produce larger bites, which (somehow) increase intake. (These same authors found, in a restaurant study, that larger forks *decreased* intake, necessitating a convoluted explanation in terms of "goal progress.")

The bite-size explanation might help to explain why people who eat larger portions tend not to report greater satiety afterward: it is satiety that terminates intake, but satiety[3] is reduced when one takes larger bites, all things equal. Weijzen et al. [70] presented snacks either as large bars or smaller nibbles. Intake was greater for the bars, an effect that Weijzen et al. attributed to sensory-specific satiety (SSS). Specifically, on a weight or calorie basis, (larger) bites of the bar spend less time in the mouth – ingestion rate by weight/calories was higher in the bar condition – and therefore induce less SSS and correspondingly greater intake. Weijzen et al. conclude that "the degree of SSS for a particular food may thus be dependent on the time-span in which the food is chewed or present in the mouth, i.e. the length of oral sensory stimulation" (p.436) and "a reduced oral sensory stimulation, due to a larger bite size, can explain the higher intake of the bars compared to the nibbles" (p.440). More chewing means more mouth time, so if larger bites mean "wolfing down" the food without chewing it much, then larger bites would mean less oral sensory stimulation, less sensory-specific satiety, and greater intake. Rolls et al. [52] found a larger PSE for men than for women, a sex difference that appears with some regularity throughout the literature [73]). One explanation for this sex difference – an explanation that has not yet been tested – is that men take larger bites than women do, so that the larger PSE might reflect the relatively limited oral exposure time for men of a gram or calorie basis.

The possibility that the PSE is mediated by bite size and its sensory consequences (rather than by considerations of appropriateness) is intriguing. Of course, considerably more research is required if this hypothesis is to be substantiated. For one thing, we need to confirm that larger portions induce larger bites (as may be implicit in [65]). Herman [28] suggested some ways to test the "bite size" hypothesis, including (a) seeing whether the PSE could be eliminated by holding bite size constant in large- and small-portion conditions, (b) seeing whether people rate the pleasantness of food the same in large- and small-portion conditions, despite differences in intake, and (c) seeing whether, if eating is prematurely terminated in both conditions after a fixed intake, people rate the food as pleasanter in the large-portion condition than in the small-portion condition.

3. Conclusions

The concern about large portions as a major contributor to the obesity epidemic, with attendant attempts to reduce portion size (see [30], for a review) appears to have distracted much of the research community from the basic question of why larger portions induce greater food intake in the first place. The PSE is treated as axiomatic – of course larger portions make people eat more – when in fact the underlying basis of the PSE is not very well understood at all, as we have made clear in this review. We have explored some leading candidate explanations for the PSE, including the dominant "appropriateness" explanation and the lesser-known "visual cues" and "bite size" explanations.

The "appropriateness" explanation, as we have seen, requires further work. Can it explain the appearance of the PSE in very young children? And what, precisely, do judgments of appropriateness entail? Do people explicitly judge the appropriateness of a given portion; and if so, why then do they so often leave part of the portion uneaten? Is it more a matter of it being appropriate to leave a certain amount (or proportion) of the food uneaten; and if so, how do people develop these "rules" for how much to eat? Can people articulate these rules? The "appropriateness" explanation would appear for the most part to depend on the apparent size of the portion, which raises the question of the role of visual cues in the process. How important are visual cues, and which visual cues are crucial — the amount served, or the amount or proportion remaining? As for the "bite size" explanation, we have already suggested some research that might help to validate it.

The appropriateness explanation (and the visual-cues explanation, with which it is entangled) could possibly be distinguished empirically from the bite-size explanation if one were to examine eaters' intentions at the beginning of the meal. According to the normative account, the "appropriate" amount to eat can be discerned as soon as the portion is presented (and before any food is consumed), even if appropriateness is based on the amount or proportion left over; and we should therefore observe portion-size-based differences in how much individuals expect to eat or how much is seen as appropriate to eat even before any eating has occurred. According to the bite-size explanation, however, the determination of how much to eat (i.e., when to stop) should not take place until the eater is already well into the meal and experiencing incipient (sensory-specific) satiety.

All of these explanations have some empirical merit, but none of them is conclusive. Perhaps other explanations will emerge to challenge them. We have attempted to identify some further questions whose answers might help to determine the cogency of the current candidate explanations. For the moment, we must remind ourselves that identifying a definitive mechanism underlying the PSE is a scientific challenge of considerable interest that should not be ignored.

[3] In this context, "satiety" refers to sensory-specific satiety, but it is possible that large bites make the food more difficult to digest, thereby reducing or delaying satiety feedback from the gut. Of course, insofar as satiety is based on volume of food ingested, rather than the digested nutrients in the food, it should not matter whether the food is ingested in large or small morsels. Wadhera and Capaldi-Phillips [64], however, argue that "gorging on food does not allow sufficient time for the release of regulatory peptides required for the development of satiety resulting in reduced feelings of fullness, increased desire to eat, and increased food intake."

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