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Misunderstood Menu Metrics: Side-length Food Sizing Leads to Quantity Underestimation and Overeating

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ABSTRACT: This research highlights consumers' failure to understand food sizing communicated using side-length metrics (e.g., 12-inch pizza, 8-inch cake, 2-inch cookie), which are ubiquitous in menus and online interfaces. A series of studies show that describing food size options using side-length metrics leads to food quantity underestimation and food intakes misaligned with consumers' objectives. This robust effect arises because of a linearization heuristic where people do not adequately adjust for the exponential difference in the surface area associated with linear changes in side-length metrics. Choice architecture interventions that replace side-length information with metrics varying linearly with quantities (e.g., surface area, numbers of servings) and training interventions that improve understanding of surface area computation reduce this bias. These findings offer important public policy implications for better food quantity choices by supporting the removal of side-length metrics from the food decision environment.

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Fact: A 9-inch pizza is 2.25 times larger than a 6-inch pizza.

Understanding the implications of various information presentation formats in food menus and online interfaces is crucial, as people rely on those more than ever for making food consumption decisions. This trend is driven by a steady increase in the proportion of meals consumed away from home, which now account for half (50.2%) of US consumers' total spending on food (Saksena et al., 2018), and the rising popularity of online food-delivery services, a global market estimated to reach $200 billion by 2025 (Singh, 2019), which accelerated greatly during the COVID-19 crisis (Henderson, 2020). Many popular food items in those menus—such as pizzas, cakes, and pies—use side-length metrics (e.g., the diameter of a circle, the side of a square) to convey sizing information to consumers (see Web Appendix A for examples). For instance, pizza, which is consumed by 1 in 8 (13%) Americans on any given day, including 1 in 4 males (25%) aged 6-19 years (Rhodes et al., 2014), is sold using such a side-length system (e.g., a 10-inch pizza). Despite the side-length metrics' ubiquity in menus and online interface, little is known about how consumers integrate these information cues into their food quantity selection process.

Research dedicated to improving food choices using information-based interventions has often identified nutritional labeling as the best tool to nudge consumers toward better options. Those inquiries have often focused on measuring the effectiveness of labeling calories and nutrients in menus (e.g., Cantu-Jungles et al., 2017; Dallas et al., 2019; Haws and Liu, 2016) or on health ratings through color-coding schemes (akin to traffic lights; Thorndike et al., 2014) to reduce the desirability of unhealthy items. Notably, decision-making related to food consumption appears complex, often influenced by a variety of exogenous factors, including social presence (McFerran et al., 2010), halo effects from other food items (Chernev and Gal, 2010), and packaging design cues (Cheema and Soman, 2008).

The current article focuses on consumers' quantity-estimation process when consumers do not directly experience the product but rely exclusively on numerical information, as when ordering from menus and online interfaces. We find that consumers evaluating food-size options using side-length information fail to recognize that linear changes in the sizing metric lead to exponential changes in food quantity. By using a numerical cognition approach to explain food quantity estimation, our work contributes to a more nuanced understanding of how marketing cues create consumer biases and identifies interventions that help consumers better align choices with preferences.

THEORETICAL BACKGROUND

Perceptual Biases and Quantity Estimates

Research into the process by which people make quantity estimations—and their biases—has traditionally focused on the interpretation of visual cues for decision-making and found support for a *perceptual salience* effect to explain volume estimations (see Table 1). According to this explanation, people heuristically assess visual changes in food items dimensions, overestimating the most salient dimension's impact while underestimating the importance of the other orthogonal dimension(s). This effect explains numerous psychophysical biases that affect consumers' decision-making. For instance, people often perceive the taller of two containers with equal capacity to contain more product (the elongation bias; Raghubir and Krishna, 1999; Yang and Raghubir, 2005). Offering a general explanation for volume estimation biases based on visual assessments, Ordabayeva and Chandon (2013) show that people mistakenly add instead of multiply the changes in individual product dimensions. Much less research has looked at the impact of numerical cues on quantity estimates. In one study about reservation prices, participants presented with information about the diameter of three sizes of pizza were willing to pay less—overall and by the rate of increase between sizes—than those who saw graphical representations of those sizes, highlighting the challenge arising from using numerical information to convey food quantities (Study 6; Krider et al., 2001).

Metrics as a Tool for Increased Accuracy

Product attributes can be expressed in multiple ways. For example, a pizza size can be described as 8-inch in diameter, 900 calories, or three portions, where each expression or "translation" should be equivalent. While, normatively, quantifying the same attribute using different metrics should not lead to different decisions, there are several reasons why this might not be the case. Decision-makers tend to use information in the form in which it is explicitly displayed, discounting inferences or mental transformations (Slovic, 1972). In particular, the human mind struggles to develop accurate mental representations of numbers (Gelman and Butterworth, 2005) and to adopt accurate-but-effortful decision-making strategies (Bettman et al., 1998).

We argue that side-length information is a suboptimal metric to convey food quantities because of the mismatch between changes in the metric and the construct it represents (i.e., food quantity). Linear changes in side length produce nonlinear changes in the food amount. For example, switching from a 6-inch to a 12-inch square-shaped cake leads not to twice the quantity but four times as much food (36 sq. inch. to 144 sq. inch.). Therefore, failing to account for the nonlinear relationship between these metrics and the food quantity can lead to choosing larger quantities than expected—which is crucial given that people typically finish what they order (Wilkinson et al., 2012).

The type of cognitive biases associated with people's inability to process nonlinear relationships is called linearization (de Langhe et al., 2017). These biases often arise from the need to use ratios and exponential components to translate the metrics into features of interest. For instance, linear gains in metrics such as miles-per-gallon (energy efficiency; Larrick and Soll, 2008), kilometers-per-hour (travel speed; Peer and Gamliel, 2013; Svenson, 1970), and megabits-per-second (download speed; de Langhe and Puntoni, 2016) offer decreasing marginal benefits (e.g., increasing one's driving speed by 10 km/h for a 100 km distance reduces drive time by 9 minutes at 80 km/h but only by 3 minutes at 120 km/h). However, people often interpret those linear increases as indicating linear gains (Camilleri and Larrick, 2014). Linearization biases also arise from a failure to adjust for compound interests in financial products, leading to overly optimistic time-to-repayment and growth assessments for debt (Soll et al., 2013; Stango and Zinman, 2009). Overall, the literature highlights the importance of designing metrics that have a linear relationship with the features people are trying to optimize for accurate decision-making (Hsee et al., 2003; Johnson et al., 2012).

When using side-length for sizing, the metric obliges consumers to make complex computations using the provided cues (e.g., diameter for circles, side for squares, diagonal for rectangles). This feature is problematic because a significant share of the adult population struggles with even simple computations involving more than one step, a division, or a ratio (National Center for Education Statistics, 2017). Therefore, those sizing metrics appear optimally designed to ensure overeating if people fail to recognize or compute the squared term implied in side-length information (e.g., circle area = $\pi/4 \times \text{diameter}^2$).

In addition to examining the effect of side-length metrics for single food items, we also consider how consumers trade-off food sizes and the number of units. We do so because firms often choose to present food to consumers using variations in the size versus the number of items in the option. Consumers thus often make decisions based on a trade-off between different cues for food amount. For example, a consumer buying a snack may face the choice between buying one 3-inch cookie and buying two 2-inch cookies. Although the quantity of cookie is larger in the first (7.07 sq inches) than in the second case (6.28 sq inches), we measure the extent to which consumers using a linearization heuristic while trying to minimize calorie intake would choose the first option ($1\times3 < 2\times2$), and thereby *maximize* caloric intake.

This article's contribution is twofold. First, we seek to help improve consumer well-being by highlighting the importance of food sizing metrics, a key element of consumers' information environment. Using insights from the linearization literature, we propose theoretically motivated interventions to address the deleterious effects of using side-length information to communicate food sizes. Our results highlight the need for the industry to consider changes in practice (refrain from using side-length in food-sizing metrics) and for policymakers to consider changes in guidelines or regulations. Second, we contribute to the literature on volume perception in marketing—which mainly focused on visual cues—by drawing attention to the context of surface area computation. We study how side-length metrics bias consumer judgments and examine how consumers make choices trading-off side-length and numerosity cues.

We present five studies that (a) demonstrate a quantity-assessment bias arising from the use of side-length metrics, (b) show how this leads to food choices misaligned with consumers' goals, (c) study implications of this linearization bias in contexts where consumers must choose between assortments that vary in side-length and number of units, and (d) propose both training and choice-architecture interventions that reduce this bias. Unless specified, we excluded no participants and reported all conditions and measures. The data is available on the Open Science Framework (https://osf.io/q5mc8/?view_only=77e8e2b66d364d1f8b48e710bae6836e).

STUDY 1

When using side-length information to communicate food quantity, linear changes in size are associated with nonlinear changes in food quantities following a convex function (i.e., u-shaped). Study 1 illustrates how consumers fail to adjust for this nonlinear component implied in side-length metrics when assessing the caloric content of different size options. To this aim, we used a within-participant factor that directly tests this quantity estimation bias. This design also mimics restaurant menu food-ordering decisions where consumers choose between multiple options varying in size.

We also examine two theoretically motivated interventions to reduce this side-length metric bias. First, we illustrate the linearization process underlying our effect by testing whether a training intervention to increase people's understanding of exponential components in surface-area computation could reduce this bias. Second, we replace side-length information with surface area information as a salient and easy-to-implement choice-architecture intervention. From a numerical cognition standpoint, the surface area is a metric that linearly varies with the feature it describes (i.e., the number of calories is a linear function of the surface area), which should facilitate quantity assessment.

Methods

Participants and Design. US Prolific participants took part in this experiment (n = 602, 52% female, M_{Age} = 34.7). This study uses a 3 (information type: side-length vs. side-length + debiasing intervention vs. area) between × 5 (food quantity) within mixed-factorial design.

Procedure. We presented participants with five pizza sizes on one page and asked them to estimate the number of calories in each size. We introduced a reference point to reduce variance in the results, informing participants that a McDonald's Big Mac contains 540 calories. In the side-length condition, we described the five sizes using the diameter of each option (8-inch, 10-inch, 12-inch, 14-inch, 16-inch). We described the same five sizes in the area condition using their equivalent surface area (50 sq. inches, 78 sq. inches, 113 sq. inches, 153 sq. inches, 200 sq. inches). In the side-length + debiasing condition, we first exposed participants to an arithmetic demonstration of the effect of a circle's diameter on its area (see

Web Appendix B). Those participants also had to correctly answer the multiple-choice question "What is the area of a circle with a diameter of 6 inches?" before they could proceed to the same measure as in the side-length condition. We removed two data points that were 56 and 205 standard deviations above the average calorie estimate for the 16-inch/200 sq. inches pizza size (138k and 500k Cal, respectively); this deletion did not change the pattern of results.

Results

A repeated-measures ANOVA revealed a main effect of the item size on calorie estimates ($F(4, 2388) = 280.41$, $p < .001$, $\eta_p^2 = .32$), consistent with larger calorie estimates for larger pizza sizes. Importantly, we also observed an interaction between the metric condition and the item size ($F(8, 2388) = 14.21$, $p < .001$, $\eta_p^2 = .05$) suggesting that the rate at which the calorie estimates increased with size varied between the conditions (see Figure 1 for detail, including an illustration of a "correct" projected estimate). Pairwise comparisons suggested that all three lines were significantly different from each other. For instance, the area condition lead to larger (i.e., less biased) estimates compared to both the side-length ($F(4, 1628) = 21.44$, $p < .001$, $\eta_p^2 = .05$) and side-length + debias ($F(4, 1572) = 8.88$, $p < .001$, $\eta_p^2 = .02$) conditions. In turn, the side-length + debias condition also lead to larger estimates than the side-length condition ($F(4, 1576) = 8.04$, $p < .001$, $\eta_p^2 = .02$).

Study 1 illustrates a linearization bias when using side-length metrics to evaluate multiple size options. This study also tests the effectiveness of two debiasing interventions to reduce the extent of this bias. We find that while a training intervention about surface area computation knowledge reduces the calorie underestimation bias significantly, it is not as effective as a choice-architecture intervention that uses a metric varying linearly with food quantities.

Additionally, we reconcile the apparent discrepancy between these results and those of Krider et al. (2001, pp. 417-420) in Web Appendix C and test whether unaided surface-area computation knowledge can also reduce this bias in Web Appendix D.

STUDY 2

Study 2 tests the debiasing effect of another choice-architecture intervention, whether indications about the number of servings, an important metric for food decision-making (e.g., Mohr et al., 2012), can reduce the quantity underestimation caused by side-length metrics.

Like surface area, providing the number of servings in each option should make it easier for consumers to evaluate food amounts. This reduction in the extent of the bias should occur because, unlike side-length, where linear changes in the metric imply *exponential* changes in quantity, linear changes in servings imply *linear* changes in quantity. According to the US Food and Drug Administration (2019), a serving refers to "the amount of food customarily consumed per eating occasion." Loosely defined to fit various food products, a serving of pizza amounts to about 300 calories[1]. Notably, while found on nutritional labels, this information is absent in most food ordering contexts. We thus compare the extent of participant's bias when using side-length information compared to servings information and a condition where both metrics are available to participants.

Methods

Participants and Design. US Prolific participants took part in this experiment (n = 600, 61% female, M_{Age} = 33.3). This study uses a 3 (information type: side-length vs. servings vs. side-length + servings) between × 5 (food quantity) within mixed-factorial design.

Procedure. Similar to Study 1, we asked participants to estimate the number of calories contained in each of five pizza sizes, while providing a caloric reference point to reduce variance. We described the sizes using each option's diameter in the side-length condition (8-inch, 10-inch, 12-inch, 14-inch, 16-inch). We described the same five sizes in the servings condition using their equivalent number of servings (3 servings, 4.5 servings, 6.5 servings, 9 servings, 12 servings)—corresponding to realistic totals between 900 and 3,600 calories. In the side-length + servings condition, both metrics were available for each size option (see Web Appendix B for stimuli).

Results

A repeated-measures ANOVA revealed a main effect of the item size on calorie estimates ($F(4, 2388) = 706.65$, $p < .001$, $\eta_p^2 = .54$), consistent with larger calorie estimates for larger pizza sizes. Importantly, we also observed an interaction between the metric condition and the item size ($F(8, 2388) = 20.93$, $p < .001$, $\eta_p^2 = .07$) suggesting that the rate at

[1] According to the U.S. Food and Drug Administration, a serving of pizza refers to a fractional slice of the pizza, with a reference amount of 145g with a possible additional 55g for sauce topping. Importantly, this recommendation is non-binding.

which the calorie estimates increased with size varied between the conditions (see Figure 2 for detail). Pairwise comparisons suggested larger (i.e., less biased) estimates in both the servings ($F(4, 1572) = 50.04$, $p < .001$, $\eta_p^2 = .11$) and side-length + servings conditions ($F(4, 1640) = 24.51$, $p < .001$, $\eta_p^2 = .06$) compared to the side-length condition. The servings and side-length + servings conditions were not significantly different from one another ($F(4, 1564) = .86$, $p = .49$, $\eta_p^2 = .00$).

This study finds that providing serving size information to consumers reduces their food-quantity underestimation bias compared to side-length information. Notably, the intervention was effective even when side-length information was presented concurrently.

STUDY 3

Studies 1 and 2 featured variations in a single unit's side length. However, consumers often face trade-offs in the marketplace where they need to select a given food quantity using various unit and size combinations—raising questions about the respective impact of each feature for decision-making. Thus, we designed Study 3 to test our linearization mechanism against alternative decision rules that consumers may utilize.

First, according to our theorizing, people poorly estimate the caloric content of foods because of a misunderstanding of how side-length metrics relate to surface size. Specifically, they linearize a nonlinear relationship. According to this account, when comparing food options varying in the number of units and size, people should multiply the number of those units by the side-length of each unit to estimate the overall food amount—this is the *Unit×Side-Length* rule. Second, research on food consumption has shown that people often underestimate the caloric content of small food items, especially if those are hedonic products (e.g., Argo and White, 2012; Coelho do Vale et al., 2008; Scott et al., 2008). This account suggests that, as the number of units increases, all else being equal, people should underestimate the caloric content of the food options—this is the *Small Units* rule. Third, and finally, research on numerosity heuristics shows that people's judgments are affected by the size of numbers, such that larger numbers, independent of their meanings, lead to larger estimates (Bagchi and Davis, 2016; Pelham et al., 1994)—this is the *Numerosity* rule. Our study asked people to estimate the caloric content of four food options to tease apart these three accounts.

Methods

Participants and Design. US Prolific participants took part in this experiment (n = 400, 69% female, M_{Age} = 28.1). The study used a 4-level (food quantity) within-participants design.

Procedure. We presented participants with four chocolate chip cookies assortments on one page. For each option, we asked them to estimate the number of calories. We also provided the same caloric reference point as in Studies 1-2. We described the food sizes in each assortment using the number of units and the diameter of each unit: "1 cookie of 6 inches in diameter," "3 cookies of 3 inches in diameter," "4 cookies of 2 inches in diameter," and "12 cookies of 1 inch in diameter" (corresponding respectively to food quantities of 28.30 sq. inches, 21.21 sq. inches, 12.56 sq. inches, and 9.42 sq. inches).

We aimed to understand participants' food quantity assessment processes by regressing their individual-level calorie estimates for the different options on the *True Area* (28.30, 21.21, 12.56, 9.42) and the number of units (1, 3, 4, 12) and *Unit×Side-Length* (6, 9, 8, 12) decision rule. Thus, because the three decision rules make different predictions, we can identify which best predicts calorie estimates. *Small Units* predicts a negative association between the number of units and calorie estimates, whereas both the *Unit×Side-Length* and *Numerosity* rules predict a negative association. In addition, the *Unit×Side-Length* rule predicts that people will estimate the second option to have more calories than the third (3*3 > 4*2), while the *Numerosity* rule on the number of units predicts the opposite (3 < 4).

Results

In an initial test of our process, we ran a series of paired-sample t-tests between the six possible estimate comparisons. Each pairwise test was highly significant (all *p*'s < .001), suggesting that the different combinations of unit numbers and unit sizes impacted calorie assessments.

We observed a negative correlation between calorie estimates and the *True Area* values (r = -.17, p < .001), such that increases in cookie amount were associated with lower calorie estimates—supporting our general estimation bias again. We also observed a positive correlation between the *Unit×Side-Length* rule and calorie estimates (r = .21, p < .001) consistent with our linearization account. Unsurprisingly, because of the correlation between the two accounts' predictions, there was also a positive correlation between the *Numerosity* rule and calorie estimates (r = .21, p < .001), consistent with a numerosity explanation, and—by virtue of our design—ruling out a *Small Units* explanation (which would have predicted smaller estimates as the number of units in each option increased). Crucially, the 3×3-inch option was estimated to contain more calories than the 4×2-inch option (t(399) = 4.50, p < .001). This contrast—and the associated rank order of the responses—provides direct evidence in line with the *Unit×Side-Length* rule (i.e., 9 > 8) and against the *Numerosity* rule (i.e., 3 < 4).

We aimed to gather further evidence to disentangle the *Unit×Side-Length* rule (i.e., our linearization account) and a *Numerosity* alternative account by running a multilevel analysis using the three accounts above as simultaneous predictors of calorie estimates nested by participant (intra-class correlation = .76; consistent with substantial clustering by participant in the data). We found that the *Unit×Side-Length* rule (b = 30.02, SE = 6.01, t(1200) = 4.992, p < .001, CI_{95}[18.22; 41.82]) significantly predicted calorie estimates, while the number of units (i.e., *Numerosity*; b = 4.30, SE = 3.30, t(1200) = 1.30, p = .19, CI_{95}[-2.17; 10.78]) and *True Area* (b = 0.33, SE = 1.07, t(1200) = .38, p = .76, CI_{95}[-1.77; 2.44]) do not. This additional analysis is thus consistent with linearization as the better predictor of participants' calorie estimates. These results held even after removing *True Area* from the model predictors.

Overall, Study 3 suggests that when choosing between assortments that vary in the number of units and the side-length of each unit, people linearize the impact of the side-length metric, leading to food quantity underestimations. We also observe that this decision heuristic impacts food quantity estimations more than numerosity or small-sample heuristics.

STUDIES 4-5

Study 4 provides real choice evidence for a food quantity linearization effect when food sizing is reported using side-length information. This study illustrates the implications of this bias using participants' self-reported food quantity goals. Following Study 3, we do so in a context where consumers have to trade-off side-length and numerosity information. We discuss Study 5, which provides a conceptual replication of Study 4 with manipulated food quantity goals, at the end of this section.

Methods

Participants and Design. Singapore undergraduates took part in this study (n = 333, 52% female, M_{Age} = 20.8). The study correlated participants' self-reported food quantity goals with their choice between two cookie quantity options.

Procedure. At the end of an unrelated experimental session, we informed participants that they could get one of two food options as a token of gratitude. They could choose to leave the lab with either "Two chocolate chips cookies of 2 inches in diameter from the Nabisco brand" or "One chocolate chips cookie of 3 inches in diameter from the Ahoy brand," such that the 1×3-inch cookie option (7.07 sq inches) contained 12.5% more cookie than the 2×2-inch cookies option (6.28 sq inches). The cookie brand associated with each option was randomized between students to give an illusion of a brand choice[2]. Only fresh cookies were served, taken from new sealed packets at the beginning of each experimental session. No participant declined taking cookies.

After they made their choice of cookies (59.8% chose the 2×2-inch option), we measured participants' food quantity goals using two items, "I wanted to get as much cookie as possible" (hereafter, Get More) and "I wanted to get the option with the least amount of calories" (hereafter, Get Less). We also presented a decoy item, "I wanted the option from the most premium brand" (1 = not at all, 7 = very much). Participants then contacted the experimenter to receive their cookies, were thanked, and dismissed.

Results

Get More. Results from a point-biserial correlation analysis between the Get More item (M = 4.15, SD = 2.00) and the choice of cookie option (coded: 0 = 1×3-inch cookie, 1 = 2×2-inch cookies) revealed a significant positive correlation (r = .36, p < .001), such that those who sought a larger quantity of cookies were more likely to select the option with the smallest amount of food.

[2] Unbeknown to most participants, Ahoy is a brand of the manufacturer Nabisco. The Ahoy brand was overall selected more often than the Nabisco brand ($\chi^2(1)$ = 6.75, p = .01, Φ = .14), consistent with a stronger association with chocolate chips cookies.

Get Less. Similarly, the correlation analysis between the Get Less item (*M* = 2.73, SD = 1.68) and the choice of cookie option revealed a significant negative correlation ($r = -.12$, $p = .025$), such that those who sought a smaller quantity of cookies (i.e., fewer calories) were more likely to select the option with the largest amount of food.

Stated differently, participants who sought to get a larger quantity of food (+1 SD on the average of the Get More and reverse-coded Get Less items) had only a 24% probability of selecting the larger of the two options, whereas those who sought a smaller quantity of food (-1 SD) had a 60% probability of selecting it.

Study 4 provides evidence of a linearization bias in real food choices. Participants making food-quantity choices using side-length information made poor food-quantity decisions, selecting the option with less food when aiming to maximize the amount of food, and selecting the option with more food when aiming to minimize their caloric intake.

In Study 5 (n = 428 Mturk, 43% female, $M_{Age} = 36.9$; described in Web Appendix E for brevity), we manipulated the food-quantity maximization (minimization) goal by mentioning that "at the last minute, you hear that more (fewer) people than expected would be present" for an office party and asked participants to choose between "One 12-inch cake" and "Two 8-inch cakes." The cakes were either square or round, depending on the experimental condition (consistently 12.5% larger for the single 12-inch option). Replicating the bias observed in Study 4, most participants selected the largest option available when aiming to select the smallest, and vice versa when aiming to select the largest (see Table 2). This study also increases our findings' generalizability across different food categories (i.e., cakes) and item shapes (see also Web Appendix D).

GENERAL DISCUSSION

As interest increases in using choice architecture to facilitate better decision-making, this article examines the implications of the ubiquitous use of side-length information as a sizing metric for food items. Highlighting the importance of studying food-size estimations using a numerical cognition perspective, we observe a widespread and robust failure to recognize the nonlinear relationship between side-length sizing metrics and food quantities, leading consumers to make food-quantity choices poorly aligned with their goals.

We observed this bias in people's ability to estimate calorie amounts accurately (Studies 1- 3), impacting actual (Study 4) and imagined (Study 5) food choices. We identify an intervention based on arithmetic training (Study 1) that reduces this bias. More importantly, we highlight how costless and straightforward choice architecture interventions relying on surface area information (Study 1) and the number of servings (Study 2) appear highly effective at reducing this bias. We also provide evidence for our linearization account against numerosity or small-sample alternative accounts by studying contexts where assortments vary based on the number of units and side-length (Study 3).

This research contributes to a rich psychophysical literature on food-quantity estimation in marketing. Using a numerical cognition perspective to study how side-length metrics bias consumer decision-making related to food, we derive easy-to-implement practical implications for business and policymaking. This article's main contribution is demonstrating the pernicious ways menus populated with side-length metrics lead consumers to make choices poorly aligned with their consumption goals.

Most importantly, our findings underline the importance of displaying information using meaningful metrics (Camilleri and Larrick, 2014). Instead of side-length information, we propose metrics such as servings and surface area in menus as choice architecture interventions to "nudge" toward better food consumption decisions (Cadario and Chandon, 2020). We contend that this beneficial effect occurs because metrics that *align* with the focal attribute (e.g., *linear* changes on the metric communicate *linear* changes in food quantity) reduce estimation biases effortlessly, without relying on complex training interventions (Study 1).

Future Research

While the current research proposes a food-sizing metric change to reduce food overconsumption from a health perspective, future research should look into how those benefits affect other aspects of consumer well-being, such as financial savings through reduced food wastage (Buzby et al., 2014) and environmental benefits from a resource and greenhouse gas emission perspective (Camilleri et al., 2019). Future research should also seek to integrate our findings with those of other approaches to address food overconsumption as a multidetermined phenomenon: for instance, socio-psychological factors such as feelings of powerlessness (Dubois et al., 2012), counterfactual thinking (Chandon and Wansink, 2007), self-affirmation (Cornil and Chandon, 2013) and other marketing cues such as price (Haws et al., 2020; Liu et al., 2019), low-fat labeling (Cornil et al., 2014), and branding (Cornil et al., 2017).

Vast amounts of calories are consumed based on food-quantity choices relying on side-length information. Our work uncovers a strong bias when consumers translate side-length information into food quantities, leading to choices that do not match consumers' goals. These results highlight the need for policymakers to consider how changes in the choice environment could facilitate better food quantity decisions. Given the pervasiveness and robustness of the linearization bias in our studies, the widespread industry reliance on side-length metrics in menus appears to be among the worst possible approaches to menu design if the goal is to help consumers make decisions well-aligned with their consumption goals.

REFERENCES

Argo, Jennifer J., and White, Katherine (2012). When do consumers eat more? The role of appearance self-esteem and food packaging cues. *Journal of Marketing, 76*, 67-80.

Bagchi, Rajesh, and Davis, Derick F. (2016). The role of numerosity in judgments and decision-making. *Current Opinion in Psychology, 10*, 89-93.

Bettman, James R., Luce, Mary Frances, and Payne, John W. (1998). Constructive consumer choice processes. *Journal of Consumer Research, 25*, 187-217.

Buzby, Jean C., Wells, Hodan F., and Hyman, Jeffrey. (2014). The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States. In U. S. D. o. Agriculture (Ed.), (Economic Research Service ed.).

Cadario, Romain, and Chandon, Pierre (2020). Which healthy eating nudges work best? A meta-analysis of field experiments. *Marketing Science, 39*, 465-486.

Camilleri, Adrian R., and Larrick, Richard P. (2014). Metric and scale design as choice architecture tools. *Journal of Public Policy & Marketing, 33*, 108-125.

Camilleri, Adrian R., Larrick, Richard P., Hossain, Shajuti, and Patino-Echeverri, Dalia (2019). Consumers underestimate the emissions associated with food but are aided by labels. *Nature Climate Change, 9*, 53-58.

Cantu-Jungles, Thaisa M., McCormack, Lacey A., Slaven, James E., Slebodnik, Maribeth, and Eicher-Miller, Heather A. (2017). A meta-analysis to determine the impact of restaurant menu labeling on calories and nutrients (ordered or consumed) in US adults. *Nutrients, 9*, 1088-1105.

Chandon, Pierre, and Ordabayeva, Nailya (2009). Supersize in one dimension, downsize in three dimensions: Effects of spatial dimensionality on size perceptions and preferences. *Journal of Marketing Research, 46*, 739-753.

Chandon, Pierre, and Wansink, Brian (2007). The biasing health halos of fast-food restaurant health claims: lower calorie estimates and higher side-dish consumption intentions. *Journal of Consumer Research, 34*, 301-314.

Cheema, Amar, and Soman, Dilip (2008). The effect of partitions on controlling consumption. *Journal of Marketing Research, 45*, 665-675.

Chernev, Alexander, and Gal, David (2010). Categorization effects in value judgments: Averaging bias in evaluating combinations of vices and virtues. *Journal of Marketing Research, 47*, 738-747.

Coelho do Vale, Rita, Pieters, Rik, and Zeelenberg, Marcel (2008). Flying under the radar: Perverse package size effects on consumption self-regulation. *Journal of Consumer Research, 35*, 380-390.

Cornil, Yann, and Chandon, Pierre (2013). From fan to fat? Vicarious losing increases unhealthy eating, but self-affirmation is an effective remedy. *Psychological Science, 24*, 1936-1946.

Cornil, Yann, Chandon, Pierre, and Krishna, Aradhna (2017). Does Red Bull give wings to vodka? Placebo effects of marketing labels on perceived intoxication and risky attitudes and behaviors. *Journal of Consumer Psychology, 27*, 456-465.

Cornil, Yann, Ordabayeva, Nailya, Kaiser, Ulrike, Weber, Bernd, and Chandon, Pierre (2014). The acuity of vice: Attitude ambivalence improves visual sensitivity to increasing portion sizes. *Journal of Consumer Psychology, 24*, 177-187.

Dallas, Steven K., Liu, Peggy J., and Ubel, Peter A. (2019). Don't count calorie labeling out: Calorie counts on the left side of menu items lead to lower calorie food choices. *Journal of Consumer Psychology, 29*, 60-69.

de Langhe, Bart, and Puntoni, Stefano (2016). Productivity metrics and consumers' misunderstanding of time savings. *Journal of Marketing Research, 53*, 396-406.

de Langhe, Bart, Puntoni, Stefano, and Larrick, Richard (2017). Linear thinking in a nonlinear world. *Harvard Business Review, 95*, 130-139.

Dubois, David, Rucker, Derek D., and Galinsky, Adam D. (2012). Super size me: Product size as a signal of status. *Journal of Consumer Research, 38*, 1047-1062.

Fernandes, Daniel, Lynch Jr, John G., and Netemeyer, Richard G. (2014). Financial literacy, financial education, and downstream financial behaviors. *Management Science, 60*, 1861-1883.

Folkes, Valerie, and Matta, Shashi (2004). The effect of package shape on consumers' judgments of product volume: attention as a mental contaminant. *Journal of Consumer Research, 31*, 390-401.

Gelman, Rochel, and Butterworth, Brian (2005). Number and language: how are they related? *Trends in Cognitive Sciences, 9*, 6-10.

Hagtvedt, Henrik, and Brasel, S. Adam (2017). Color saturation increases perceived product size. *Journal of Consumer Research*, *44*, 396-413.

Haws, Kelly L., and Liu, Peggy J. (2016). Half-size me? How calorie and price information influence ordering on restaurant menus with both half and full entrée portion sizes. *Appetite*, *97*, 127-137.

Haws, Kelly L., Liu, Peggy J., Dallas, Steven K., Cawley, John, and Roberto, Christina A. (2020). Any Size for a Dollar: The Effect of Any- Size- Same- Price Versus Standard Pricing on Beverage Size Choices. *Journal of Consumer Psychology, 30*, 392-401.

Henderson, Brooke (2020). We're eating a lot more pizza during the pandemic. Why Domino's is getting the biggest slice of the pie. *Fortune Magazine*.

Hsee, Christopher K., Yu, Fang, Zhang, Jiao, and Zhang, Yan (2003). Medium maximization. *Journal of Consumer Research, 30*, 1-14.

Hsee, Christopher K., and Zhang, Jiao (2010). General evaluability theory. *Perspectives on Psychological Science*, *5*, 343-355.

Johnson, Eric J., Shu, Suzanne B, Dellaert, Benedict G. C., Fox, Craig, Goldstein, Daniel G., Häubl, Gerald, Larrick, Richard P., Payne, John W., Peters, Ellen, and Schkade, David (2012). Beyond nudges: Tools of a choice architecture. *Marketing Letters, 23*, 487-504.

Krider, Robert E., Raghubir, Priya, and Krishna, Aradhna (2001). Pizzas: π or square? Psychophysical biases in area comparisons. *Marketing Science*, *20*, 405-425.

Krishna, Aradhna (2006). Interaction of senses: The effect of vision versus touch on the elongation bias. *Journal of Consumer Research*, *32*, 557-566.

Larrick, Richard P., and Soll, Jack B. (2008). The MPG illusion. *Science*, *320*, 1593-1594.

Liu, Peggy J., Haws, Kelly L., Scherr, Karen, Redden, Joseph P., Bettman, James R., and Fitzsimons, Gavan J. (2019). The primacy of "what" over "how much": How type and quantity shape healthiness perceptions of food portions. *Management Science, 65*, 3353-3381.

McFerran, Brent, Dahl, Darren W., Fitzsimons, Gavan J., and Morales, Andrea C. (2010). I'll have what she's having: Effects of social influence and body type on the food choices of others. *Journal of Consumer Research*, *36*, 915-929.

Mohr, Gina S, Lichtenstein, Donald R, and Janiszewski, Chris (2012). The effect of marketer-suggested serving size on consumer responses: the unintended consequences of consumer attention to calorie information. *Journal of Marketing*, *76*, 59-75.

Morewedge, Carey K., Kassam, Karim S., Hsee, Christopher K., and Caruso, Eugene M. (2009). Duration sensitivity depends on stimulus familiarity. *Journal of Experimental Psychology: General*, *138*, 177-186.

National Center for Education Statistics. (2017). Program for the International Assessment of Adult Competencies. In U. S. D. o. Education (Ed.).

Ordabayeva, Nailya, and Chandon, Pierre (2013). Predicting and managing consumers' package size impressions. *Journal of Marketing*, *77*, 123-137.

Peer, Eyal, and Gamliel, Eyal (2013). Pace yourself: Improving time-saving judgments when increasing activity speed. *Judgment and Decision Making*, *8*, 106-115.

Pelham, Brett W., Sumarta, Tin T., and Myaskovsky, Laura (1994). The easy path from many to much: The numerosity heuristic. *Cognitive Psychology*, *26*, 103-133.

Raghubir, Priya, and Krishna, Aradhna (1999). Vital dimensions in volume perception: Can the eye fool the stomach? *Journal of Marketing Research*, *36*, 313-326.

Rhodes, Donna G. , Adler, Meghan E., Clemens, John C., LaComb, Randy P., and Moshfegh, Alanna J. (2014). Consumption of pizza: What we eat in America. In US Department of Agriculture (Ed.), (Vol. FSRG Dietary Data Brief - No. 11).

Saksena, Michelle J., Okrent, Abigail M., Anekwe, Tobenna D., Cho, Clare, Dicken, Christopher, Effland, Anne, Elitzak, Howard, Guthrie, Joanne, Hamrick, Karen S., Hyman, Jeffrey, Jo, Young, Lin, Biing-Hwan, Mancino, Lisa, McLaughlin, Patrick W., Rahkovsky, Ilya, Ralston, Katherine, Smith, Travis A., Stewart, Hayden, Todd, Jessica, and Tuttle, Charlotte. (2018). America's eating habits: Food away from home. In US Department of Agriculture (Ed.), (Vol. EIB-196).

Scott, Maura L, Nowlis, Stephen M., Mandel, Naomi, and Morales, Andrea C. (2008). The effects of reduced food size and package size on the consumption behavior of restrained and unrestrained eaters. *Journal of Consumer Research, 35*, 391-405.

Singh, Sarwant. (2019). The soon to be $200B online food delivery is rapidly changing the global food industry. In *Forbes* (Sept 9 ed.).

Slovic, Paul (1972). From Shakespeare to Simon: Speculations—and some evidence—about man's ability to process information. *Oregon Research Institute Bulletin, 12*, 1-19.

Soll, Jack B., Keeney, Ralph L., and Larrick, Richard P. (2013). Consumer misunderstanding of credit card use, payments, and debt: Causes and solutions. *Journal of Public Policy & Marketing, 32*, 66-81.

Stango, Victor, and Zinman, Jonathan (2009). Exponential growth bias and household finance. *The Journal of Finance, 64*, 2807-2849.

Svenson, Ola (1970). A functional measurement approach to intuitive estimation as exemplified by estimated time savings. *Journal of Experimental Psychology, 86*, 204-210.

Thorndike, Anne N., Riis, Jason, Sonnenberg, Lillian M., and Levy, Douglas E. (2014). Traffic-light labels and choice architecture: promoting healthy food choices. *American Journal of Preventive Medicine, 46*, 143-149.

US Food and Drug Administration. (2019). Code of Federal Regulations Title 21, Part 101 - Food Labeling. In: Sec. 101.12 Reference amounts customarily consumed per eating occasion.

Van Ittersum, Koert, and Wansink, Brian (2012). Plate size and color suggestibility: The Delboeuf illusion's bias on serving and eating behavior. *Journal of Consumer Research, 39*, 215-228.

Wilkinson, Laura L., Hinton, Elanor C., Fay, Stephanie H., Ferriday, Danielle, Rogers, Peter J., and Brunstrom, Jeffrey M. (2012). Computer-based assessments of expected satiety predict behavioural measures of portion-size selection and food intake. *Appetite, 59*, 933-938.

Yang, Sha, and Raghubir, Priya (2005). Can bottles speak volumes? The effect of package shape on how much to buy. *Journal of Retailing, 81*, 269-281.

FIGURE 1

Study 1: Calorie Estimates By Size and Information Type. The dashed line represents a correct projection based on the 8-inch pizza calorie estimate in the side-length condition. (Note. Our graphical illustrations of this bias imply a constant calories-by-sq. inch ratio for our various food size options whereas, in practice, it might have varied slightly, for instance, by having a different crust-to-topping ratio between sizes of pizzas. Nevertheless, we do not expect this possibility to have a meaningful impact on our findings.)

FIGURE 2. Study 2: Calorie Estimates By Size and Information Type. The dashed line represents a correct projection based on the 8-inch pizza calorie estimate in the side-length condition.

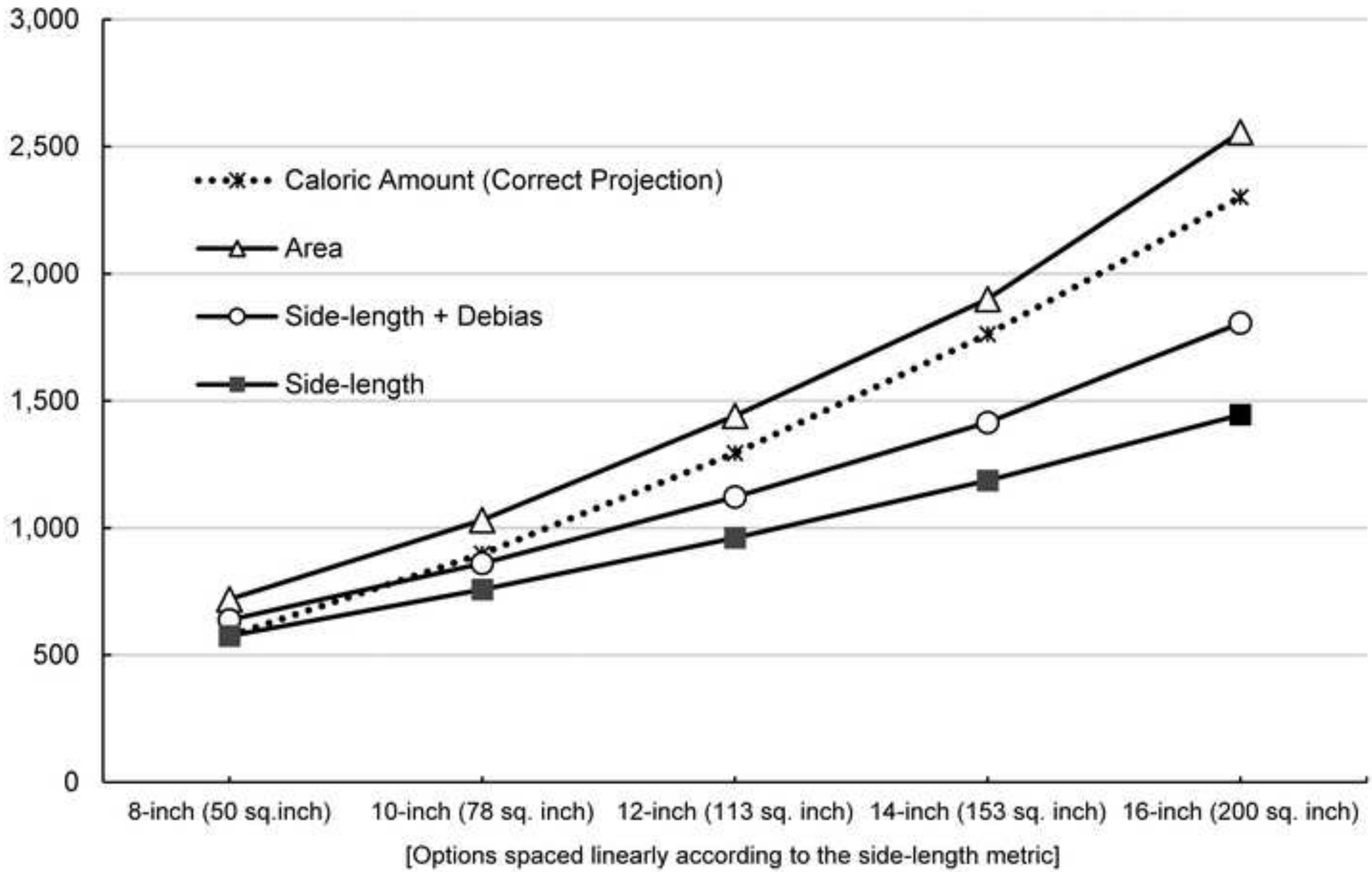
FIGURE 3. Study 3: Calorie Estimates By Units And Side-Length Combinations

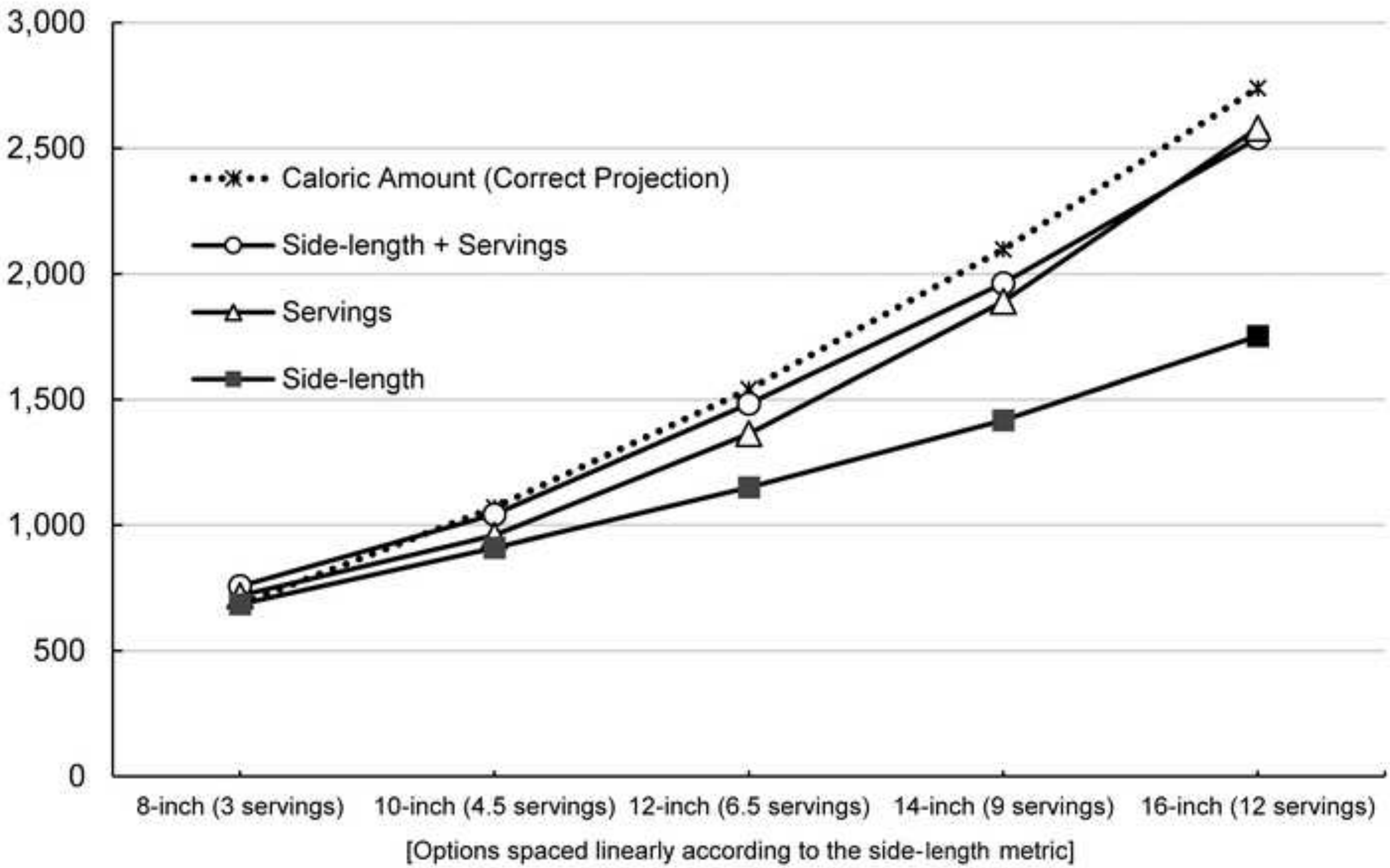
TABLE 1. Contribution Table: Marketing Variables Affecting Food-Quantity Estimates.

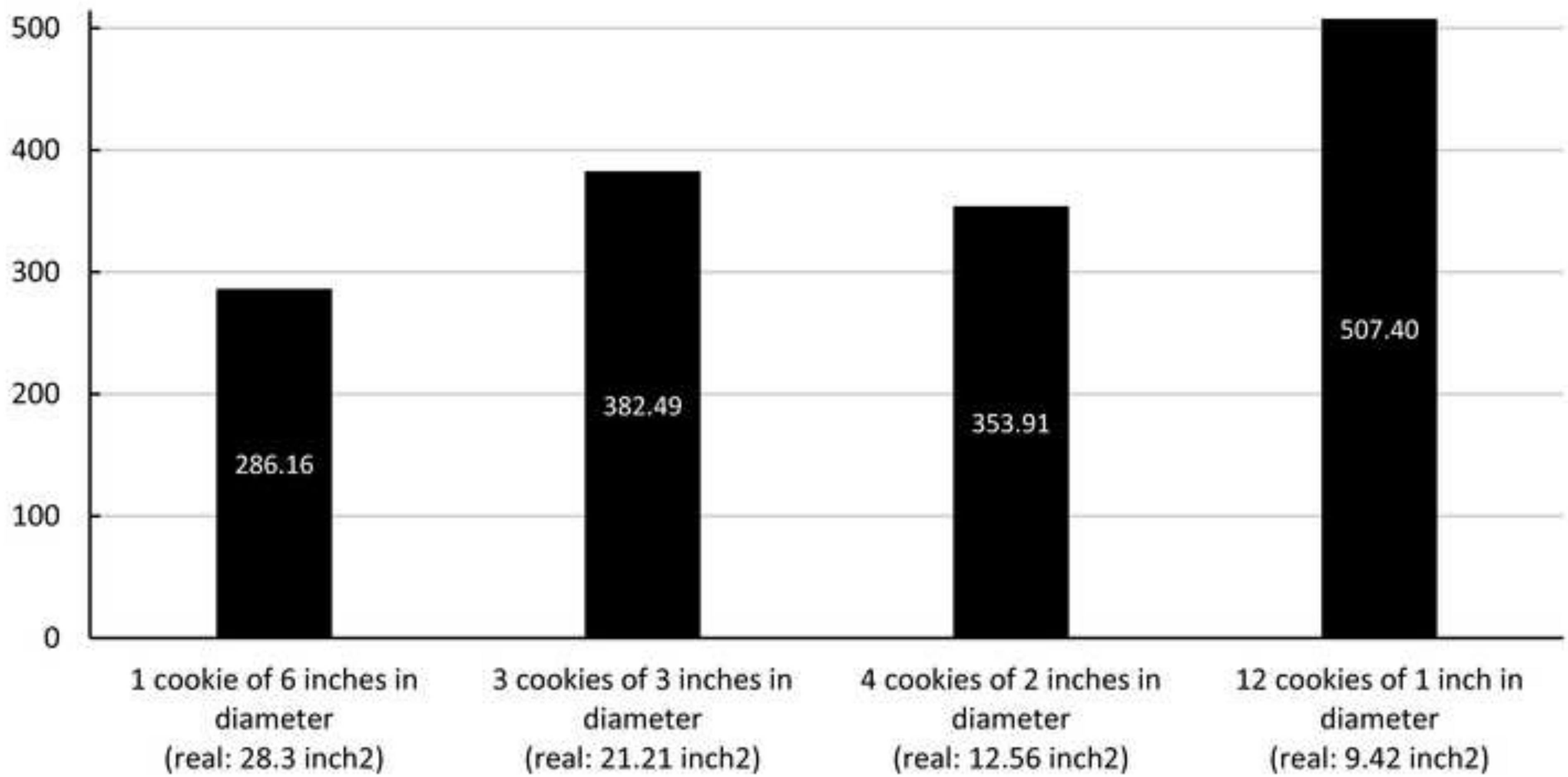
Source	Focus	Process	Key Findings
Raghubir and Krishna (1999)	Effect of container elongation	**Visual bias:** People focus primarily on the height of a container (i.e., elongation) to estimate its volume.	More elongated containers are associated with larger perceived volumes, less perceived consumption, higher actual consumption, higher preference, and less post-consumption satisfaction than less elongated ones.
Krider, Raghubir, and Krishna (2001)	The process by which consumers make area comparison judgments (e.g., circles vs. squares)	**Visual bias:** People focus on the change on the most salient dimension and insufficiently adjust for change on the other orthogonal dimension (locus of attention).	People make effort-accuracy trade-offs in area comparison judgments by focusing on the primary dimension. The reliance on one dimension vs. others depends on the dimensions' relative salience. Semantic descriptors (diameter) reduce the salience of the primary dimension on which consumers make judgments (reservation price for pizzas; p. 420) compared to seeing the items.
Folkes and Matta (2004)	Effect of using unusual container shapes	**Visual bias:** Increased attention given to unusual container shapes leads to a "mental contamination" in volume judgment (amount of attention).	Containers with shapes that attract more attention (vs. less attention) are also perceived to contain a larger volume of the product.
Krishna (2006)	Interaction between visual and haptic senses on the elongation bias	**Sensory bias:** Vision dominates touch in predicting the direction of the elongation bias.	Whereas vision is associated with an elongation bias for volume estimates (i.e., tall-thin > short-fat), haptic is associated with its opposite. The direction of the bias depends on the dominant sense when those two interact.
Chandon and Ordabayeva (2009)	Effect of using packages that vary in size on three vs. one spatial dimension	**Visual bias:** The authors assume an attentional process, either in the form of amount or locus of attention (p. 752).	Variations in size appear smaller when packages and portions change in all three dimensions (height, width, and length) than changes in only one dimension, affecting product choice, dosage, and expected discount.
Van Ittersum and Wansink (2012)	Effect of dinnerware measurement on servings and intake	**Visual bias:** Effects of the diameter ratio of the serving size vs. dinnerware creating contrast and assimilating effects between sizes (i.e., Delboeuf illusion).	The Delboeuf illusion biases serving and eating behaviors. Bringing attention to the target, providing attention to the illusion, and reducing the color contrast between dinnerware and tablecloth reduce this bias.
Cornil et al. (2014)	Effects of attitude ambivalence on visual evaluation of portion sizes	**Visual bias:** Size estimation accuracy depends on restrain-eating tendencies (more accurate) and whether the food is perceived/labeled as unhealthy (more accurate) or low-fat (less accurate).	Attitude ambivalence better predicts visual sensitivity to increasing portion sizes than the two main effects of desire and perceived unhealthiness and their positive interaction.
Ordabayeva and Chandon (2013)	Predicting volume impressions for 1D, 2D, and 3D package changes	**Visual bias:** People incorrectly combine (add rather than multiply) perceived volume changes on each dimension.	Consumers underestimate product size changes, especially with 3D changes (vs. 2D or 1D) or when dimensions change in different directions (i.e., elongation).
Hagtvedt and Brasel (2017)	Effect of color saturation on the perceived product size	**Visual bias:** Saturated color capture more attention and, thus, creates more arousal (amount of attention).	Increasing color saturation increases size perception, with downstream consequences on evaluation, willingness to pay, and usage.
Our Research	Effects of side-length metrics on food quantity estimates and choices	**Numerical bias:** Consumers fail to adjust for the exponential component implied in the side-length sizing metric (linearization heuristic).	Consumers using side-length metrics for quantity assessment underestimate size changes and make choices inconsistent with their dietary goals. Training (surface area knowledge) and choice-architecture (providing surface area and servings information) interventions reduce this otherwise robust bias.

TABLE 2. Study 5: Food Choice Counts As A Function Of Shape And Food Quantity Goal

Manipulated Food quantity goal	Item shape	Chose 1×12-inch (*larger option*)	Chose 2×8-inch (*smaller option*)
Minimization goal	Round	79	29
(*Fewer people would be present*)	Square	78	36
Maximization goal	Round	35	63
(*More people would be present*)	Square	41	67


3,000
2,500
2,000
1,500
1,000
500
0
Caloric Amount (Correct Projection)
Area
Side-length + Debias
Side-length
8-inch (50 sq.inch)
10-inch (78 sq. inch)
12-inch (113 sq. inch)
14-inch (153 sq. inch)
16-inch (200 sq. inch)
[Options spaced linearly according to the side-length metric]


3,000
2,500
2,000
1,500
1,000
500
0
Caloric Amount (Correct Projection)
Side-length + Servings
Servings
Side-length
8-inch (3 servings)
10-inch (4.5 servings)
12-inch (6.5 servings)
14-inch (9 servings)
16-inch (12 servings)
[Options spaced linearly according to the side-length metric]

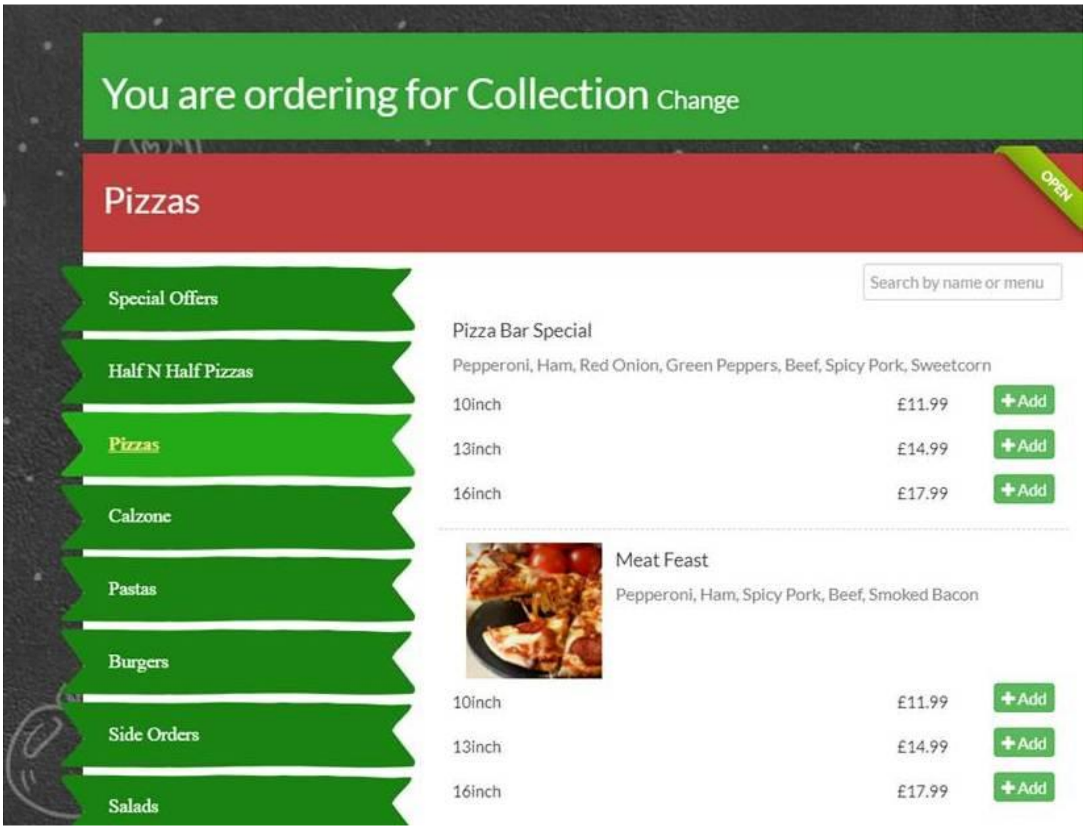

500
400
300
200
100
0
286.16
382.49
353.91
507.40
1 cookie of 6 inches in diameter (real: 28.3 inch2)
3 cookies of 3 inches in diameter (real: 21.21 inch2)
4 cookies of 2 inches in diameter (real: 12.56 inch2)
12 cookies of 1 inch in diameter (real: 9.42 inch2)

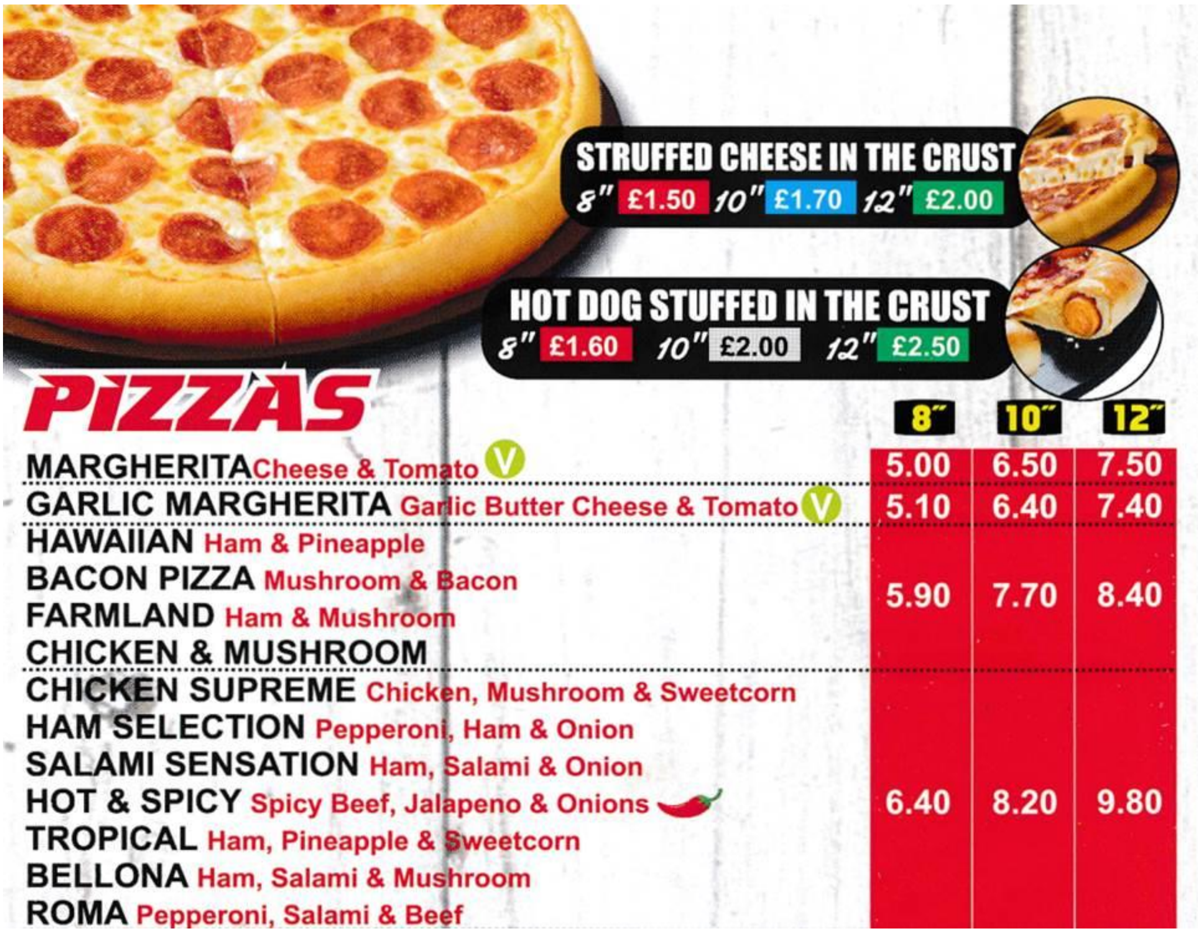
ONLINE APPENDIX

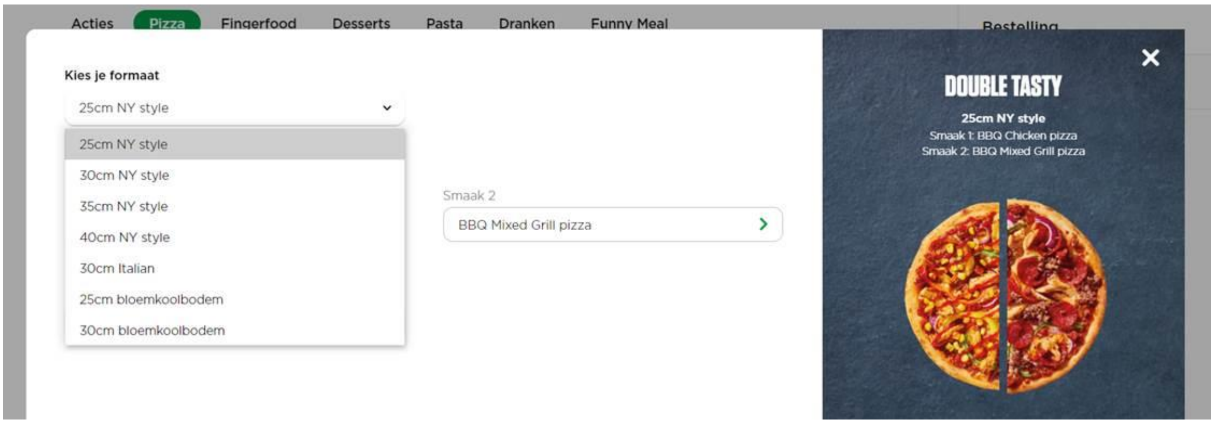
- Online Appendix A: Examples Of Menus And Marketing Communications Using Side-Length For Food Sizing
- Online Appendix B: Stimuli and Detailed Results For Experiments
- Online Appendix C: Reconciliation With Krider et al. (2001) Study
- Online Appendix D: Effect Of Surface Area Knowledge Study
- Online Appendix E: Study 5 Detailed Write-Up

ONLINE APPENDIX A

EXAMPLES OF MENUS AND MARKETING COMMUNICATIONS USING SIDE-LENGTH FOR FOOD SIZING




STRUFFED CHEESE IN THE CRUST
8" £1.50 10" £1.70 12" £2.00
HOT DOG STUFFED IN THE CRUST
8" £1.60 10" £2.00 12" £2.50
PIZZAS
8" 10" 12"
MARGHERITA Cheese & Tomato V 5.00 6.50 7.50
GARLIC MARGHERITA Garlic Butter Cheese & Tomato V 5.10 6.40 7.40
HAWAIIAN Ham & Pineapple
BACON PIZZA Mushroom & Bacon
FARMLAND Ham & Mushroom
CHICKEN & MUSHROOM
5.90 7.70 8.40
CHICKEN SUPREME Chicken, Mushroom & Sweetcorn
HAM SELECTION Pepperoni, Ham & Onion
SALAMI SENSATION Ham, Salami & Onion
HOT & SPICY Spicy Beef, Jalapeno & Onions
TROPICAL Ham, Pineapple & Sweetcorn
BELLONA Ham, Salami & Mushroom
ROMA Pepperoni, Salami & Beef
6.40 8.20 9.80


Acties
Pizza
Fingerfood
Desserts
Pasta
Dranken
Funny Meal
Bestelling
Kies je formaat
25cm NY style
25cm NY style
30cm NY style
35cm NY style
40cm NY style
30cm Italian
25cm bloemkoolbodem
30cm bloemkoolbodem
Smaak 2
BBQ Mixed Grill pizza
DOUBLE TASTY
25cm NY style
Smaak 1: BBQ Chicken pizza
Smaak 2: BBQ Mixed Grill pizza

ONLINE APPENDIX B

Stimuli used in Study 1

Below is a list of pizza sizes. Your task is to estimate the number of calories contained in one pizza for each of the sizes listed below.

For reference, a **McDonald's Big Mac contains 540 calories**.

Pizza sizes (diameter):

8 inches **10 inches** **12 inches** **14 inches** **16 inches**

Estimate the number of calories for each pizza size below (digits only):

8 inches	
10 inches	
12 inches	
14 inches	
16 inches	

(side-length condition)

Below is a list of pizza sizes. Your task is to estimate the number of calories contained in one pizza for each of the sizes listed below.

For reference, a **McDonald's Big Mac contains 540 calories**.

Pizza sizes (area):

50 sq inches **78 sq inches** **113 sq inches** **153 sq inches** **200 sq inches**

Estimate the number of calories for each pizza size below (digits only):

50 sq inches	
78 sq inches	
113 sq inches	
153 sq inches	
200 sq inches	

(area condition)

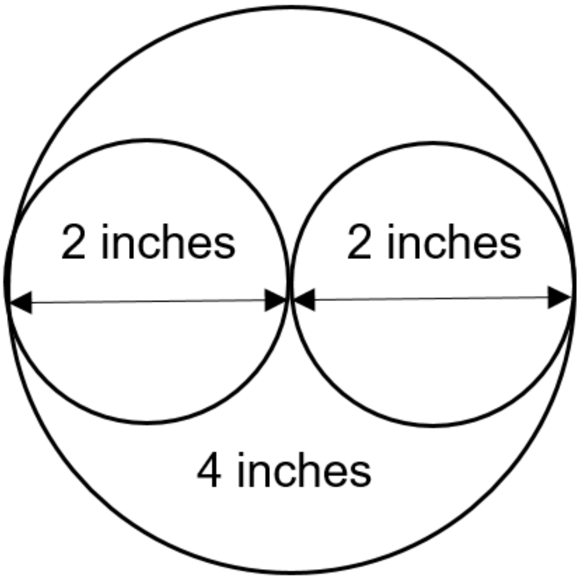
Stimuli used in Study 1 (con't)

How to Calculate the Area of a Circle Using the Diameter

The area of a circle is the amount of space the circle covers. The formula for calculating the area of a circle is A = πr^2, where pi (π) equals 3.14, and the radius (r) is half the diameter.

Once you have the diameter (d) of the circle, you can find the radius (r) by dividing the diameter by 2.

You are now ready to use the equation for area: $A=\pi r^2$



For example, a circle with a diameter of **2 inches** has a radius of **1 inch**. Its area is thus equal to **$3.14(1)^2$** or **3.14 sq inches.**

Similarly, a circle with a diameter of **4 inches** has a radius of **2 inches**. Its area is thus equal to **$3.14(2)^2$** or **12.56 sq inches**.

What is the area of a circle with a diameter of 6 inches?

- ◯ ≈ 20 sq inches
- ◯ ≈ 28 sq inches
- ◯ ≈ 38 sq inches

(debiasing manipulation – page 1)

You are right. The correct answer is **≈ 28 sq inches**

That is, a circle with a diameter of **6 inches** has a radius of **3 inches**. Its area is thus equal to **$3.14(3)^2$** or **28.27 sq inches.**

(debiasing manipulation – page 2)

Detailed results for Study 1

	8-inch (50 sq. inch)	10-inch (78 sq. inch)	12-inch (113 sq. inch)	14-inch (153 sq. inch)	16-inch (200 sq. inch)
Calorie amount (correct projection)	575.26	898.85	1294.34	1761.74	2301.05
Area	719.64	1031.03	1441.16	1899.83	2556.69
Side-length + debias	638.44	861.08	1121.48	1414.88	1805.55
Side-length	575.26	758.11	961.07	1186.40	1445.14

Stimuli used in Study 2

Below is a list of pizza sizes. Your task is to estimate the number of calories contained in one pizza for each of the sizes listed below.

For reference, a **McDonald's Big Mac contains 540 calories**.

Pizza sizes (diameter):

8 inches **10 inches** **12 inches** **14 inches** **16 inches**

Estimate the number of calories for each pizza size below (digits only):

8-inch

10-inch

12-inch

14-inch

16-inch

(side-length condition)

Below is a list of pizza sizes. Your task is to estimate the number of calories contained in one pizza for each of the sizes listed below.

For reference, a **McDonald's Big Mac contains 540 calories**.

Pizza sizes:

3 servings **4.5 servings** **6.5 servings** **9 servings** **12 servings**

Estimate the number of calories for each pizza size below (digits only):

3 servings

4.5 servings

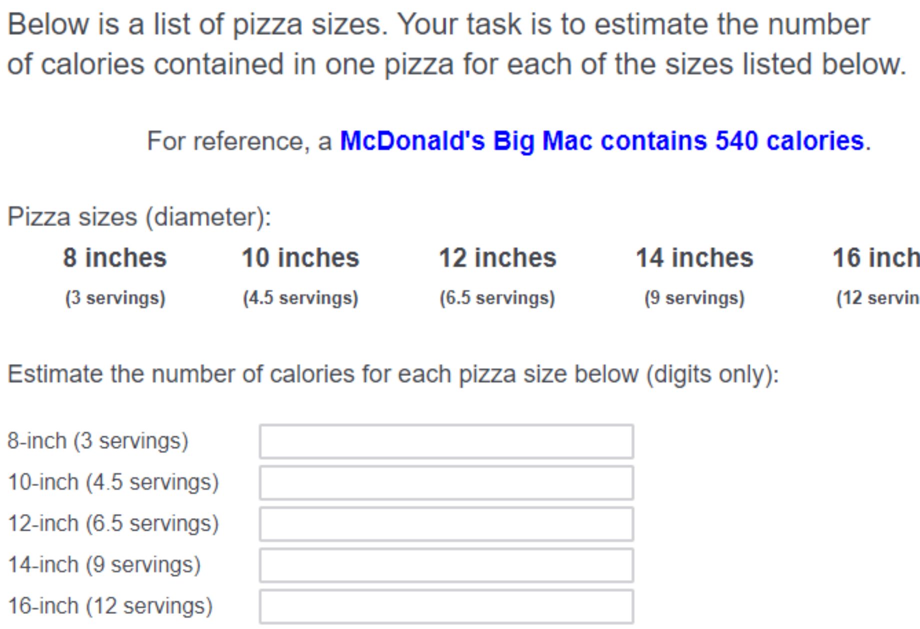
6.5 servings

9 servings

12 servings

(servings condition)

Stimuli used in Study 2 (Con't)



Below is a list of pizza sizes. Your task is to estimate the number of calories contained in one pizza for each of the sizes listed below.

For reference, a **McDonald's Big Mac contains 540 calories**.

Pizza sizes (diameter):

8 inches	10 inches	12 inches	14 inches	16 inches
(3 servings)	(4.5 servings)	(6.5 servings)	(9 servings)	(12 servings)

Estimate the number of calories for each pizza size below (digits only):

8-inch (3 servings)
10-inch (4.5 servings)
12-inch (6.5 servings)
14-inch (9 servings)
16-inch (12 servings)

(side-length + servings condition)

Detailed results for Study 2

	8-inch (3 servings)	10-inch (4.5 servings)	12-inch (6.5 servings)	14-inch (9 servings)	16-inch (12 servings)
Calorie amount (correct projection)	684.89	1070.14	1540.99	2097.46	2739.55
Side-length + servings	757.19	1042.35	1483.12	1962.75	2540.19
Servings	719.64	959.56	1363.84	1890.00	2579.83
Side-length	684.89	910.21	1150.08	1416.92	1751.72

Stimuli used in Study 3

Below is a list of **four** chocolate chip cookie assortment options. Your task is to estimate the number of calories contained in each of the options listed below.

- 1 cookie of 6 inches in diameter
- 3 cookies of 3 inches in diameter
- 4 cookies of 2 inches in diameter
- 12 cookies of 1 inch in diameter

For reference, a **McDonald's Big Mac contains 540 calories**.

---

1. If you ate the following assortment, how many calories would you have consumed? (digits only)

1 cookie of 6 inches in diameter

---

2. If you ate the following assortment, how many calories would you have consumed? (digits only)

3 cookies of 3 inches in diameter

---

3. If you ate the following assortment, how many calories would you have consumed? (digits only)

4 cookies of 2 inches in diameter

---

4. If you ate the following assortment, how many calories would you have consumed? (digits only)

12 cookies of 1 inch in diameter

Stimuli used in Study 4

Thank you!

As a token of gratitude for participating in this study, we would like to offer you the opportunity to leave with a chocolate chip cookies snack.

Two different sample options are available for you to choose:

-Two chocolate chips cookies of 2 inches in diameter from the Nabisco brand

or

-One chocolate chips cookie of 3 inches in diameter from the Ahoy brand.

Which one of these two snacks do you want to get?

Two 2-inch cookies ○ One 3-inch cookie ○

Stimuli used in Study 5

Birthday party:

Imagine that you are in charge of buying the cake for one of your coworker's birthday party at the office. At the last minute, you hear that **more** people than expected will show up. You can order either:

-One 12-inch cake (round)

-Two 8-inch cakes (round)

Which of these two options would you order?

I would order one 12-inch cake	I would order two 8-inch cakes
○	○

(Food quantity maximization goal and Round-shape condition)

Birthday party:

Imagine that you are in charge of buying the cake for one of your coworker's birthday party at the office. At the last minute, you hear that **fewer** people than expected will show up. You can order either:

-One 12-inch cake (square)

-Two 8-inch cakes (square)

Which of these two options would you order?

I would order one 12-inch cake	I would order two 8-inch cakes
○	○

(Food quantity minimization goal and Square-shape condition)

Note: See Online Appendix E for a detailed writeup of Study 5

This is the author's accepted manuscript without copyediting, formatting, or final corrections. It will be published in its final form in an upcoming issue of the Journal of the Association of Consumer Research, published by The University of Chicago Press on behalf of The Association for Consumer Research. Include the DOI when citing or quoting: https://doi.org/10.1086/720445 Copyright 2022 Association for Consumer Research.

ONLINE APPENDIX C

RECONCILIATION WITH KRIDER ET AL. (2001) STUDY

We designed this study to reconcile the apparent discrepancy between our results in Study 1 and the ones of Krider et al. (2001; pp. 417-420). Namely, Krider et al. did not find a difference in willingness to pay (i.e., reservation price) between side-length and surface area information describing sizes of round pizzas. They also did not find an effect of knowledge about surface area computation (p. 418).

However, our two designs differ in two ways: 1) Krider et al.'s size options were ordered to linearize the surface metric variation (i.e., 50 sq inches, 100 sq inches, 150 sq, inches; equivalent to 8 inches, 11.25-inches, and 13.75-inches, respectively), whereas our design linearizes the side-length metric variation (i.e., 8-inch, 10-inch, 12-inch, 14-inch, 16-inch)—as commonly found in restaurant menus. 2) Our dependent variable is calorie estimates, which linearly varies with food quantity, whereas Krider et al. used willingness to pay, which can be affected by quantity discount expectations. Therefore, we adopt a sizing array that linearizes surface area changes in this experiment, comparing those results with equivalent sizes described using side length. We also test the effect of the same debiasing manipulations as in Study 1 on those calorie estimates. Note that the 8-inch (50 sq inch equivalent) and 16-inch (200 sq. inch equivalent) sizes allow for a direct comparison with the results of Study 1.

Methods

Participants and Design. Five hundred and ninety-nine US participants recruited through Prolific took part in this experiment in exchange for money (54% female, M_{Age} = 33.8). This study uses a 3 (information type: side-length vs. side-length + debiasing intervention vs. area) × 4 (food quantity) mixed-factorial design, with the first factor manipulated between participants and repeated measures for the second factor.

Procedure. Similar to Study 1, we asked participants to estimate the number of calories contained in each of four pizza sizes, this time with the size options ordered to linearize the changes in the surface area metric. In the side-length condition, we described sizes using each option's diameter (8-inch, 11.25-inch, 13.75-inch, 16-inch). We described the same five sizes using their equivalent surface area in the area condition (50 sq. inches, 100 sq. inches, 150 sq. inches, 200 sq. inches). In the side-length + debiasing condition, we first exposed participants to the same arithmetic demonstration of the effect of a circle's diameter on its area as in Study 1 before they evaluated the options described using their diameter.

Results

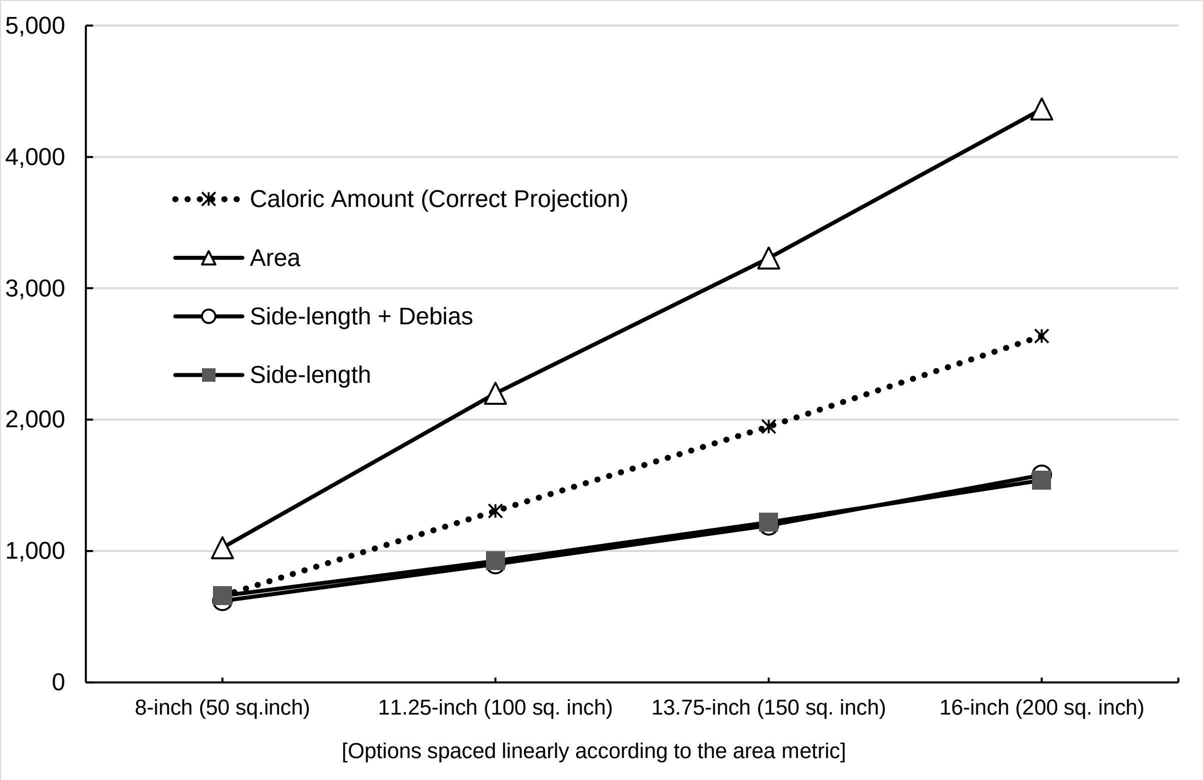
A repeated-measures ANOVA revealed a main effect of the item size on calorie estimates ($F(3, 1788) = 81.98$, $p < .001$, $\eta_p^2 = .12$), consistent with larger calorie estimates for larger pizza sizes. Importantly, we also observed an interaction between the metric condition and the item size ($F(6, 1788) = 18.06$, $p < .001$, $\eta_p^2 = .06$) suggesting that the rate at which the calorie estimates increased with size varied between the conditions (see Figure below). Pairwise comparisons suggested that the area condition lead to larger estimates compared to both the side-length debias ($F(3, 1239) = 20.31$, $p < .001$, $\eta_p^2 = .05$) and side-length + debias ($F(3, 1152) = 16.49$, $p < .001$, $\eta_p^2 = .04$) conditions. In turn, the side-length + debias was not different from the side-length condition ($F(3, 1185) = .54$, $p = .65$, $\eta_p^2 = .00$).

Discussion

This study reconciles our findings with Krider et al.'s. First, it appears that knowledge about surface area computation did not have an effect in Krider et al. because their size options were ordered to linearize the surface metric variation (area: 50 sq. inches, 100 sq. inches, 150 sq. inches; diameter: 8-inch, 11.25-inch, 13.75-inch), which we replicate in this study. It appears that because their size options described using side-length were not organized linearly, participants failed to recognize this metric's relationship to the surface area. Second, our results showed differences in estimates between the sizes described using side-length and surface areas, consistent with Study 1. We contend that this discrepancy with the results observed in Krider et al. (2001) could be attributed to 1) their use of willingness to pay as a proxy for quantity estimate, a variable that can be affected by quantity discount expectations—unlike calorie estimate. 2). This design also used an additional size (16-inch / 200 sq. inches) which could have also prompted higher estimates due to, for instance, a numerosity effect. This finding remains to be tested.

Overall, and consistent with our linearization theorizing, this supplemental study suggests that training interventions aimed at reducing side-length linearization biases in food quantity are less effective when the size options' order is already adjusted to reflect the exponential change in quantity (e.g., 8-inch vs. 11.25-inch vs. 13.75-inch). These results also suggest that choice-architecture interventions using metrics that vary linearly with features people are trying to optimize should instead be adopted. We also replicated our observed difference between side-length and surface area information when using calorie estimates instead of willingness to pay.

Calorie Estimates As A Function Of Size and Information Type



Note: The dashed line represents a correct projection based on the 8-inch pizza calorie estimate in the side-length condition.

	8-inch (50 sq. inch)	11.25-inch (100 sq. inch)	13.75-inch (150 sq. inch)	16-inch (200 sq. inch)
Calorie Amount (Correct Projection)	659.12	1303.43	1947.11	2636.48
Area	1025.20	2201.15	3229.52	4363.67
Side-length + Debias	620.39	901.46	1193.63	1578.73
Side-length	659.12	923.87	1218.84	1538.85

Future research should further test whether differences between our results and those found in other work could depend on the fluency of different metrics and numbers (e.g., the numbers used in Krider et al., 2001 seem less fluent and may indicate other considerations than calorie estimates).

Stimuli used in this study

Below is a list of pizza sizes. Your task is to estimate the number of calories contained in one pizza for each of the sizes listed below.

For reference, a **McDonald's Big Mac contains 540 calories**.

Pizza sizes (diameter):

8 inches **11.25 inches** **13.75 inches** **16 inches**

Estimate the number of calories for each pizza size below (digits only):

8 inches

11.25 inches

13.75 inches

16 inches

(side-length condition)

Below is a list of pizza sizes. Your task is to estimate the number of calories contained in one pizza for each of the sizes listed below.

For reference, a **McDonald's Big Mac contains 540 calories**.

Pizza sizes (area):

50 sq inches **100 sq inches** **150 sq inches** **200 sq inches**

Estimate the number of calories for each pizza size below (digits only):

50 sq inches

100 sq inches

150 sq inches

200 sq inches

(area condition)

ONLINE APPENDIX D

EFFECT OF SURFACE AREA KNOWLEDGE STUDY

This study investigates whether the linearization bias associated with using side length to convey the size of food items is affected by knowledge about surface area computation when people are not explicitly trained before making their choice (unlike in Study 1). Therefore, we measure the effect of knowledge about surface computation using two approaches. First, we manipulate the shape of the target, comparing the extent of the bias for square-shaped items, a shape for which the surface area is more straightforward to compute (i.e., side-length^2) than for round-shaped items (i.e., π*(side-length/2)^2). Second, we measure *ex-post* participants' knowledge by measuring their success in solving a simple surface area computation task. This study also measures whether this bias occurs across the range of people's involvement with the food quantity decision by measuring familiarity with ordering this type of food. Specifically, we anticipate those more familiar with the stimulus, measured as ordering frequency, to have more ease in evaluating the size differences (Hsee and Zhang, 2010; Morewedge et al., 2009).

Methods

Participants and Design. Two hundred and seven US participants recruited through MTurk took part in this experiment in exchange for money (44% female, M_{Age} = 35.2). The study used a 2 within (size options: 1×12 inches vs. 2×8 inches) × 2 between (shape: round vs. square) × 2 between (surface area knowledge: yes vs. no) mixed-factorial design.

Procedure. First, we asked participants to "Imagine that you are sitting at a restaurant, about to order some pizza for your next meal. The ongoing promotion applies to either: One 12" round (square) pizza or Two 8" round (square) pizzas." We asked them to provide a calorie estimate of each option using sliders, while aiming to reduce response variance by introducing a reference point (i.e., the number of calories in a Big Mac; see Study 1-3). Note that the total pizza quantity is consistently 12.5% larger for the single 12-inch option (113.1 inches^2 vs. 2×50.3 inches^2 for round shapes; 144 inches^2 vs. 2×64 inches^2 for square shapes).

On the next page, participants answered a question aimed at measuring their knowledge about surface area computation. We asked them to estimate a shape's surface, providing them with a diagram that indicated the target side length. Depending on the shape condition, participants estimated the surface of a 4-inch square shape using square inches or a 4-inch round shape using pi square inches (to simplify calculation)[1]. Overall, a total of 32% of the participants failed the surface computation task in the square shape condition, and 59% of the participants failed that task in the round shape condition, supporting the assertion that surface computation is harder for circles than for squares ($\chi^2(1) = 15.48$, $p < .001$, $\Phi = .27$). Finally, we measured their familiarity with ordering this type of food on two items: "How often do you consume pizza?," "How often do you order pizza (on the phone, online, in store, etc.)? (1 = Never; 7 = Daily; *M* = 3.52, SD = 1.06, r = .76).

Results

We first ran a repeated-measures GLM analysis to test the effect of the product shape and surface area knowledge on the two size options calorie estimates. Results revealed an highly significant effect of size option ($F(1, 203) = 99.27$, $p < .001$, $\eta_p^2 = .33$) in the *opposite* direction than the actual difference in food quantity, such than participants estimated the 1×12-inch pizza option to contain fewer calories (*M* = 1489.45, SD = 584.30) than the 2×8-inch pizza option (*M* = 1781.12, SD = 661.28). Importantly, there was otherwise no effect of the item shape ($F < 1$) or the results of the surface area computation knowledge task ($F < 1$), nor was there an interaction effect between these two factors ($F < 1$), see Table below for details.

Calorie Estimates As A Function Of Shape And Surface Area Knowledge

Shape	Round		Square	
Surface area knowledge task	Succeeded n = 41	Failed n = 59	Succeeded n = 73	Failed n = 34
1×12-inch (larger option)	1466.02 (560.36)	1418.03 (614.38)	1518.18 (618.33)	1579.97 (482.61)
2×8-inch (smaller option)	1807.78 (572.77)	1705.27 (674.23)	1797.07 (692.20)	1846.32 (686.74)

Note: Mean (St. Dev)

[1] To account for the harder-to-process pi component in the round shape condition, we categorized participants' responses as successful when they answered either 4 (for 4 pi square inches) or responses between 12 and 13 (for 12.56 square inches, assuming participants estimated the pi value as close 3).

Next, we tested the effect of ordering familiarity on this pattern of results. We used the calorie estimates of each option to create a difference score ($M_{1\times12\text{-ich}} - M_{2\times8\text{-inch}}$) and regressed the effect of the item shape (coded: -1 = round, +1 = square), surface area computation knowledge task results (coded: -1 = succeeded, +1 = failed), and ordering familiarity (mean-centered) on that score. Results revealed only a significant two-way interaction between the shape of the options and ordering familiarity (β = .16, b = 60.65, SE = 27.06, $t(199) = 2.24$, $p = .03$). We explored these results using the Johnson-Neyman technique. Only for those ranked in the top 10^{th} percentile (*M* = 4.57) or above in familiarity with ordering there was a reduction in the calorie estimation bias between the circle (*M* = -337.36) and the square-shaped (*M* = -261.14) options—consistent again with the surface area for squares being easier to compute than for circles. Importantly, the signs of these difference score estimates remained negative, whereas they should have been positive.

Discussion

This study tested the robustness of our food quantity underestimation bias without a training intervention across food shapes and in light of consumer knowledge about surface area computation. We again find strong support for a linearization effect, the notion that participants fail to integrate the exponential component implied in food size information using side length. We still find a strong food quantity underestimation bias even when considering surface area computation knowledge implicitly (i.e., the area of a square is more straightforward to evaluate than the one of a circle) and explicitly (i.e., the results of a circle a surface area computation task). Consistent with prior literature on financial education, showing the importance of "just-in-time" training (Fernandes et al., 2014), these results suggest that unaided surface-area knowledge (i.e., without salient intervention to remind people) offers limited debiasing benefits.

Stimuli used in this study:

(Round condition)

Ordering at a restaurant:

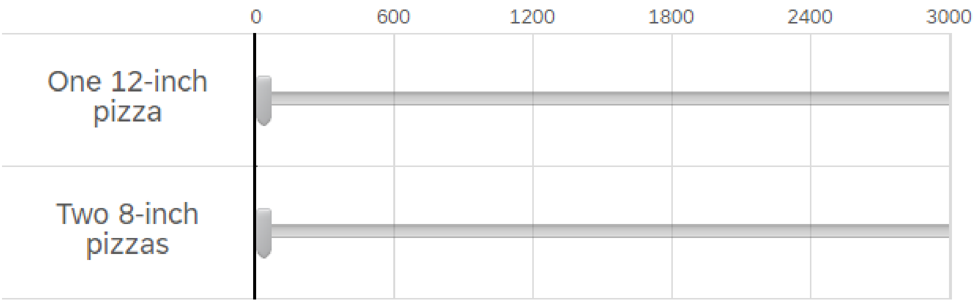
Imagine that you are sitting at a restaurant, about to order some pizza for your next meal. The ongoing promotion applies to either:

-One 12" round pizza

-Two 8" round pizzas

What is the total amount of calories in each of these options? (scale from 0 to 3,000 cal)

For reference, a **McDonald's Big Mac contains 540 calories**.



(Square condition)

Ordering at a restaurant:

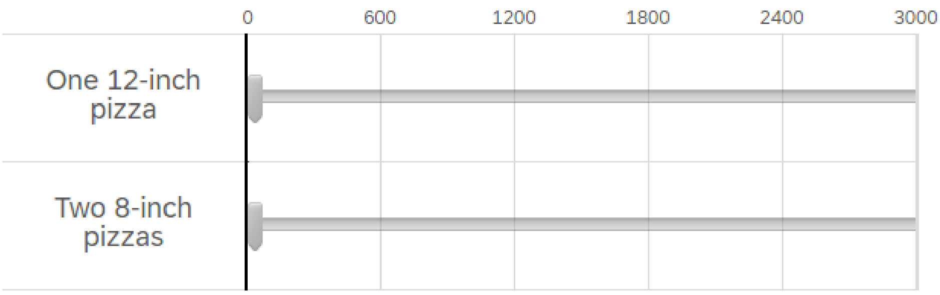
Imagine that you are sitting at a restaurant, about to order some pizza for your next meal. The ongoing promotion applies to either:

-One 12" square pizza

-Two 8" square pizzas

What is the total amount of calories in each of these options? (scale from 0 to 3,000 cal)

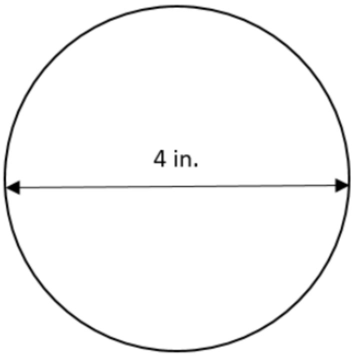
For reference, a **McDonald's Big Mac contains 540 calories**.



Computation task used in this study:

Computation task

The circle below has a diameter of 4 inches.

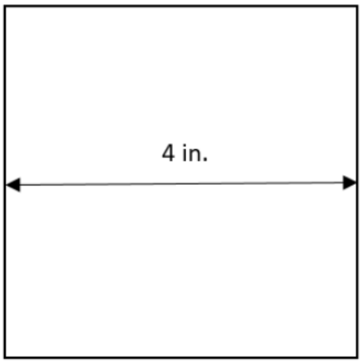


Please estimate the surface area of the circle above [use numbers only; in pi square inches (i.e., π $inch^2$)]

(Round condition)*

Computation task

The square below has a side length of 4 inches.



Please estimate the surface area of the square above [use numbers only; in square inches (i.e., $inch^2$)]

(Square condition)

*We used the π $inch^2$ units to simplify the calculation for participants in the round condition.

Note: To account for the harder-to-process pi component in the round shape condition, we categorized participants' responses as successful when they answered either 4 (for 4 π $inch^2$) or responses between 12 and 13 (for 12.56 square inches, assuming participants estimated the pi value as close 3).

ONLINE APPENDIX E

STUDY 5 DETAILED WRITEUP

Study 5 further tests the generalizability of our size-to-quantity underestimation bias on participants' food choices. To this aim, this study manipulates food quantity goals and measures the extent to which our size-to-quantity underestimation bias impacts food choices. As suggested by the correlational findings of Study 4, we expect participants with a salient goal to select smaller versus larger food quantities will select options inconsistent with their goal. This study also uses shape replicates to test the robustness of the linearization bias across round- and square-shaped items. It also extends our finding to cake choices, another everyday food category often sold by side length.

Methods

Participants and Design. US MTurk participants took part in this experiment (n = 428, 43% female, M_{Age} = 36.9). The study used a 2 (shape: square vs. round) × 2 (food quantity goal: minimization vs. maximization) between-participants design.

Procedure. We asked participants to imagine that they were in charge of buying the cake for a coworker's birthday party at the office. We manipulated the food-quantity maximization (minimization) goal by mentioning that "at the last minute, you hear that more (fewer) people than expected would be present." We then asked them to choose between "One 12-inch cake" and "Two 8-inch cakes." The cakes were described as either square cakes or round cakes, depending on the experimental condition. Note that the total cake quantity is consistently 12.5% larger for the single 12-inch option (113.1 inches^2 vs. 2×50.3 inches^2 for round shapes; 144 inches^2 vs. 2×64 inches^2 for square shapes).

Results

We estimated a logistic regression of cake choice (coded: 0 = 1×12 inches, 1 = 2×8 inches) using item shape (coded: 0 = round, 1 = square), food quantity goal (coded: 0 = minimization, 1 = maximization), and their interaction as predictors. The results show the expected main effect of the food quantity goal (b = 1.59, SE = .30, $Z = 5.25$, $p < .001$, CI_{95} [1.00; 2.18]; OR = 4.90; see Table 2). For those aiming to select the smaller option (i.e., fewer people than expected would join the party), 71% (157/222) chose the larger option (i.e., 1×12-inch; significantly different from a 50% chance; $Z = 6.17$, $p < .001$). In contrast, for those aiming to select the larger option (i.e., more people than expected would join the party), 63% (130/206) chose the smaller option (i.e., 2×8-inch; significantly different from a 50% chance; $Z = 3.76$, $p < .001$). The main effect of item shape and its interaction with the food quantity goal were non-significant (*ps* > .40), indicating that the linearization bias did not vary by food shape.

Study 5 manipulated participants' food quantity goals to show that people make suboptimal food choices when relying on side-length information. Most participants selected the largest option available when aiming to select the smallest, and vice versa when aiming to select the largest. This study also increases our findings' generalizability by showing they are robust to different food categories (i.e., cakes) and for round and square-shaped items (see also Online Appendix D).

Study 5: Food Choice Counts As A Function Of Shape And Food Quantity Goal

Food quantity goal	Item shape	Chose 1×12-inch (*larger option*)	Chose 2×8-inch (*smaller option*)
Minimization goal	Round	79	29
(*Fewer people would be present*)	Square	78	36
Maximization goal	Round	35	63
(*More people would be present*)	Square	41	67