



Marketing Science Institute Working Paper Series 2026

Report No. 26-104

Why Segmented Food Portions Appear Larger: Evidence for Numerosity and Surface Area but Not Reassembly Difficulty, with Implications for Smarter Downsizing

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2 February 2026

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Abstract

Segmented portions often appear larger than intact ones, prompting consumers to choose smaller amounts when food is divided into multiple units. However, the effect is inconsistent across studies, and its underlying psychological mechanisms remain unclear, limiting the development of more effective product downsizing strategies. Across six studies, we disentangle the contributions of three mechanisms: numerosity (the number of units), surface area (the space those units occupy), and reassembly difficulty (the mental effort required to recombine units). Contrary to the prevailing account, reassembly difficulty does not influence perceived size. Instead, segmentation increases perceived size through numerosity and surface area, both independently and interactively. These insights help explain inconsistent findings in prior work, such as negligible effects when segmentation minimally increases surface area or when numerosity differences are small. Leveraging these mechanisms, we design an enhanced virtual segmentation that combines high-numerosity segmentation with reduced thickness to promote downsizing even when portions cannot be physically cut and spread out. We show that this intervention increases the choice of a smaller food portion over a larger one, even when thickness is visible, or in a field study, when consumers can directly assess weight by holding the products in their hands.

Keywords

Consumer perception; food and nutrition; psychophysics; judgment and decision-making

Cutting food portions into smaller units, known as portion segmentation, has been shown to reduce intake (see Almiron-Roig et al. 2020; Roose, Van Kerckhove, and Huyghe 2017 for reviews). In a field experiment, for example, people took 41% less pretzel by weight from a lobby snack bowl on days when the pretzels were cut in half compared with days when they were left whole. (Geier, Rozin, and Doros 2006). The classic explanation for this effect is the social norm of eating just one “unit” regardless of size (Geier, Rozin, and Doros 2006). However, this norm cannot explain why portion segmentation reduces intake even when all participants consume more than one unit (Marchiori, Waroquier, and Klein 2011). More generally, social norms cannot explain why portion segmentation reduces intake in animals (Capaldi, Miller, and Alptekin 1989).

This research examines the mechanisms underlying a perceptual (rather than normative) explanation for why portion segmentation reduces intake, namely that cutting a food portion into pieces makes it appear larger. If a food portion is perceived as larger when divided than when it is whole, consumers may select or serve themselves less food from the segmented portion than from an equivalent whole portion. For example, chocolate-loving consumers who mistakenly believe that five 9-gram pieces of chocolate are more food than a single 50-gram bar would be more likely to choose the segmented portion over the entire bar, reducing their intake by 10%.

Although the notion that segmentation increases perceived size is established, the underlying mechanisms and moderators remain unclear. Consequently, the variability in this effect, including cases when segmented portions do not appear larger, is not fully understood. In this research, we test three potential mechanisms that have been suggested in prior research but not yet systematically investigated. The first is the numerosity heuristic, the tendency to estimate quantities based on the number of units, while neglecting the size of each unit. Although

segmentation always increases numerosity, the magnitude of this increase can vary, for example, when a portion is divided into two pieces versus twenty pieces. The second mechanism is the larger surface area occupied by segmented portions. The third is the difficulty of mentally reassembling units into a single continuous figure. We systematically investigate these three mechanisms, finding evidence for the main and interaction effects of numerosity and surface area, while ruling out reassembly difficulty as an explanatory mechanism.

Understanding the mechanisms by which segmented portions appear larger enables us to reinterpret previously inconsistent findings and add to the literature on quantity perception, which has emphasized number cognition and symbolic representations rather than the role of perceptual information. Although the idea that perceptual segmentation increases quantity perceptions is not new, the empirical evidence reveals more variability than one might expect. Table 1 summarizes the stimuli, interventions, and results of the five existing studies of perceptual segmentation. Pelham, Sumarta, and Myaskovsky (1994) found that cutting a circle into nine pieces increased perceived size when the slices were aligned ($p < .01$) but produced only a marginal effect ($p = .056$) when the slices remained closely arranged (see Figure 1). Oldham-Cooper et al. (2017) found that food portions appeared larger when cut into three pieces, but found no difference between three- and six-unit portions. Finally, Vandenbroele, Van Kerckhove, and Zlatevska (2019) found that segmenting chocolate does not always increase perceived quantity. In their second study, for example, participants judged that a portion contained the same amount of chocolate whether it was cut into three 50-gram pieces or four 37.5-gram pieces. They also found that segmentation does not affect size perceptions when consumers are primed to focus on the size of portions, suggesting that segmentation may not influence quantity perceptions when they pay close attention or are motivated to be accurate.

Table 1: Summary of the effects of perceptual segmentation on size perception

Publication	Stimuli	Interventions	Summarized findings
(Pelham, Sumarta, and Myaskovsky 1994) <i>Study 1</i>	Participants saw black geometric figures of the same size, along with a reference triangular unit.	An intact circle and reference unit were presented along with either the same circle divided into 9 slices (“easy reassembly”) or the same 9 slices spread on a horizontal line (“difficult reassembly”).	Segmentation significantly increased perceived size in the “difficult reassembly” ($p < .001$) condition, but only marginally in the “easy reassembly” condition ($p = .056$).
(Scisco et al. 2012) <i>Study 2</i>	Online participants were asked to assess photos of two JELL-O servings.	Two side-by-side photos of 160g of JELL-O: one cut into 9 equal pieces and the other cut into 16 equal pieces.	44% of participants reported more JELL-O in the 16-piece serving than in the 9-piece serving, 47% reported the same amount, and 9% reported less.
(Oldham-Cooper et al. 2017)	Food portions (200, 400, 600, 800, and 1,000 kcal) were presented either whole or cut into 3 or 6 equal pieces.	Participants assessed the volume in images of three foods (salted peanuts, spaghetti Bolognese, and chicken tikka masala) displayed on a widescreen monitor.	Portions divided into three units appeared larger than portions presented as a single unit, but there was no difference between the three-unit and six-unit portions.
(Vandenbroele, Van Kerckhove, and Zlatevska 2019) <i>Study 2</i>	Sixteen photos of 25g-200g portions plated as 1 to 4 chocolate chunks (12.5g, 25g, 37.5g, or 50g each).	Participants estimated the weight (in grams) of the chocolate in four randomly selected photos.	Controlling for actual size, portions with more units were generally perceived as larger, though not always (e.g., four 37.5g chunks did not appear larger than three 50g chunks).
(Vandenbroele, Van Kerckhove, and Zlatevska 2019) <i>Study 3</i>	Plates containing either two 50g brownies or six 16.6g brownies (equal total weight).	Participants were first primed to focus on either unit size (larger containers) or unit number (more containers), then ate brownies while watching videos, and later estimated the amount of food.	When participants were primed to focus on unit size, six small brownies were perceived as less food than two large brownies, but the opposite occurred when primed to focus on unit number.

Identifying the factors that mediate and moderate the effects of perceptual segmentation helps predict when marketers can rely on segmentation to promote smaller portions. For example, a simple virtual segmentation (e.g., suggesting individual portions with dotted lines on the packaging or product, as on a chocolate bar) would suffice if the effects of segmentation are driven by numerosity, but not if they require an increased surface area. Similarly, if segmentation is driven by the difficulty of mentally reassembling the cut units, then segmentation may not

influence size perceptions when consumers are highly motivated to judge quantity accurately or when they can directly assess a portion's weight by holding it themselves.

Establishing the boundary conditions of these effects creates opportunities to design improved interventions for cases in which portion segmentation alone does not reliably influence size perception. For example, after demonstrating that segmentation does not reliably increase quantity perception when surface area is not enlarged, we design a modified intervention that combines high-numerosity virtual segmentation (where segments are only suggested) with reduced portion thickness. We show that this new intervention leads consumers to choose smaller food and nonfood portions, even when they can estimate their weight by holding them, thereby offering a new tool for healthy eating interventions.

How Does Portion Segmentation Increase Size Perceptions?

The literature on number cognition (Bagchi and Davis 2016) shows that people tend to focus on symbolic quantity information (the number, expressed in Arabic numerals) and neglect the unit of measurement (e.g., measuring energy in kcal or kJ, as shown by Pandelaere, Briers, and Lembregts 2011). Consequently, presenting abstract symbolic quantity information in different units of measurement (e.g., servings rather than unit count: Lewis and Earl 2018; \$20 vs. ¥2954: Raghurir and Srivastava 2009; or 7 on a 10-point scale vs. 700 on a 1000-point scale: Schley, Lembregts, and Peters 2017) or decomposing that information into subcomponents (Morwitz, Greenleaf, and Johnson 1998) influences quantity perceptions. In contrast to this work on symbolic quantity estimation, far less research has examined perceptual quantity estimation in the absence of symbolic information, such as when estimating the amount of food on a plate.

Definitions

We define perceptual segmentation as either physically cutting a whole product, such as a

food portion, into multiple units or virtually representing it as a collection of units without actually cutting it. For example, segmentation could involve cutting a chocolate bar into chunks or representing an intact bar as a collection of individual units by delineating chunks on it, even though it remains a single block. Segmentation is a physical or visual intervention that increases numerosity by dividing a single portion into smaller parts (e.g., cutting a pizza into four slices). By this definition, segmentation refers to the initial transformation of a single, continuous portion into multiple units and additional cuts (e.g., increasing a pizza from 4 to 8 slices) further increase numerosity but do not constitute a separate instance of segmentation.

Segmentation is related to, but remains distinct from, what is known as “partitioning” (Cheema and Soman 2008) or “grouping” (Roose, Van Kerckhove, and Huyghe 2017), which change how food portions are packaged rather than altering the food portions themselves (e.g., packaging 12 cookies in one large bag vs. three bags of four cookies). Packaging is central to partitioning or grouping effects. For instance, partitioning effects are moderated by concerns about losing self-control when opening large packs (Argo and White 2012; Coelho do Vale, Pieters, and Zeelenberg 2008; Holden and Zlatevska 2015; Scott et al. 2008). In contrast, segmentation modifies the product itself by cutting an item into smaller pieces or by visually suggesting such cuts. Accordingly, none of the stimuli used in this research was packaged.

Although prior work suggests that perceptual segmentation increases size perceptions, there is no consensus on its underlying mechanisms or boundary conditions. We focus on three potential factors: numerosity, surface area, and reassembly difficulty.

Numerosity

Segmentation increases numerosity by dividing a single unit into multiple discrete elements (e.g., five slices of bread rather than one loaf), a process sometimes referred to as discretization

(Lembregts and Van Den Bergh 2018). Numerosity is nested within, but not confounded with, segmentation. For example, a pizza can be segmented into portions that vary in numerosity (e.g., 2 large slices versus 20 small slices). Numerosity is also broader than segmentation, as it applies to symbolic representations (e.g., comparing “8+7” with “3+4+2+6”).

Many studies have found that humans and some other animals possess an innate, specialized capacity for processing collections of discrete objects (Butterworth 2001). Lembregts and Van Den Bergh (2018) showed that the same quantities are easier to estimate, and hence differences loom larger, when expressed as a number of discrete objects (e.g., 25 and 50 discrete chunks of chocolate) rather than as a continuous measure (e.g., 250 grams and 500 grams of chocolate). Relatedly, Ma and Roese (2012) found that perceptions of inequity are heightened when quantities can be compared using whole numbers (e.g., [three vs. two chocolate bars] vs. [a large vs. a small chocolate bar]). However, these studies are about symbolic numerosity (comparing numerals), not perceptual segmentation (dividing objects).

As summarized in Table 1, some perceptual segmentation studies have found that higher numerosity (e.g., dividing a single portion into four rather than two units) increases quantity estimates. However, in all prior studies, manipulations that increased numerosity also increased surface area, and in some cases, reassembly difficulty, making it difficult to disentangle the unique contributions of these individual factors.

In a recent contribution, Wu et al. (2023) created abstract representations of nine or 16 square chocolate units assembled into a larger square and varied the distance between the units. They asked participants to either estimate the total weight of chocolate or the weight of each unit. They found that both estimates were larger in the 16-unit than in the 9-unit condition, supporting the effects of numerosity when surface area and reassembly difficulty are held

constant. However, because their studies did not include a condition in which the chocolate was intact, they do not directly test whether numerosity mediates or moderates the effects of segmentation (moving from one to many units).

Surface Area

In the real world, cutting products often involves spacing the pieces apart, which increases the visible “surface area” of the portion. We define surface area as the space covered by the outer contour of the portion presented (i.e., the footprint of all units together when viewed from the perspective presented). For instance, sliced fruit, pizza, or cake spreads over a larger surface than the corresponding whole fruit, pizza, or cake.

Past research has found that a larger surface area serves as a cue to quantity even in the absence of plates or bowls that could create contrast effects with the container (e.g., un-plated foods). For example, the same amount of wool was perceived as smaller (in weight or total length) when rolled into a ball than when spread out on a table (Chandon and Ordabayeva 2009). Similarly, clouds of dots are judged to contain more elements not only when the number of dots increases (numerosity effect) but also when the cloud occupies more space on a page or screen while holding the number of dots constant, a surface area effect (Allik and Tuulmets 1991; Cicchini, Anobile, and Burr 2016; Harvey et al. 2013).

Yet, past research has produced mixed findings. Wadhera, Wilkie, and Capaldi-Phillips (2018) found that rats run faster when their food is flattened to cover a larger surface area than when it is rolled into a ball. However, they also found that spreading a group of pellets across a larger area, rather than bunching them together, does not affect the rats’ preferences or running speed. Among humans, Wu et al. (2023) found that increasing the surface area of abstract representations of chocolate squares arranged into a larger square increased the perceived

amount of chocolate when it was estimated as a whole, but not when it was derived by multiplying the estimated size of each unit. Importantly, none of these studies has examined whether surface area mediates or moderates segmentation effects.

Reassembly Difficulty

Estimating the size of segmented objects first requires mentally recombining the pieces into a single entity, a process also known as grouping. When reassembly is difficult, people may be more likely to mistakenly include empty space when estimating the size of the segmented portion. Although some types of grouping (e.g., by shape or color) are mostly automatic and not modulated by attention (Kimchi and Razpurker-Apfeld 2004), more complex forms of reassembly typically require higher cognitive resources to process. For example, Pomè, Caponi, and Burr (2021) showed that physically connecting separate segments with a dotted line better improves grouping when visual distractors are absent.

The argument that reassembly difficulty drives segmentation effects is supported by studies showing that segmentation increases quantity perceptions more strongly when the task is more cognitively complex or when cognitive resources are taxed. Pelham, Sumarta, and Myaskovsky (1994) found that *symbolic* numerosity effects (e.g., computing the value of a sum of coins based on the number of coins rather than their denominations) are larger when stimulus presentation is brief, time pressure is high, or mathematical calculations are complicated.

The evidence that reassembly difficulty influences perceptual segmentation is less convincing. When Pelham, Sumarta, and Myaskovsky (1994) increased reassembly difficulty by aligning the nine slices of a circle horizontally rather than keeping them in the shape of a circle, they also enlarged the surface area of the stimuli by increasing inter-unit distance. It remains unclear whether reassembly difficulty alone influences segmentation effects.

Overview

Taken together, existing research suggests that perceptual segmentation increases perceived quantity (H1) and that numerosity, surface area, and reassembly difficulty mediate (H2) and moderate (H3) this effect. Formally:

- H1** Perceptual segmentation increases perceived quantity.
- H2** The effects of segmentation on perceived quantity are mediated by numerosity (H2a), surface area (H2b), and reassembly difficulty (H2c).
- H3** Segmentation more strongly increases perceived quantity when numerosity (H3a), surface area (H3b), and reassembly difficulty (H3c) increase.

We test these hypotheses across six studies, supplemented by two additional studies reported in the Web Appendix. We first replicate the Pelham et al. (1994) study and extend it by measuring whether their intervention influenced perceived size through numerosity, surface area, or reassembly difficulty. The next two studies test the role of reassembly difficulty by incentivizing participants to provide accurate quantity estimates (Study 2) and by directly manipulating reassembly difficulty (Study 3). Study 3 also examines the effects of numerosity by comparing segmentation into 6 or 12 pieces and its interaction with reassembly difficulty. Study 4 jointly examines surface area and numerosity, showing that numerosity only increases quantity perception when surface area increases. Drawing on these findings, Studies 5a and 5b show that virtual segmentation (without increasing surface area) can still reliably promote the selection of smaller portions, including in the field, when segmented portions are also thinner. The university's institutional review board approved all studies. All experimental stimuli, survey instruments, data (including unanalyzed sociodemographic variables obtained from Prolific), and code are available on https://osf.io/rzfb2/?view_only=b7fa7a6f9e514f75ad6162e4005574e1.

Study 1: Replication of Pelham et al. (1994) with Additional Mediation Analyses

Procedure

We recruited 189 adult participants via Prolific, retaining 177 after applying the pre-registered exclusion criteria (<https://aspredicted.org/yw3bf9.pdf>). Web Appendix A provides detailed information about exclusion criteria and outcomes across all the studies. We used the same stimuli as in Pelham et al. (1994), except that they were presented on a screen rather than on paper. Segmentation was manipulated within-subjects by showing all participants three figures: a triangle (described as “the reference”), an intact circle (described as “Figure 1”) placed above the reference, and the same circle segmented into nine wedges (described as “Figure 2”) placed below the reference. Both the intact and segmented circles were 2.3 times the size of the reference triangle.

As in Pelham et al. (1994), we manipulated the layout of the segmented figure between subjects (see Figure 1). In the “radial layout” condition, the nine wedges were slightly spaced apart while preserving a circular shape. In the “linear layout” condition, the nine wedges were aligned horizontally with more space between them. Pelham et al. (1994) described these two conditions as “easy reassembly” and “difficult reassembly”, respectively, terminology we avoid here because the layout manipulation also increased surface area, not only reassembly difficulty.

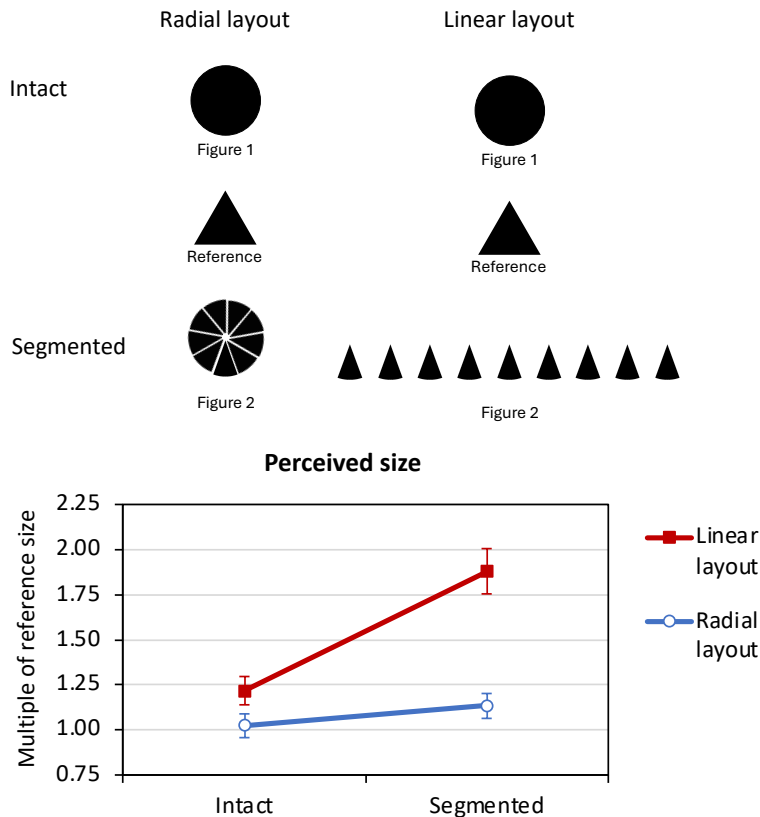
After a common practice task designed to familiarize the respondents with the slider scale, we measured perceived size for the intact and segmented figures by having participants complete the sentence “Figure 1 [Figure 2] is x times larger than the reference triangle” using a 0-4 slider to set the value of x . Finally, participants rated their agreement (on 7-point scales) with items measuring perceived numerosity (“Figure 2 has more units than Figure 1”), surface area (“Figure

2 occupies a larger area on the screen than Figure 1”), and task complexity¹ (“I found the task difficult to complete”).

Results

A mixed-model ANOVA revealed significant effects of segmentation ($F(1,175)=26.5$, $p<.001$, $\eta^2=.132$), reassembly difficulty ($F(1,175)=22.7$, $p<.001$, $\eta^2=.115$), and their interaction ($F(1,175)=13.7$, $p<.001$, $\eta^2=.072$). As Figure 1 shows, segmentation increased perceived size by 18.7% in the radial layout condition (from $M=1.03$, $SD=.62$ to $M=1.13$, $SD=.66$, $F(1,89)=5.6$, $p=.020$) and by 65.8% in the linear layout condition (from $M=1.22$, $SD=.74$ to $M=1.88$, $SD=1.16$, $F(1,86)=20.9$, $p<.001$).

Figure 1: Study 1—Replication of Pelham et al. (1994): Stimuli (top) and Results (bottom)



Note: In all figures, error bars show the standard errors.

¹ We measured task complexity rather than reassembly difficulty because the segmented figure does not, technically, need to be reassembled in the radial condition. In Study 3, we measured both task and reassembly difficulty for the segmented portions and found them to be highly correlated ($r=.59$).

Study 1 also revealed an intriguing difference from the original results. In Pelham et al. (1994), the perceived size of the intact figure was reported to be identical ($M=1.85$) in the radial and linear layouts. In Study 1, however, the intact figure was judged to be 10.6% larger in the linear layout ($M=1.22$, $SD=.74$) than in the radial layout ($M=1.03$, $SD=.62$). Although the difference was only marginal ($F(1,175)=3.48$, $p=.064$, $\eta^2=.020$), it suggests a potential contamination of the perceived size of the intact figure by the perceived size of the segmented figure. In fact, when averaging the estimates across both radial and linear layouts, the size of the intact figure ($M=1.12$, $SD=.69$) is no longer statistically different from the size of the segmented figure in the radial condition ($M=1.13$, $SD=.66$; $t=-.14$, $p=.891$). To avoid contamination, we show the intact and segmented portions separately (monadic estimations) in Studies 2—4.

To better understand the layout intervention implemented by Pelham et al. (1994), we conducted parallel mediation analyses with Process Model 4 (Hayes 2013, using 5,000 simulations). The dependent variable was the difference in perceived size between the segmented and intact figures. The independent variable was the layout intervention (linear vs. radial). Perceived numerosity, surface area, and complexity were parallel mediators. Perceived numerosity did not mediate the intervention's effects ($B = -.01$, 95% $CI: [-.082, .070]$), likely because the number of units was held constant across conditions. Surface area was a statistically significant mediator in the expected direction ($B = -.25$, 95% $CI: [.124, .403]$), such that a higher perceived area was associated with a larger size estimate. On the other hand, perceived complexity was a significant mediator, but in the opposite direction predicted by Pelham et al. (1994), as higher complexity was associated with lower size estimations ($B = -.06$, 95% $CI: [-.141, -.001]$).

Discussion

As hypothesized in H1, Study 1 replicated the findings of Pelham, Sumarta, and Myaskovsky (1994) that segmentation increases perceived size in a dyadic comparison task, especially when the segments are spread out. By more than tripling the sample size compared to the original study (N=177 vs. N=48), Study 1 also showed that segmentation increased perceived size even when the units are only slightly spread out, and the original shape is preserved, which reflects how a food portion would typically be cut. This suggests that the marginally statistically significant effects reported in the original paper ($p=.056$) were due to insufficient power.

In addition, the mediation analyses suggest that the layout change implemented by Pelham et al. (1994) influenced perceived size by increasing surface area, and not by increasing reassembly complexity, as they hypothesized. However, these mediation analyses examined the effects of the radial vs. linear layouts, not of segmentation itself. In addition, because numerosity was not manipulated and because surface area and reassembly difficulty were confounded in this design, Study 1 does not allow for definitive conclusions about whether these factors moderate segmentation effects.

In the next two studies, we further probe the role of reassembly difficulty by rewarding estimation accuracy (in Study 2) and directly manipulating reassembly difficulty (in Study 3). We also avoid potential comparison effects introduced by the dyadic task used in Study 1 by having respondents estimate the intact and segmented portions separately (in Study 2) or by manipulating segmentation between subjects (in Study 3). Study 2 also measured three downstream consequences of size estimations of interest to marketers: willingness to pay and expected consumption duration. To explore the relationship between size perceptions and eating norms, it also measured the perceived appropriateness of the portions.

Study 2: Manipulating Incentives and Measuring Downstream Consequences

Procedure

We recruited 412 adult participants via Prolific and retained 400 (224 women) after pre-registered exclusions (<https://aspredicted.org/df2-2pwy.pdf>), yielding 800 observations (two per respondent). This study used a 2 x 2 mixed design that manipulated the presence of monetary rewards for estimation accuracy between subjects. Segmentation was manipulated within subjects by asking each respondent to sequentially estimate the sizes of two loaves of bread, one intact and one sliced, relative to a common reference portion. The order of these two evaluations was randomized between subjects.

The reference portion weighed 219 grams (see Web Appendix B for photos of the weighing procedure). Unlike in Study 1, where the intact and segmented portions were the same size, the intact portion weighed more than the segmented one (504 grams vs. 386 grams, respectively). This design choice was intended to provide a stricter test of H1 by examining whether a segmented, smaller portion could erroneously appear larger than an intact, larger portion. Figure 2 displays photos of the stimuli.

After indicating their levels of liking and hunger, participants in the incentive condition were informed that the ten participants with the most accurate size estimations would receive a £2 bonus. Participants in the control condition received no incentive for accuracy. All participants then completed a practice estimation task. Perceived size was measured by asking participants to complete the sentence “The large bread is x times larger than the small bread” on a 1 to 4 sliding scale. Participants were informed that they had 30 seconds per question and that their response time would be recorded.

We then measured three downstream consequences of size perceptions. First, we asked

participants how much they would be willing to pay for the target portion using a sliding scale from \$3 to \$12, after informing them that the small reference loaf costs \$3. Second, we asked them to estimate the number of adults that could be appropriately served with the target portion by selecting a value from 2 to 12, after indicating that the reference loaf can serve two adults. Finally, we assessed expected consumption duration and effort. Participants were told that two hand-to-mouth movements are required to consume the reference loaf of bread and were asked to select a value from 2 to 32 on a sliding scale with the prompt “I would need this many movements to eat the large bread.” After estimating portion size and answering the three additional questions for one loaf of bread, participants repeated these tasks for the other loaf.

Results

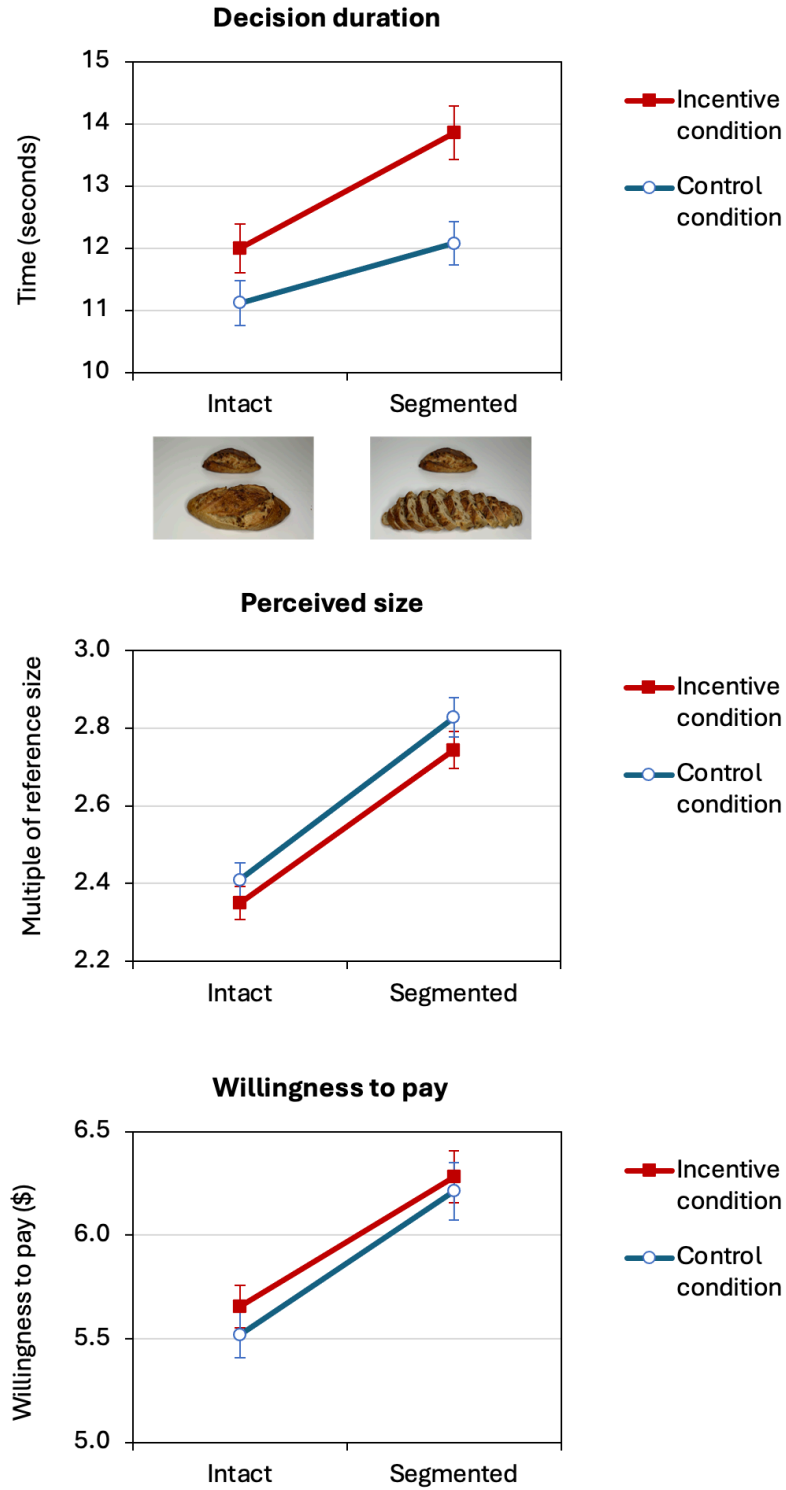
As preregistered, we conducted a series of mixed linear regressions to account for the fact that each participant evaluated two portions. The dependent variables were the time spent on the task, perceived size, and the three downstream consequences. The independent variables were three binary indicators representing the effects of segmentation, incentives, and their interaction.

As shown in Figure 2, participants spent 11.4% more time on the task in the incentive condition ($M=12.9$ seconds, $SD=5.9$) than in the control condition ($M=11.6$ seconds, $SD=5.0$), indicating that the incentive manipulation was successful at increasing the attention devoted to the task ($t=3.03$, $p<.01$, $\eta^2=.02$). There was also a main effect of segmentation ($t=4.37$, $p<.001$, $\eta^2=.05$), with participants spending more time when the portion was segmented, but no interaction between segmentation and incentive ($t=1.39$, $p=.16$, $\eta^2<.01$).

Consistent with H1, segmentation significantly increased perceived size ($t=12.6$, $p<.001$, $\eta^2=.29$): the loaf appeared 2.38 times larger ($SD=.69$) than the reference when whole, and 2.79 times larger ($SD=.69$) when sliced, a 17.2% increase. Neither the main nor the interaction effects

of incentives reached statistical significance ($t=-1.27, p=.20, \eta p^2<.01$; $t=-.39, p=.70, \eta p^2<.01$, respectively).

Figure 2: Study 2—Stimuli and Effects of Segmentation and Incentives



Segmentation had statistically significant effects on all three downstream consequences. Respondents were willing to pay more for the bread when the portion was segmented ($M=\$6.25$, $SD=1.87$) than when it was intact ($M=\$5.59$, $SD=1.53$, $t=8.70$, $p<.001$, $\eta^2=.16$), as shown in Figure 2. Additionally, participants indicated that the portion served more people when it was segmented ($M=5.43$ adults, $SD=1.82$) than when it was intact ($M=4.71$ adults, $SD=1.36$, $t=8.67$, $p<.001$, $\eta^2=.16$). Finally, participants estimated more hand-to-mouth movements to be required to eat the portion when it was segmented ($M=15.16$ movements, $SD=8.42$) than when it was intact ($M=11.19$ movements, $SD=7.64$, $t=11.5$, $p<.001$, $\eta^2=.25$). These results are not shown in Figure 2 due to space constraints. In contrast, incentives did not affect willingness to pay ($t=.67$, $p=.51$, $\eta^2<.01$) or the estimated number of people that could be adequately served by the portion ($t=.51$, $p=.61$, $\eta^2<.01$), although incentives did increase the expected number of hand-to-mouth movements (from $M=12.6$ without incentives to $M=14.4$ with incentives, $t=2.18$, $p=.03$, $\eta^2=.01$). None of the interaction effects involving incentives was statistically significant (respectively, $t=-.44$, $p=.66$, $\eta^2<.01$; $t=.16$, $p=.87$, $\eta^2<.01$; and $t=-1.86$, $p=.06$, $\eta^2<.01$).

Mediation analyses using Process Model 4 (Hayes 2013, using 5,000 simulations) further revealed that perceived size fully mediated the effects of segmentation on willingness to pay ($B=.60$, 95% CI : [.450, .750]) and serving size ($B=.56$, 95% CI : [.420, .703]). Perceived size partially mediated the effects of segmentation on expected consumption duration ($B=.89$, 95% CI : [.510, 1.328]).

Discussion

Study 2 provides further evidence that segmentation increases size perceptions (H1) using a monadic, separate evaluation task (rather than the dyadic, joint task used in Study 1) and actual photos of portions (rather than geometric figures, as in Study 1). It also illustrates the magnitude

of these effects: the intact portion of bread, which contained 31% more bread, was perceived as 14.7% smaller than the segmented portion. Study 2 also shows that segmentation increases willingness to pay (+11.8%) and the perceived number of people who could be appropriately served by the portion (+15.3%), a measure of eating norms. The effects of segmentation on willingness to pay and the expected number of servings are entirely mediated by perceived portion size. This indicates that segmentation itself does not directly increase willingness to pay or the expected number of servings. Only when segmentation increases perceived size are people willing to pay more or estimate that the portion is appropriate for more consumers. Perceived size only partially mediated the expected duration and effort of consumption, since the simple act of slicing the loaf into pieces prevents consumers from eating it all in one go.

Study 2 demonstrates that motivating people to pay more attention to the task by providing incentives for accuracy does not reduce the segmentation effect. If segmentation increased perceived quantity due to the cognitive cost of reassembling segmented units, its impact should have been attenuated by incentivizing accuracy. The fact that the segmentation effect remained unchanged is therefore difficult to reconcile with the proposed role of reassembly difficulty (H2c and H3c).

To further test the role of reassembly difficulty, Study 3 directly manipulates it while holding surface area constant. Additionally, Study 3 examines the role of numerosity by comparing intact and segmented portions that vary in numerosity (low vs. high). Like Study 1, Study 3 tests the effects of segmentation with portion sizes held constant, thereby allowing a direct comparison of quantity perceptions across conditions.

Study 3: Segmentation, Numerosity, and Reassembly Difficulty

Procedure

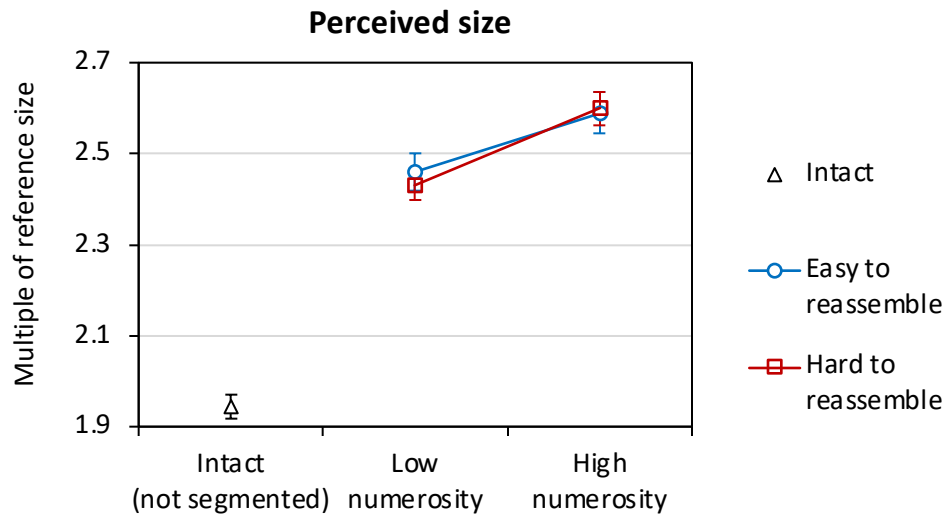
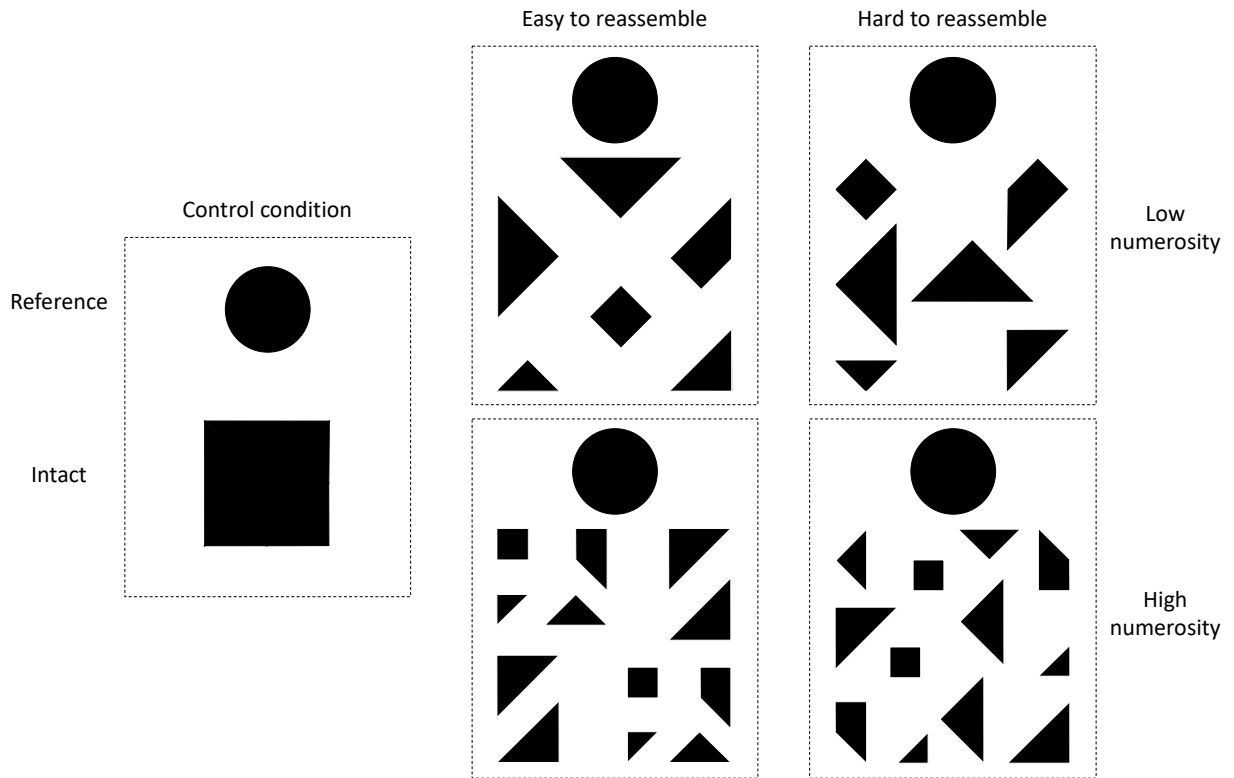
We recruited 2,325 adult participants via Prolific and retained 1,992 participants after applying the pre-registered exclusion criteria (<https://aspredicted.org/2t3ic7.pdf>). Participants were randomly assigned to one of five experimental conditions in a 2 (numerosity: low vs. high) by 2 (ease of reassembly: easy vs. hard) between-subjects design with an additional control condition in which the target figure was intact.

Figure 3 shows the stimuli. (The dotted lines serve to delineate the five stimuli in Figure 3 and were not shown to participants.) In the control condition, the target figure was an intact square 3.9 times the size of the reference circle. In the four segmented conditions, the target figure was cut into pieces that could be reassembled to form the same square. To hold the surface area constant, the outer contours (perimeters) of the four segmented figures were identical.

The target figure was divided into six segments in the low-numerosity condition and twelve in the high-numerosity condition. In the easy-to-reassemble condition, the contours of the figures retained the square shape of the intact figure, and the segments needed only to be joined to recreate the intact square. In the hard-to-reassemble conditions, the segments were rotated, flipped, and dispersed. As detailed in Web Appendix C, a pre-test showed that the ease-of-reassembly manipulation was successful.

After a practice task, we asked participants to estimate its size relative to the reference circle. The reference circle was always displayed at the same distance from the center of the target figure. Reassembly difficulty was measured by asking participants to rate their agreement with two items (“It would be hard to reassemble this figure into a square,” and “I found the task difficult to complete”) on a 7-point scale from 1 (strongly disagree) to 7 (strongly agree).

Figure 3: Study 3—Stimuli (top) and Size Estimates (bottom)



Results

As pre-registered, the intact portion was compared to the average of the four segmented portions. Taken together, the four segmented figures appeared 29.9% larger, on average, than the intact figure ($M=2.52$ times the reference, $SD=.77$, vs. $M=1.94$, $SD=.53$, $t=14.09$, $p<.001$,

$\eta^2=.09$), which is consistent with H1.

We then estimated the effects of reassembly difficulty, numerosity, and their interaction among the four segmented figures. This regression showed that higher numerosity significantly increased perceived size ($B=.15$, $t=3.84$, $p<.001$, $\eta^2=.01$), supporting the hypothesized moderation effect of numerosity (H3a). As shown in the bottom panel of Figure 3, cutting the figure into 12 pieces rather than 6 (while holding the surface area it occupies constant) increased its perceived size by 6.1% (from $M=2.44$, $SD=.71$ to $M=2.59$, $SD=.82$) across the two ease-of-reassembly conditions. In contrast, perceived size was not significantly influenced by reassembly difficulty ($B=-.01$, $t=-.34$, $p=.74$, $\eta^2<.01$) nor its interaction with numerosity ($B=.04$, $t=-.34$, $p=.59$, $\eta^2<.01$).

Further analyses revealed that perceived reassembly difficulty (measured as the average of the two items) was significantly influenced by reassembly difficulty ($B=.78$, $t=10.82$, $p<.001$, $\eta^2=.07$), but not by numerosity ($B=.09$, $t=1.22$, $p=.219$, $\eta^2<.01$) or their interaction ($B=-.18$, $t=-1.27$, $p=.205$, $\eta^2<.01$). Moderated mediation analyses performed with Process Model 7 (Hayes 2013, using 5,000 simulations) with numerosity as the independent variable, reassembly difficulty as the moderator, and size estimation as the dependent variable did not reveal a statistically significant mediation by perceived reassembly difficulty in either the easy- or difficult-to-reassemble condition (respectively, $B=-.01$, 95% $CI:[-.01,.01]$ and $B=.001$, 95% $CI:[-.01,.01]$), contradicting the hypothesized mediation effect of reassembly difficulty (H2c).

Discussion

Study 3 provides further evidence that perceptual segmentation increases perceived size (H1) with stimuli different from those in the previous two studies and in a between-subjects design. Additionally, whereas Studies 1 and 2 contrasted intact and segmented portions, Study 3

shows that perceived size further increases with the numerosity of the segmented portion: increasing the number of units from 6 to 12 increased perceived size by 6.1%, even though surface area remained constant. Notably, Study 3 directly manipulated reassembly difficulty and found that it did not moderate the effects of segmentation on perceived size (ruling out H3c) or mediate these effects (ruling out H2c). Taken together with the results of Studies 1 and 2, these findings indicate that reassembly difficulty does not play a meaningful role in the perceptual segmentation effect, contrary to the original hypothesis advanced by Pelham, Sumarta, and Myaskovsky (1994).

What remains to be tested is the role played by surface area and its interplay with segmentation and numerosity. The results of Study 3 indirectly suggest that surface area plays an important role, because the increase in perceived size was much larger (25.7%) when surface area increased (from 1 to 6 units), than when it remained constant (6.1%, when going from 6 to 12 units). However, this difference could also reflect diminishing marginal effects of numerosity. More importantly, surface area was confounded with segmentation in Studies 1 to 3 because it was lower in the intact condition than in the segmentation conditions. For these reasons, we need a study that independently manipulates segmentation, numerosity, and surface area.

We implement this in Study 4 using virtual segmentation, which involves marking segments on the original portion without actually cutting or separating the pieces. Study 4 further examines the robustness of perceptual segmentation by manipulating the visual representation of segmentation (photos of portions vs. abstract graphical representations), the shape of the portions (circles, rectangles, or diamonds), and the target food (pizza, chocolate bars, and tortillas). Because Studies 1—3 ruled out the role of reassembly complexity, it is not examined in Study 4.

Study 4: Segmentation, Numerosity, and Surface Area

Procedure

We recruited 806 adult participants via Prolific and retained 786 after applying the pre-registered exclusion criteria. Study 4 used the same monadic, separate-estimation task as in Study 3 but manipulated numerosity (the number of units) and surface area (i.e., the amount of white space between units) independently. As depicted in Figure 4, each participant was randomly assigned to one of 10 experimental conditions in a 5 (segmentation) by 2 (visual representation: photos vs. abstract shapes) between-subjects design with three within-subject replications (three different foods).

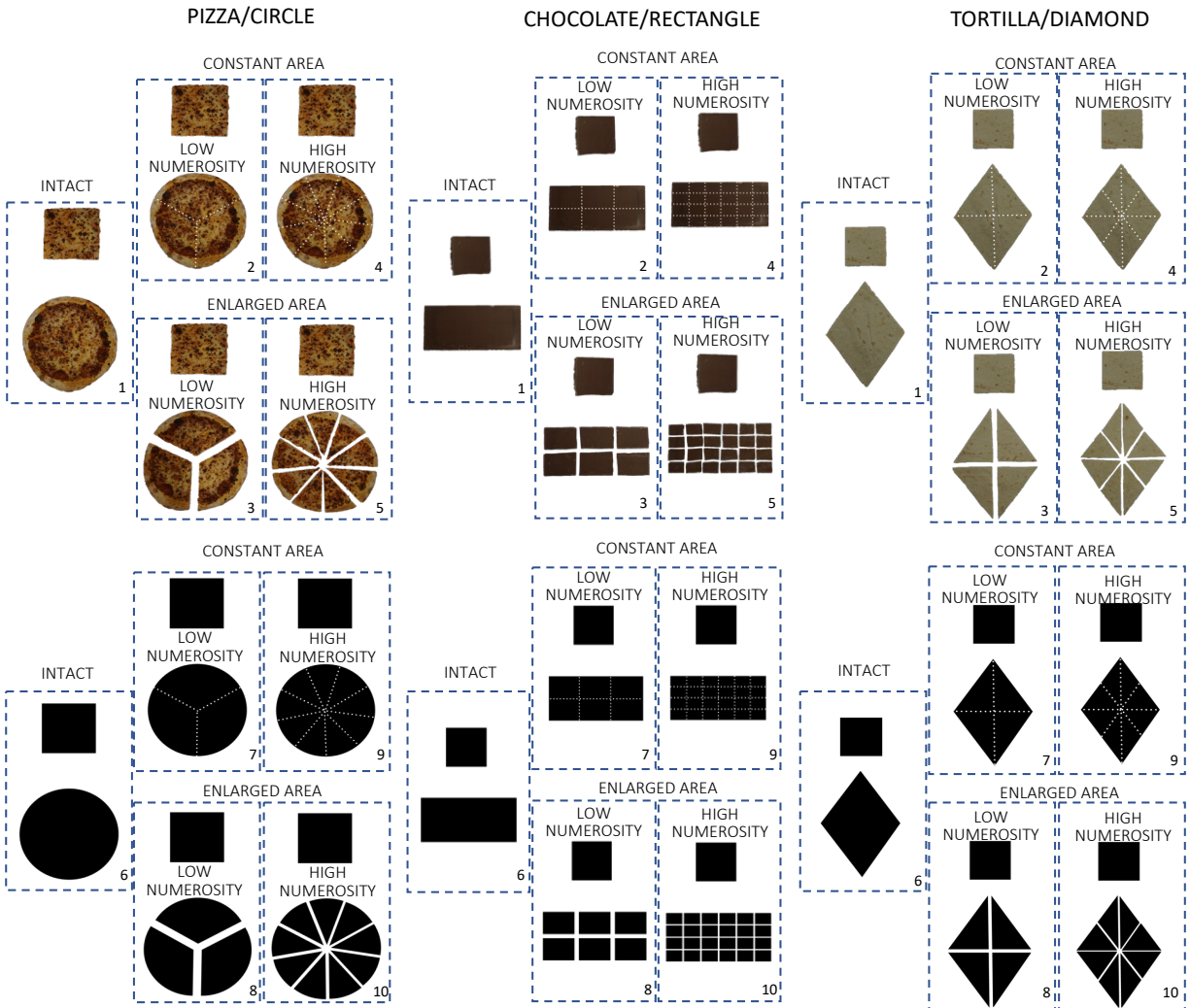
As in Study 3, the five segmentation conditions included a control (intact) portion and four segmented portions, using a 2 (numerosity: low vs. high) by 2 (surface area: constant vs. enlarged by spreading the units and adding white space between them) between-subjects design. To test the robustness of the effects and their applicability to real-world food portions, participants viewed either photos of actual portions (as in Study 2, numbered 1 to 5 in Figure 4) or geometric shapes (as in Studies 1 and 3, numbered 6 to 10 in the same figure).

Drawing on past research showing that object shapes (e.g., circle vs. square) influence size perceptions (Krider, Raghubir, and Krishna 2001), each respondent evaluated three differently shaped products within the same experimental condition. Participants estimated the size of pizzas (circles), chocolate bars (rectangles), and tortillas (diamonds). The order of the three products was counterbalanced across participants. For example, participants in condition 3 (see Figure 4) viewed photos of a pizza cut into three pieces, a chocolate bar cut into six pieces, and a tortilla cut into four pieces, with all portions separated by white space (enlarged-area condition).

As in Studies 2 and 3, participants first completed a practice trial task. We measured

perceived size using the same scale as in Studies 1—3 (“how many times larger than the reference”). For added reliability, we informed participants of the reference portion’s weight in grams and asked them to estimate the weight of the target portion. We then rescaled these weight estimates relative to the reference portion and averaged the two perceived-size measures (which were highly correlated, $r=.87$).

Figure 4: Study 4—Stimuli in the 10 Experimental Conditions



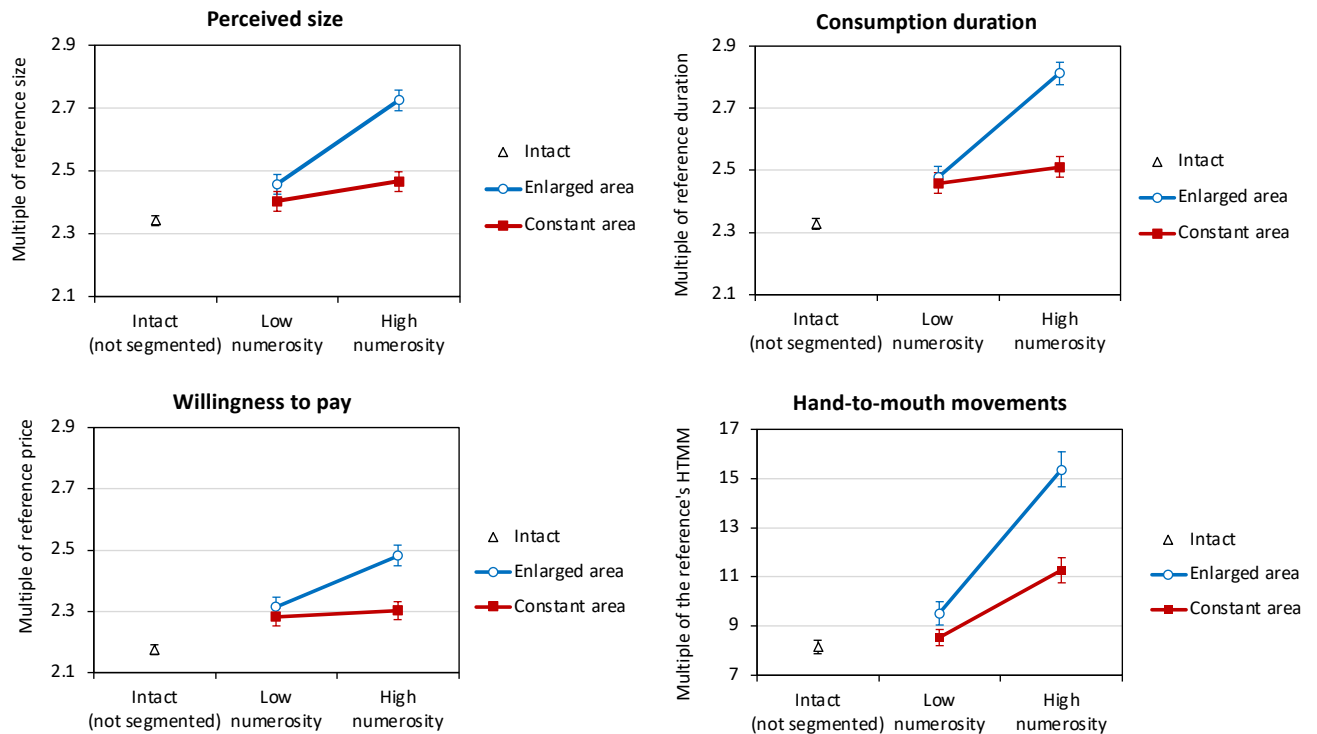
As in Study 2, we measured downstream consequences, including willingness to pay and the expected number of hand-to-mouth movements required to eat the portion. To provide another measure of consumption duration, we asked them to estimate how long it would take them to eat

the entire target portion. Finally, participants rated how easy and convenient it would be to consume the portions and how much they liked pizza, chocolate, and tortillas on 7-point scales.

Results

As in Study 3, we compared the intact portion with the average of the four segmented portions (see Model 1 in Table 2). Then, we estimated the effects of enlarging the surface area (i.e., separating the segments with white space, captured by the SPACE binary variable), increasing numerosity (NUM), and their interaction. We also assessed the effects of showing real food portions rather than abstract shapes (FOOD) and its interaction with the other variables. Finally, we controlled for the effects of having a rectangle or diamond shape rather than a circle shape (RECT and DIAM) and accounted for repeated measures. All factors were deviation-coded ($\frac{1}{2}$ and $-\frac{1}{2}$), and all of the dependent variables were rescaled as a multiple of the reference portion's value to combine the data across products and dependent variables.

Figure 5: Study 4—Effects of Segmentation, Numerosity, and Surface Area



Perceived size

The intact portions were perceived to be 2.34 times larger ($SD=.60$) than the reference portions. Despite being the same size as the intact portion, the four segmented portions were, on average, perceived to be 2.51 times larger ($SD=.70$) than the reference portions. Segmentation, on average, led to a 7.3% increase in perceived size that was statistically significant ($t=-4.09$, $p<.001$, $\eta^2=.02$, see Model 1 in Table 2), as hypothesized in H1.

Table 2: Study 4—Regression Results

	Model 1				Model 2				
	(Intact portion vs. all segmented portions combined)				(Effects of spacing and numerosity among segmented portions)				
	Size (mult.)	WTP (£)	Cons. duration (min)	Hand to mouth (mvmt)		Size (mult.)	WTP (£)	Cons. duration (min)	Hand to mouth (mvmt)
INTACT	-.172*** (.042) .02	-.172*** (.042) .02	-.241*** (.048) .03	-3.047*** (.771) .02	SPACE	.152*** (.037) .03	.105** (.037) .01	.157*** (.041) .02	2.525*** (.683) .02
					NUM	.164*** (.037) .03	.093* (.037) <.01	.189*** (.041) .03	4.303*** (.683) .06
					SPACE × NUM	.210** (.074) .01	.150* (.075) <.01	.287*** (.083) .02	3.159* (1.366) <.01
FOOD	.191*** (.042) .03	.065 (.042) <.01	.187*** (.048) .02	1.736* (.771) <.01	FOOD	.176*** (.037) .03	.086* (.037) <.01	.160*** (.041) .02	2.154** (.683) .02
FOOD × INTACT	.033 (.084) <.01	-.043 (.085) <.01	.057 (.096) <.01	-.813 (1.543) <.01	FOOD × SPACE	-.231** (.074) .02	-.235** (.075) .02	-.246** (.083) .01	-2.152 (1.366) <.01
					FOOD × NUM	-.105 (.074) <.01	-.050 (.075) <.01	-.101 (.083) <.01	1.519 (1.366) <.01
					FOOD × NUM × SPACE	.203 (.147) <.01	.238 (.150) <.01	.341* (.166) <.01	1.388 (2.731) <.01
RECT	.485*** (.027) .17	.171*** (.029) .02	.390*** (.029) .10	-1.903*** (.417) .01	RECT	.461*** (.031) .15	.149*** (.033) .02	.356*** (.033) .08	-1.826*** (.489) .01
DIAM	.364*** (.027) .10	.078** (.029) <.01	.187*** (.029) .03	-4.791*** (.417) .08	DIAM	.367*** (.031) .10	.060 (.033) <.01	.190*** (.033) .03	-4.959*** (.489) .08

Note: *** $p<.001$, ** $p<.01$, * $p<.05$. The first result is the unstandardized regression coefficient, the second is the standard error (in parentheses), and the third is the partial eta squared (in italics).

Within the four segmented conditions, Model 2 reveals a statistically significant main effect of numerosity ($t=4.44, p<.001, \eta^2=.03$), surface area/space ($t=4.14, p<.001, \eta^2=.03$), and their interaction ($t=2.86, p=.004, \eta^2=.01$). These results are consistent with the moderating roles predicted in H3a and H3b. Additional planned contrast tests found that a higher numerosity increased perceived size by 12% in the enlarged area condition when the segments were separated by white space ($t=5.15, p<.001, \eta^2=.04$), but not when the segments were only virtually delineated (+3.2%, $t=1.15, p=.253, \eta^2<.01$), as shown in Figure 5. In fact, when the segments were not spread and separated with white space, perceived size was not significantly different in the intact condition ($M=2.34, SD=.60$) relative to the low numerosity condition ($M=2.40, SD=.65, t=1.43, p=.154, \eta^2<.01$), although it was smaller than in the high numerosity condition ($M=2.47, SD=.69, t=2.94, p=.003, \eta^2=.01$).

Table 2 further shows that size perceptions were higher for photos than for abstract shapes, while the effects of segmentation were similar for both real and abstract stimuli. Enlarging surface areas by adding white space had a smaller impact for photos than for abstract shapes ($t=-3.14, p=.002, \eta^2=.02$). Finally, the rectangle- and diamond-shaped portions appeared larger than the round ones, even though all stimuli were 2.67 times larger than the reference. None of the other effects was statistically significant.

Downstream consequences

As in Study 2, the results for downstream consequences mirrored those for perceived size: high numerosity combined with high surface area increased willingness to pay by 14.2%, expected consumption time by 20.8%, and hand-to-mouth movements by 88.6%, compared to the intact condition. Finally, moderated mediation analyses performed with Process Model 7 (Hayes 2013, using 5,000 simulations), reported in Web Appendix D, showed that perceived size

fully mediated the effects of numerosity and surface area on willingness to pay and partially mediated their effects on perceived duration and the number of hand-to-mouth movements.

Discussion

Study 4 provides further evidence that segmentation increases size perceptions (and impacts related downstream consequences) when it enlarges surface area and segments are clearly separated, mirroring how most segmented food portions appear in reality. These effects are observed regardless of whether people evaluate photographs of real food or abstract geometric representations, and for circular, rectangular, or diamond-shaped portions, further supporting H1. In addition, Study 4 shows that segmenting a portion into many units increases size perceptions and downstream consequences more strongly than segmenting into a few units, even when total surface area is held constant, replicating Study 3's results and providing further support for H3a.

Study 4 also shows a strong interaction between area and segmentation (H3b). Segmentation has a much weaker effect when it does not increase surface area. When segments are only virtually delineated, segmentation increases perceived size only when numerosity is high, and not when it is low. Similarly, increasing numerosity by further cutting already segmented portions does not reliably increase size perceptions when portions are not spread out.

Finding that virtual segmentation does not always increase size perceptions provides an important boundary condition for segmentation effects. At the same time, it uncovers a problem for marketers who cannot physically cut their products and spread the pieces apart. For example, cutting a pizza, a wheel of cheese, or a chocolate tablet into pieces inside their packaging is impractical, as the pieces may not stay in place during transport, compromising their integrity.

In the final two studies, we examine an “enhanced” intervention that combines virtual segmentation with a reduction in the product's thickness. Many studies have shown that depth is

difficult to estimate from 2D representations (see Krishna 2007 for a review). Consequently, we hypothesize that virtual segmentation can increase perceived size when accompanied by a reduction in portion depth (i.e., thickness). We test this intervention in the marketing context of product downsizing, when a company seeks to promote a new format that is smaller than both its old format and the category standard. This context corresponds to shrinkflation, in which the price is unchanged, as is the case here (Claus and Pandelaere 2024; Evangelidis 2024). Our goal is to determine whether this combination of virtual segmentation and reduced thickness can mask portion downsizing when consumers judge photos of portions (Study 5a) or actual portions (Study 5b), and whether it continues to do so even when attention is drawn to the downsizing by showing the thickness of the portions (Study 5a) or by allowing consumers to weigh the portions by hand (Study 5b). Finally, we also test these effects for non-food products (Study 5b).

Study 5a: Can Enhanced Virtual Segmentation Hide Portion Downsizing?

Procedure

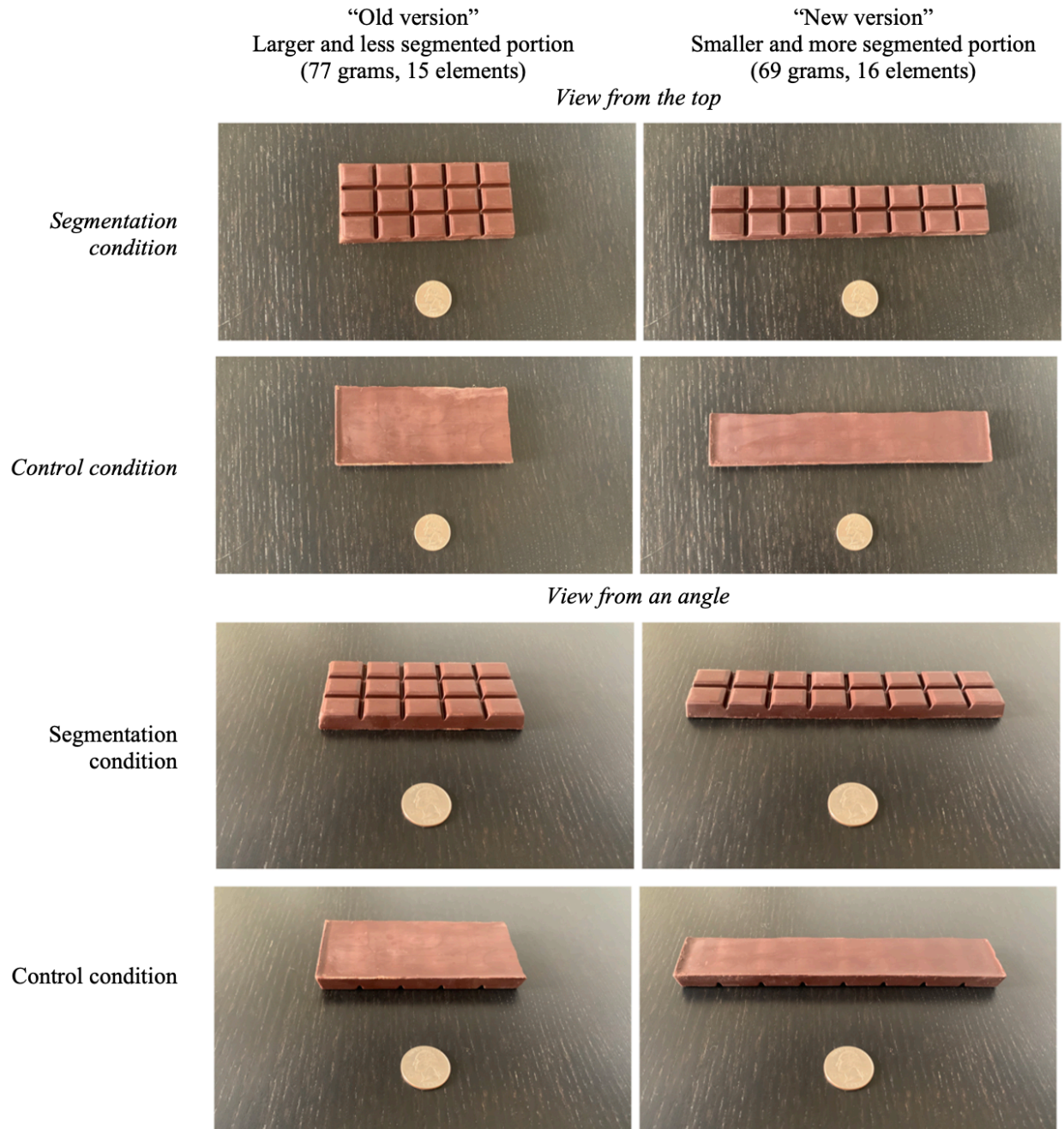
Study 5a employs a dyadic joint-evaluation task, in which, rather than estimating the size of portions as done previously, consumers indicate which of two portions is larger: the “old version” or the “new version” (which is actually smaller). This task mirrors the context consumers face in the marketplace when products are downsized and assesses whether the enhanced virtual segmentation can promote the selection of downsized portions.

As shown in Figure 5, the stimuli in Study 5a were created from two widely sold Nestlé chocolate dessert bars that differ in thickness. The “new version” consisted of 16 thinner squares of “Nestlé Noir Absolu” in a 2x8 layout², weighing 69 grams. The “old version” consisted of 15

² We selected the 2x8 shape for the “new version” because research on the elongation bias (Krishna 2006; Raghurir and Krishna 1999) suggests that it should already appear larger than the less elongated 3x5 shape of the larger “old version” in the control condition, thereby providing a conservative test of the intervention’s ability to further promote the choice of the smaller portion.

thicker squares of “Nestlé Noir” in a 3x5 format, weighing 77 grams (11.6% more).

Figure 6: Study 5a—Stimuli in the “Larger on the Left” Condition



Study 5a used a 2 (intact vs. segmented) by 2 (weight cue: top view vs. angle view) between-subjects design. As shown in Figure 6, in the control condition, both portions were intact (e.g., participants saw the bottom of a chocolate bar, without marks), so we expected most

consumers to accurately identify the “old version” as the larger one. In the segmented condition, we showed the top of the chocolate bars, so that both portions appeared segmented into ‘virtual’ units (without altering the surface area of the bars). As shown in Figure 6, the “new version” has a higher numerosity than the “old version” (16 vs. 15 virtual units) despite containing less chocolate by weight. The weight cue was manipulated by showing the photo from an angle (rather than from the top) to draw attention to the bars’ contrasting thicknesses.

We recruited 786 participants via Prolific and retained 750 (431 women) after the pre-registered exclusions (https://aspredicted.org/65W_85V). The two photos in Figure 6 were displayed side by side, with no time limit, and the left/right positions of the portions were counterbalanced across participants. After selecting which portion contained more chocolate by weight, participants indicated how difficult it was to make the judgment and to gauge the thickness of the bars on two 7-point scales anchored at -3 (“extremely easy”) and 3 (“extremely difficult”).

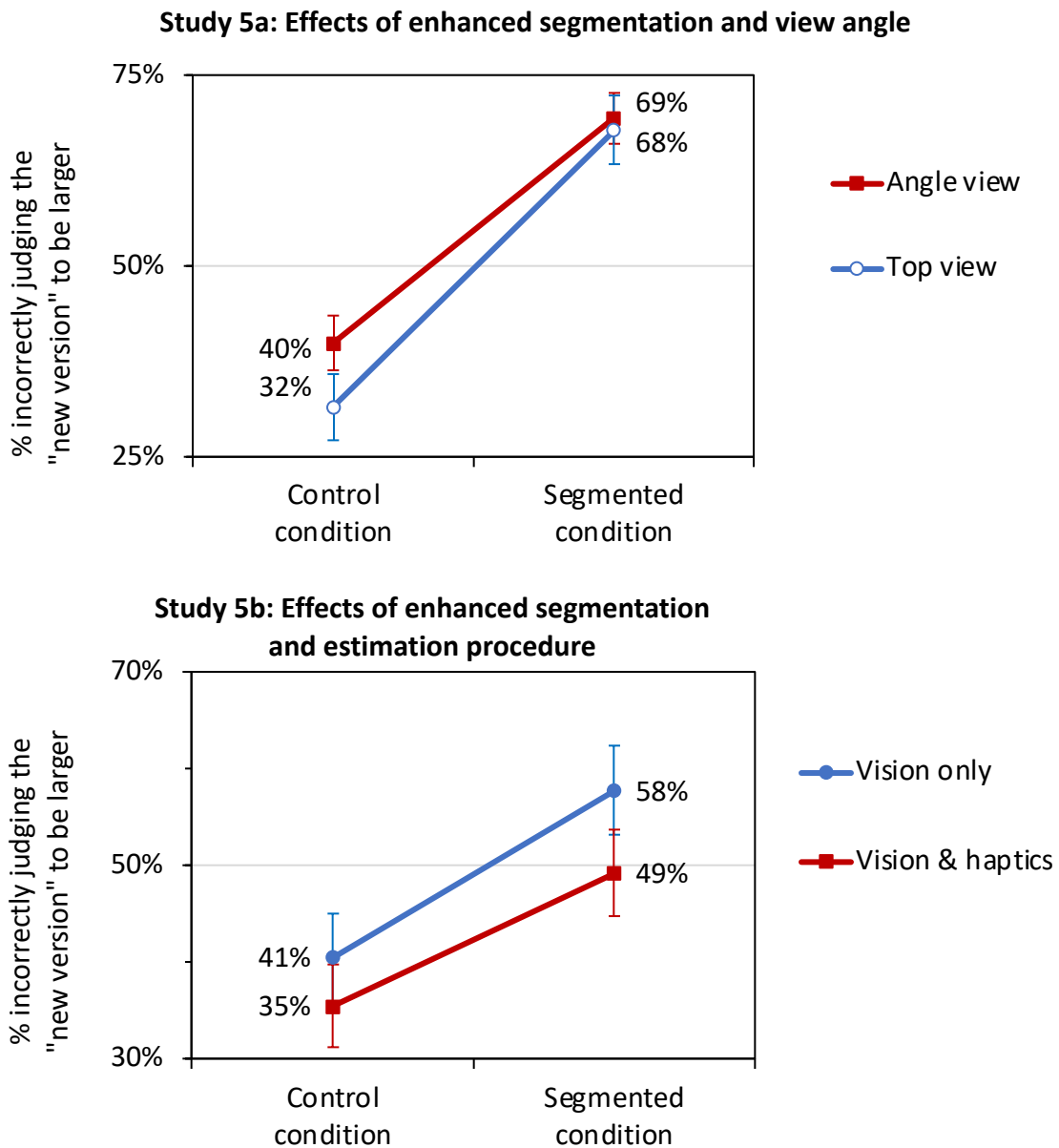
Results

The task was perceived as easier when the chocolate bars were shown from an angle ($M=-.54$) than when they were shown from the top ($M=-.16$, $t=3.14$, $p=.002$, $\eta^2=.01$), indicating that the weight-cue manipulation was effective. Subjective difficulty was unrelated to left/right position ($t=.27$, $p=.787$, $\eta^2<.01$), but was lower in the segmented condition ($M=-1.07$) than in the intact condition ($M=.39$, $t=12.39$, $p<.001$, $\eta^2=.17$), suggesting that participants counted the number of units in the segmented condition, as intended.

As preregistered, we estimated a binary logistic regression with incorrect choice (coded as 1 if participants incorrectly identified the “new version” as the larger one and 0 otherwise) as the dependent variable. The predictors were segmentation ($\frac{1}{2}$ in the segmentation condition and $-\frac{1}{2}$

in the control condition), angle ($\frac{1}{2}$ in the angle view and $-\frac{1}{2}$ in the top view), and position ($\frac{1}{2}$ when the larger bar was on the right side and $-\frac{1}{2}$ when it was on the left), as well as their interactions with the segmentation intervention.

Figure 7: Results of Study 5a online (top) and Study 5b in the field (bottom)



The effect of segmentation was statistically significant ($B=1.39$, $Wald=78.9$, $p<.001$, $OR=4.01$), supporting H1. In the segmented condition, the “new” chocolate bar was more likely

to be (incorrectly) identified as larger than the “old” bar ($M=68.7\%$ across the two views) than in the control condition, where the portions were not segmented ($M=35.7\%$ across the two views).

This suggests that segmentation, not the shape of the bars, biased size perceptions.

As shown in the top panel of Figure 7, photo angle had no main effect ($B=.22$, $Wald=1.90$, $p=.168$, $OR=1.24$). There was a significant effect of position ($B=-.41$, $Wald=6.98$, $p=.008$, $OR=.66$), with more accurate responses when the old version was on the right ($M=52.1\%$) than on the left ($M=42.8\%$). However, the photo position did not interact with the segmentation manipulation ($B=.032$, $Wald=.01$, $p=.918$, $OR=1.10$).

Discussion

Study 5a showed that an enhanced segmentation intervention, which increased numerosity and thinness, led more than two-thirds of participants (68.7%) to judge that a smaller chocolate bar was larger than one that contained 11.6% more chocolate. This is a strong reversal compared to the control condition, in which almost two-thirds of participants (64.3%) correctly identified the larger bar.

In Study 5a, the intervention’s effects were unaffected by highlighting portion depth, indicating that the effect is robust. Still, these results, like those of the other studies, were obtained using photographs of food portions. Although portions are often depicted in photos (on packages or menus, for example), another study is needed to determine whether segmentation can influence perceived size when consumers evaluate actual portions, including when holding them in their hands. Study 5b was designed to answer these questions and to extend the study of segmentation effects to nonfood products.

Study 5b: Can Enhanced Virtual Segmentation Promote Smaller Portions in the Field When Consumers Hold Actual Portions in Their Hands?

Procedure

Study 5b used the same procedure as Study 5a and the same 2 (intact vs. segmented) by 2 (weight cue: visual only vs. visual and haptic) between-subjects design, but with two within-subject replications (chocolate bars and sticky notes). As pre-registered, trained research assistants interviewed people in a public park and a suburban neighborhood over 15 half-days, yielding 242 participants (136 females) and 484 observations (https://aspredicted.org/LSL_VJN).

As in Study 5a, participants indicated which of two options they believed contained more chocolate or more paper by weight. In the visual condition, they made this judgment solely based on viewing the products, as in all previous studies. In the visual-and-haptic condition, participants were asked to hold each portion by hand before making the quantity judgment. Next, participants indicated which option they would purchase if both were sold at the same price. There was no time limit for these tasks.

The food stimuli were the chocolate portions used in Study 5a, placed inside plastic pouches so that participants could weigh them by hand. The nonfood items were sticky notes (see Web Appendix B for photos of all stimuli). The paper stimuli were selected to parallel the chocolate ones. In the intact condition, the “old version” of paper consisted of a pad of 40 sticky notes (50 grams, 155 cm²). This pad was thicker and therefore weighed 25% more than the “new version”, a pad of 31 sticky notes weighing 43.2 grams and with a slightly larger 174.4 cm² surface area. In the segmented condition, the pads were split into smaller notes: the thicker 50-gram “old version” was divided into 8 notes, whereas the thinner 45.3-gram “new version” was divided into 9 notes. For both products, the “new version” had higher numerosity but a lower weight, as in

Study 5a. The product weights were identical in the control and segmentation conditions.

Results

As pre-registered, we conducted a logistic regression of incorrect choice (coded as 1 if people incorrectly identified the “new version” as the larger one and 0 otherwise) with segmentation ($\frac{1}{2}$ in the segmentation condition and $-\frac{1}{2}$ in the control condition), estimation task ($\frac{1}{2}$ in the visual condition and $-\frac{1}{2}$ in the visual and haptic condition), their interaction, and an extra control variable capturing the product type (chocolate vs. sticky notes) used. As hypothesized (H1), the coefficient of the segmentation variable was positive and statistically significant ($B=.64$, $Wald=11.68$, $p<.001$, $OR=1.89$): As shown in Figure 7, segmentation increased the proportion of incorrect responses by 15.4 percentage points, from 37.9% (across both products and estimation tasks) in the intact condition to 53.3% in the segmented condition. In contrast, neither the main nor interaction effects of the estimation task (visual vs. visual and haptic) were statistically significant ($B=.28$, $Wald=2.28$, $p=.131$, $OR=1.33$ and $B=.13$, $Wald=.13$, $p=.724$, $OR=1.14$, respectively).

The effects of the enhanced segmentation were similar when analyzing each product separately. For chocolate, the proportion of consumers selecting the smaller portion across the two estimation tasks increased from 42.5% in the intact condition to 57.2% in the segmented condition ($B=.62$, $Wald=5.61$, $p=.018$, $OR=1.85$). For sticky notes, the respective numbers were 33.3% in the intact condition and 49.2% in the segmented condition ($B=.69$, $Wald=6.46$, $p=.011$, $OR=1.98$). Further, the segmentation intervention did not interact with the task manipulation ($p=.165$ for chocolate and $p=.318$ for sticky notes). The main effect of the task estimation was not significant for chocolate ($p=.994$) but was statistically significant for sticky notes ($B=.60$, $Wald=4.88$, $p=.027$, $OR=1.81$), indicating that consumers were more likely to select the new

version of sticky notes regardless of the segmentation condition.

To compare the results obtained with photos and real products, we now focus on the results of Study 5b in the vision-only condition and for chocolate only. In Study 5b, only 37.9% of participants in the intact condition incorrectly selected the smaller chocolate portion, indicating that it was relatively easy to identify the larger portion without segmentation-induced misperception. In the segmented condition, incorrect choices rose to a majority ($M=62.1\%$, $\chi^2=6.8$, $p<.01$, $OR=2.68$), representing a statistically significant increase relative to the intact condition. This proportion was not statistically different from the 68.7% found in Study 5a ($\chi^2(1,441)=1.00$, $p=.32$), indicating that the results obtained with photos replicated when participants evaluated real products.

Finally, additional exploratory analyses examined purchase intentions for the two portion options. A greater share of consumers intended to purchase the smaller “new” chocolate version in the segmentation condition ($M=45.1\%$) than in the control condition ($M=32.5\%$, $\chi^2= 4.03$, $p=.045$, $OR=1.71$). For sticky notes, however, segmentation did not significantly influence purchase intentions ($M=47.5\%$ vs. $M=45.0\%$, $\chi^2=.16$, $p=.692$, $OR=1.11$).

Discussion

Study 5b corroborates in the field the online findings of Study 5a by using physical products, rather than product photos, as experimental stimuli. Taken together, both studies demonstrate the effectiveness of the enhanced virtual segmentation to promote smaller chocolate portions.

Although most consumers readily identified the larger chocolate portion of the pair when it was intact, a majority incorrectly judged the smaller portion to be larger when it was thinner but more segmented. Moreover, these results were obtained even when drawing attention to the product’s thickness in the photos or when asking consumers to hold the products by hand. This suggests

that numerosity, aided by reduced thickness, can be a reliable strategy for promoting smaller products even when surface area is not increased. Of course, segmentation is an even stronger intervention to promote downsizing when it is accompanied by an increase in surface area, as shown in a supplementary study reported in Web Appendix E.

General Discussion

Serving food in multiple segmented units is an effective way to reduce consumption, and prior research suggests this may occur because segmented portions appear larger. Yet the fundamental question of why segmentation influences size perceptions in the first place has remained largely unanswered. Nor was it clear when this effect holds, why it sometimes fails to materialize, or how it might be strengthened. Across six studies, we first demonstrate that portion segmentation reliably increases size perceptions. We document that this effect holds even when consumers are incentivized to pay attention, when they judge photos rather than abstract representations, when they hold actual products in their hands, evaluate products separately, or directly compare them side by side. These studies, therefore, capture many of the ways in which products are displayed in real-world settings, including store packaging, physical menus, electronic kiosks, computer screens, and beyond.

This research clarifies the mechanisms that mediate and moderate the perceptual effects of segmentation. First, it rules out reassembly difficulty, which was the original explanatory mechanism. Second, it provides convergent evidence that numerosity and surface area jointly account for segmentation effects. Portion segmentation increases perceived size more as the number of segments increases and as the segmented parts are spread out. When segmentation does not increase surface area, as seen with “virtual” segmentation, its effects are greatly reduced, and a high level of numerosity is needed to reliably boost size perceptions.

Implications for Perception Research

Our findings offer a reinterpretation of classical results in the literature. First, they show that the stronger segmentation effect observed in what Pelham, Sumarta, and Myaskovsky (1994) termed the “difficult reassembly” condition is not driven by reassembly difficulty but by an enlarged surface area. Similarly, the weaker effect found by these authors in the “easy reassembly” condition is likely driven by the relatively small surface area occupied by the segmented circle when the units are only slightly spread out. Surface area can explain other mixed past results. For example, the surface area of the food portions tested by Oldham-Cooper et al. (2017) strongly increased between the intact and three-unit conditions, but barely changed between the three- and six-unit conditions. This can explain why three-unit portions looked larger than single-unit portions, but three- and six-unit portions appeared similar.

The moderating effect of numerosity can explain the inconsistent results of Vandebroele, Van Kerckhove, and Zlatevska (2019). Their second study asked consumers to estimate the weight (in grams) of chocolate portions depicted in four photos, randomly selected from 16 photos showing one to four chocolate chunks (12.5g, 25g, 37.5g, or 50g each) arranged into portions ranging from 25g to 200g. We categorized the comparisons of same-weight portions into a “low-numerosity gap” group (four 37.5g chunks vs. three 50g chunks and three 25g chunks vs. two 37.5g chunks) and a “high-numerosity gap” group (four 25g chunks vs. two 50g chunks; four 12.5g chunks vs. one 50g chunk; four 12.5g chunks vs. one 37.5g chunk; and two 12.5g chunks vs. one 25g chunk). Consistent with our results, the increase in perceived size was low (+9.0%) and not statistically significant ($t(190) = 1.09, p = .278$) in the low-numerosity gap group, but was large (48.5%) and statistically significant ($t(225) = 6.31, p < .001$) in the high-numerosity gap group.

In addition, our results offer a revised interpretation of the idea that social norms about appropriate eating, such as “having just one unit,” explain why segmentation reduces intake (Geier, Rozin, and Doros 2006). In Studies 2 and 4, we found that segmentation not only increases perceived size but also influences perceptions of whether a given portion constitutes an appropriate serving size. Specifically, we found that segmented portions are judged as appropriate for more people because they appear larger. As we showed, segmented portions also require more physical movements to be eaten, which draws attention to the act of eating and to its social appropriateness. Taken together, our results suggest that social norms about appropriate portions may be a consequence of these perceptual effects rather than an alternative explanation for how segmentation influences consumption. This account could also explain segmentation effects on intake that cannot be attributed to social norms, such as those observed in animals (Capaldi, Miller, and Alptekin 1989) and in very young children (Marchiori, Waroquier, and Klein 2012).

Our results also underscore the importance of distinguishing between symbolic and perceptual numerosity. Whereas prior research found that tasks such as estimating the monetary value of coins or the sum of numbers are influenced when cognitive resources are taxed (Pelham, Sumarta, and Myaskovsky 1994), we found that neither cognitive complexity nor incentives alter the effects of perceptual segmentation. Unlike the coins or numbers studied in previous research, food portions do not carry symbolic information that could be uncovered with further scrutiny. Hence, the perceptual segmentation effect appears to be a true perceptual bias and, as such, is unlikely to be corrected by incentives, disclosures, or training (Arkes 1991).

Our results raise the question of whether segmentation increases the *accuracy* of size estimates. In Studies 5a and 5b, segmentation misled most consumers into perceiving a

segmented portion as larger, reducing their accuracy relative to the control condition, where no portion was segmented. The results were less consistent in the studies that used a monadic separate-evaluation task. Segmentation improved accuracy in Studies 1 and 3, where consumers underestimated the intact portions, but the opposite was observed in Study 5. In the absence of a clear pattern, further research is necessary to determine when the larger perceived size, driven by segmentation, increases or decreases the accuracy of the estimates. For example, because consumers tend to underestimate the size of large objects but overestimate the size of smaller objects (Chandon and Wansink 2007), segmentation should improve the accuracy of size estimates for larger objects but not smaller ones.

Future research should also examine how different segmentation patterns influence size perceptions. For example, segmenting foods into units of unequal sizes may moderate the perceptual segmentation effect (Allik and Tuulmets 1991). Also, Sevilla and Kahn (2014) found that donuts with a hole appear smaller than donuts without a hole, although this pattern reverses when consumers expect the food to have holes (e.g., Swiss cheese). It would be interesting to examine whether segmentation that reduces completeness (e.g., removing the center to create a hole) affects size perceptions differently from other types of segmentation.

Implications for Healthier and More Sustainable Eating

As food portions grow, so do food intake and waste (Monteiro and Cannon 2021; Steenhuis and Poelman 2017). Zlatevska, Dubelaar, and Holden (2014) estimated that doubling the size of a meal leads to a 35% increase in energy intake. Conversely, reducing a portion by 100 calories is enough to lower total daily energy intake by 14 calories after accounting for subsequent compensation effects during the day (Robinson et al. 2022), which would offset the median excess daily energy intake in the US population (Hill et al. 2003). Portions of nutrient-deficient

and calorie-dense foods, like sodas and fries, are up to five times larger than they were 30 years ago (Young and Nestle 2021), and this supersizing has not been confined to food. For instance, the size of sticky notes has increased since their invention (3M 2024), necessitating more resources and potentially creating more waste.

In this context, portion size reduction is one of the most promising routes to obesity prevention, but also one of the most challenging. Convincing consumers to accept smaller food portions, or a smaller product quantity in general, is difficult (Almiron-Roig et al. 2020), and doing so without negative commercial consequences is even more challenging (Riis, Fisher, and Rowe 2016).

Our results suggest that segmentation may be a powerful strategy to help reduce population-level overconsumption. First, segmentation is easier for food companies to implement than other interventions known to influence size perceptions, such as changing the shape of the portion (Raghubir and Krishna 1999), because it works even with abstract product representations, such as circles and rectangles. Second, our results illustrate how to maximize the effects of segmentation by fully leveraging its two perceptual mechanisms, a larger surface area and higher numerosity, or by combining segmentation with a reduced thickness, when surface area cannot be enlarged. Finally, segmentation effects have downstream consequences for willingness to pay. For example, we found that willingness to pay increased by 14.2% when photos depicted pizza, chocolate bars, or tortillas cut into many pieces and spread out slightly. In summary, this research provides robust evidence for segmentation as a low-cost intervention that can meaningfully influence consumer behavior.

Because reducing demand is the most powerful lever for lowering environmental impact, our results also carry important implications for sustainability. This is particularly true for food,

which accounts for a third of global anthropogenic greenhouse gas emissions (Intergovernmental Panel on Climate Change 2022). By making smaller portions appear larger, segmentation enables restaurants and food service providers to reduce the quantity of carbon-intensive foods served without visibly impairing the perceived value of the offering, thereby preserving consumer acceptance and business viability. Beyond food, segmentation applies to other domains where the amount of material used carries clear environmental consequences. In our study with sticky notes, for example, segmenting paper pads into multiple smaller units increased their appeal while reducing total material consumption. By making reduced quantities appear sufficient, segmentation can contribute to greater material efficiency, allowing products to deliver the same perceived value while using less raw material and less energy in production and processing (Worrell, Allwood, and Gutowski 2016). In this way, segmentation functions not only as a behavioral lever for healthier eating but also as a scalable design approach that promotes more efficient and sustainable patterns of production and consumption.

Future research should examine the effects of portion segmentation among children, given the importance of eating habits and behaviors established during childhood. A classic strategy to address food neophobia in children is to cut portions into smaller units (Cole et al. 2017). Our results suggest that this strategy may be less effective than intended, as it can make the portion appear larger to the child. Studying the long-term effects of segmentation is also important because the effectiveness of most behavioral interventions tends to decline over time. Finally, because interventions need not only to be effective but also to be acceptable to consumers and policymakers alike, it would be important to test the acceptance of segmentation versus other interventions designed to reduce intake, such as smaller plates.

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Web Appendix

Why Segmented Food Portions Appear Larger: Evidence for Numerosity and Surface Area but Not Reassembly Difficulty, with Implications for Smarter Downsizing

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Web Appendix A: Data Exclusions

Study 1

A total of 189 adult participants were recruited via Prolific to take part in Study 1. All 189 participants confirmed using a laptop, and therefore, none were excluded based on device type. As pre-registered (<https://aspredicted.org/yw3bf9.pdf>), we removed four respondents who failed the validation check and one who did not consent to participate. We also removed seven participants who stopped the study during the practice task. This resulted in a final sample of 177 participants.

Study 2

A total of 425 adult participants were recruited via Prolific and began the study. Seven participants did not consent to participate, six stopped during the practice task, 1 had their consent revoked, and two did not finish the survey. Following these initial exclusions, 409 participants remained. As pre-registered (<https://aspredicted.org/dtf2-2pwy.pdf>), we removed four respondents who shared duplicate IP addresses and five participants identified as time outliers. This resulted in a final sample of 400 participants.

Study 3

A total of 2,325 adult participants were recruited via Prolific and began the study. As pre-registered (<https://aspredicted.org/2t3ic7.pdf>), we removed five respondents who completed the study on a mobile device instead of a computer, 37 who failed the validation check, one who declined to consent, and 79 who abandoned the study during the instructions and were therefore never randomly assigned. Consistent with the pre-registration, we also removed 211 participants who judged the target stimulus as smaller than or equal to the reference, indicating they were not

paying attention, since the target was 2.9 times larger than the reference. This yielded a final sample of 1,992 participants.

Study 4

A total of 806 adult participants were recruited via Prolific and began the study. We excluded one participant for failing the attention check (i.e., a food evaluation recall task), and 19 participants for ineligible device use, leaving 786 valid participants (512 female) for a total of 2,358 observations, since each participant rated three products.

Study 5a

A total of 786 adult participants were recruited via Prolific and began the study. As pre-registered (https://aspredicted.org/65W_85V), we removed 10 participants who did not complete the study, 3 who shared duplicate IP addresses, and 23 who failed the manipulation check. This resulted in a final sample of 750 participants (431 female).

Study 5b

A total of 258 participants were approached and invited to participate by trained research assistants in a public park or suburban neighborhood across 15 half-days. Sixteen refused to participate, 3 could not complete the study due to physical limitations such as a hand injury, and 23 did not complete the study. Refusals to participate were more common for people categorized as older ($\chi^2=27.1$ $p<.001$) and as male ($\chi^2=4.2$, $p=.04$) by the research assistants. This led to a final sample of 242 participants (136 female) and 484 observations, as each participant completed two evaluations (https://aspredicted.org/LSL_VJN).

Web Appendix B: Stimuli for Studies 2 and 5b

Figure W1: Study 2—Stimuli.



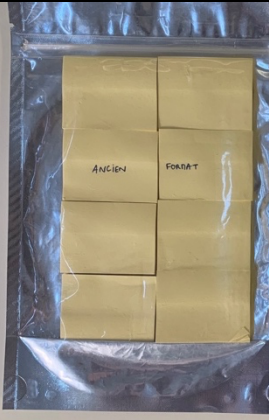
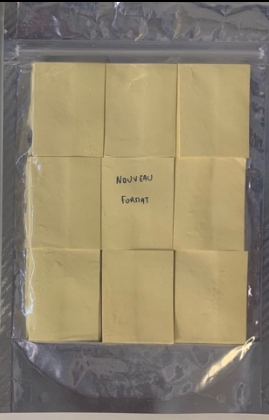




Reference portion



Segmented portion (before being fully sliced)	Intact portion
	

Notes: There was an error in the pre-registration, which listed a lighter weight for the reference portion. However, this does not impact the results because the same photo of the reference portion was used consistently across conditions.

Figure W2: Study 5b—Stimuli

	<i>“Old version” Larger and less segmented portion (77 grams, 15 elements)</i>	<i>“New version” Smaller and more segmented portion (69 grams, 16 elements)</i>	<i>“Old version” Larger and less segmented portion (50 grams, 8 elements)</i>	<i>“New version” Smaller and more segmented portion (43 grams, 9 elements)</i>
<i>Segmentation condition</i>				
<i>Control condition</i>				

Web Appendix C: Study 3 Pre-test

Sample

The goal of this study was to verify that the stimuli used in Study 3 manipulated reassembly difficulty as intended. Fifty Prolific participants began the study, confirmed that they were using a desktop computer, and passed the validation check. One participant did not provide consent, yielding a final sample of 49 participants.

Procedure

Participants completed two pairwise judgments of reassembly difficulty: one for the low numerosity version of the stimuli, in which the intact square was cut into six pieces, and one for the high numerosity version, in which it was cut into twelve pieces. In each case, we displayed the easy-to-reassemble figure, the hard-to-reassemble figure, and the intact figure on the same screen. Participants were asked, “Which figure can most easily be reassembled into the plain square in the center?” and were instructed to choose one of the two segmented figures.

Participants completed this task twice, once for the low-numerosity figures and once for the high-numerosity figures.

Results

We examined whether participants selected the “easy-to-reassemble” figure above chance in each numerosity condition. In both the low and high numerosity conditions, 44 of the 49 participants selected the easy-to-reassemble figure. This corresponds to a proportion of .898, 95% *CI*: [.75, .95]. A binomial proportion test confirmed that this proportion was significantly greater than chance ($p < .001$). These results validate that the “easy-to-reassemble” stimuli were perceived as easier to reassemble than the “hard-to-reassemble” stimuli in both the low and high numerosity conditions.

Web Appendix D: Mediation results for Study 4

Table W1: Mediation Results for Willingness to Pay, Consumption Duration, and Hand-to-mouth Movements.

Dependent variable	Surface area (moderator)	Indirect effect (standard errors)	95% confidence interval	
			Lower limit	Higher limit
1. Willingness to pay	Low	.037 (.025)	-.012	.087
	High	.161 (.028)	.107	.217
2. Expected consumption duration	Low	.049 (.036)	-.016	.117
	High	.213 (.037)	.145	.286
3. Expected hand-to-mouth movements	Low	.080 (.063)	-.028	.220
	High	.350 (.128)	.118	.632

Notes: We used PROCESS Model 8 with Numerosity as the independent variable, surface area as the moderator, perceived portion size as the mediator, and mode of presentation as the control variable. Each outcome (Y) is modeled in a separate analysis: willingness to pay, expected consumption duration, and expected number of hand-to-mouth movements. Indirect effects are unstandardized and based on 5,000 bootstrap samples. Values in parentheses are bootstrap standard errors.

Web Appendix E: Supplementary Study

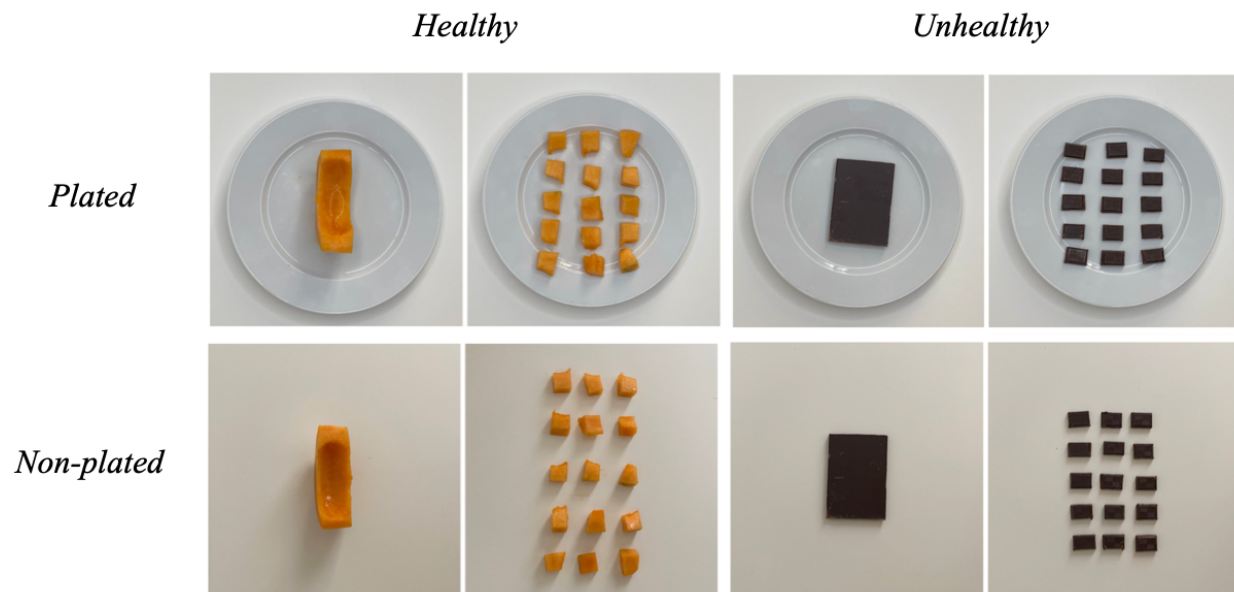
Procedure

This supplementary study examined the effects of portion segmentation on quantity perceptions in the context of downsizing. In the segmented condition, we cut a portion of melon (healthy food) or chocolate (unhealthy food) into 16 pieces, removed one piece, spread the remaining pieces, and then placed the segmented portion next to a larger intact portion. The intact portion of melon weighed 7.8% more than the segmented one (135.5 g vs. 125.7 g), and the intact portion of chocolate weighed 6.8% more than the segmented one (67.4 g vs. 63.1 g).

As pre-registered (https://aspredicted.org/Z6V_4S8), 816 participants were recruited for the study via Prolific. Twenty-one participants were excluded because they did not complete the survey on a desktop computer, leaving 795 eligible participants. Of these, 784 consented to participate. Following the pre-registered exclusion criteria, we removed eight participants who failed the attention check, which required them to correctly recall the type of food they had been shown. The final sample consisted of 776 participants (418 female).

After rating their liking for the food and their hunger level, participants saw one photo of the segmented portion and another of the intact one (Figure W3) side by side on their screen. They were told that the photos were shown to scale and that one photo truly displayed more food than the other (i.e., no deception). They were then asked: “Which photo has more melon [chocolate] (by weight)?” Finally, they indicated how difficult it had been to make the size judgment.

Figure W3: Supplementary Study—Stimuli in the “Intact Portion on the Left” Condition.



Results

Overall, 66.1% of the participants indicated that the segmented portions contained more food than the intact portions (one-sample proportion test of difference from 50%: $z = 9.0$, $p < .001$), even though the opposite was true. Similar results were obtained with the pre-registered binomial test, but we report the proportion test because it provides an indication of the effect size, which can be compared across studies. A binary logistic regression model further revealed that this proportion was similar across the two foods (67.6% for melon and 64.6% for chocolate, $Wald = .75$, $p = .386$) and was not influenced by the presence or absence of a plate (63.7% in the plated condition and 68.8% in the unplated condition, $Wald = 2.05$, $p = .152$). The position of the intact and segmented plates had a statistically insignificant effect ($Wald = 3.56$, $p = .059$). These results remained unchanged when incorporating food liking and hunger as control variables, and these variables did not influence choice ($p = .624$ and $p = .684$, respectively).

Despite failing to correctly identify the larger portion in most cases, participants judged the task to be neither easy nor difficult ($M=0.35$ on the 7-point scale anchored at -3 “extremely easy”, 0 “neither easy nor difficult,” and +3 “extremely difficult”). Furthermore, perceived difficulty was unrelated to choice ($p=.466$). Decision duration was also unrelated to choice ($p=.259$).

Discussion

This supplementary study documents a perceptual segmentation effect that led two-thirds of consumers to judge a segmented portion as larger than an intact portion containing more food. This segmentation effect was observed for both healthy and unhealthy foods, regardless of the visual contrast created by a plate’s presence and the horizontal positioning of the two portions.