Visual illusions and plate design: The effects of plate rim widths and rim coloring on perceived food portion size

Arianna McClain, PhD MPH,
Solutions Science Lab, Division of General Pediatrics, Department of Pediatrics and Stanford Prevention Research Center, Department of Medicine, Stanford University School of Medicine

Wouter van den Bos, PhD,
Department of Psychology, Stanford University

Donna Matheson, PhD,
Solutions Science Lab, Division of General Pediatrics, Department of Pediatrics and Stanford Prevention Research Center, Department of Medicine, Stanford University School of Medicine

Manisha Desai, PhD,
Quantitative Science Unit, Department of Medicine, Stanford University School of Medicine

Samuel M. McClure, PhD, and
Department of Psychology, Stanford University

Thomas N. Robinson, MD MPH
Solutions Science Lab, Division of General Pediatrics, Department of Pediatrics and Stanford Prevention Research Center, Department of Medicine, Stanford University School of Medicine; Center for Healthy Weight, Stanford University and Lucile Packard Children's Hospital at Stanford

Abstract

OBJECTIVE—The Delboeuf Illusion affects perceptions of the relative sizes of concentric shapes. This study was designed to extend research on the application of the Delboeuf illusion to food on a plate by testing whether a plate's rim width and coloring influence perceptual bias to affect perceived food portion size.

DESIGN AND METHODS—Within-subjects experimental design. Experiment 1 tested the effect of rim width on perceived food portion size. Experiment 2 tested the effect of rim coloring on perceived food portion size. In both experiments, participants observed a series of photographic images of paired, side-by-side plates varying in designs and amounts of food. From each pair,

CORRESPOND: Arianna D. McClain, PhD MPH Stanford Prevention Research Center Stanford University School of Medicine 1070 Arastradero Road, Suite 300 Palo Alto, California 94304 Phone: 650.723.3573 Fax: 650.723.6450 mcclaina@stanford.edu.

participants were asked to select the plate that contained more food. Multi-level logistic regression examined the effects of rim width and coloring on perceived food portion size.

RESULTS—Experiment 1: Participants overestimated the diameter of food portions by 5% and the visual area of food portions by 10% on plates with wider rims compared to plates with very thin rims ($P<0.0001$). The effect of rim width was greater with larger food portion sizes. Experiment 2: Participants overestimated the diameter of food portions by 1.5% and the visual area of food portions by 3% on plates with rim coloring compared to plates with no coloring ($P=0.01$). The effect of rim coloring was greater with smaller food portion sizes.

CONCLUSION—The Delboeuf illusion applies to food on a plate. Participants overestimated food portion size on plates with wider and colored rims. These findings may help design plates to influence perceptions of food portion sizes.

Keywords

portion size; visual illusions; mindless eating; perceptual bias; dishware; plate

INTRODUCTION

Small changes in the food environment can alter perceptions of food size, influence food choices, and reduce how much food people serve themselves and consume (1). These environmental changes include, but are not limited to alterations in portion size (2-6), container size (7-11), food variety (12, 13), and visual cues about the amount consumed (8). As a result, it may be possible to develop environmental interventions that bypass conscious, cognitive self-control and, instead, "passively" or "mindlessly" produce consistent reductions in energy intake and weight loss over time.

Plate size is one environmental factor that researchers have focused on because it may be an easy factor to manipulate. In the last three decades, the size of the average dinner plate increased more than a third (36%) (14). Observational data suggest that the increase in the average size of plates used at meals is concurrent with the rise in obesity rates in the United States (15). Research using mathematical modeling indicates that a small increase in dishware size can lead to a substantial increase in energy intake, particularly if food is energy dense (16). Experimental studies show that larger plates make a given portion size look smaller (17). However, smaller plates did not reduce food intake at meals in laboratory studies (18). It is possible that reducing total plate size may be insufficient to reduce intake because substantially smaller plates may make people more aware of smaller portion sizes, which might subsequently result in caloric compensation. However, not all same-sized plates are equal. It may be necessary to pay more attention to plate design characteristics, such as plate color and rim design.

Plate designs that make use of visual illusions, such as the Delboeuf illusion, may independently affect perceived portion size and subsequent food intake. The Delboeuf illusion demonstrates that a circle appears larger when surrounded by a slightly larger circle, but smaller when surrounded by a much larger circle (19) (Figure 1). The proximity and the color contrast of the concentric circles affect the illusion (20-23). Research suggests that

when the space between concentric circles is small (right image of Figure 1), the circles appear to be one whole object (24). Therefore, people are more likely to emphasize the similarities between the two circles and perceive the inner circle as looking larger than it actually is (25). Conversely, when the space between concentric circles is large (left image of Figure 1), the circles are perceived as two different objects. Therefore, people will emphasize the differences between the two circles (23), leading the inner circle to be perceived as smaller than it actually is (26). In the case of food on a plate, a portion of food may be perceived as larger on a small plate, but smaller on a large plate due to the space between the food and the edge of the plate. Increasing color contrast between the circles has also been shown to enhance the differences between concentric circles (22). Manipulating rim coloring may highlight the edge of the outer circle and color contrast leads people to perceive the size of the inner circle as larger than it actually is (22, 27, 28) and perceive a larger food portion size when the color of the plate is different from the color of the food.

Recent research by Van Ittersum and Wansink illustrates that the Delboeuf illusion influences serving behavior as the diameter of dishware increases and when there is a color contrast between food and dishware (17). Big bowls (larger diameter) lead people to serve more food and small bowls (smaller diameter) lead people to serve less food. People also serve themselves more food when food and plates had similar coloring (low-contrast). Conversely, people serve themselves less food when food and plates were different colors (high-contrast).

The current study extends previous research on how the Delboeuf illusion applies to food on a plate. Because the rim of a round plate can be conceptualized as an outer circle surrounding food, we hypothesized that the Delboeuf illusion would apply to plate rims surrounding food on a plate. We describe two experiments in which we manipulated images of plate rim designs and food portions on plates. Our goal was to determine the effect of rim width and color on the perception of portion size. To do this, we quantified perceived food portion size for each rim design used in the study. **Experiment 1** examines the effect of rim width on perceived food portion size. **Experiment 2** examines the effect of rim coloring on perceived food portion size. Prior work suggests that the Delboeuf illusion is strongest when the outer circle is only slightly larger and/or the color is more greatly contrasted with the inner circle (20-23). Therefore, in Experiment 1 we hypothesized wider rims (and thus the closer the inner edge of the rim surrounds the food) would cause food to appear larger on the same sized plate (Hypothesis 1). In Experiment 2 we hypothesized colored rims (highlighting the rim to create contrast) would cause food to appear larger than uncolored rims (Hypothesis 2). Results could help inform a superior plate design to influence perceived portion size.

METHODS AND PROCEDURES

Participants

We recruited adult participants (age 18 years or older) via Amazon's Mechanical Turk (AMT), an online labor market that allows researchers to run experiments in similar formats to computer simulations. AMT has proven to be a reliable tool to conduct behavioral experiments quickly, with valid data (29). Workers in AMT tend to be more representative

of the US population as a whole and exhibit behaviors and biases more similar than participants recruited from traditional university subject pools (30). On AMT, we posted a task that required participants to complete an experiment in exchange for $0.50. The task was only visible to participants who were in the United States and were considered to be good workers, defined as having greater than 95% of their past AMT surveys approved as acceptable for data-use by other surveyors.

Research Design

Both experiments used a within-subject experimental design. In each experiment, participants observed multiple side-by-side photographic images of two plates of identical size (total diameter 600 pixels). In both experiments we included test stimuli with seven food portion sizes (images were sized to 170, 175, 180, 185, 190, 195, 200 pixels in diameter) on plates with varying rim characteristics in a random order to quantify perceived food size for each rim design used in the study. Every rim characteristic and food size combination was then compared to a standard stimulus (i.e. a referent plate), defined as an image with a 185 pixel-food portion size on a plate and a rim width-to-plate radius ratio of 1/3 with no rim coloring (Figure 2). Varying food portion sizes in addition to plate design characteristics is instrumental to quantifying the effects of rim size and coloring on perceived portion using a psychophysical response curve (described below). The test stimuli showing varying food portion sizes and rim characteristics were presented randomly to the left or right of the standard stimulus and the trials were displayed in random order. From each pair, participants were asked to select the plate that contained more food. Food type (macaroni and cheese or fruit salad) was the same in both images within each trial but varied from trial-to-trial and subject-to-subject.

Experiment 1 consisted of 42 trials (7 depicted food portion sizes × 6 rim widths; no rim, and 1/8, 1/4, 1/3, 3/8, and 1/2 rim width-to-plate radius proportions). Rim widths were chosen by methodically increasing the rim width-to-plate radius proportion of a plate with no rim until the rim width-to-plate radius proportion was half the size of the plate, and no longer judged realistic in a real world setting.

Experiment 2 consisted of 28 trials (7 depicted food portion sizes × 4 rim colors; plain uncolored rim, solid blue colored rim, colored blue line marking the inner border of rim, and colored blue lines around inner and outer borders of rim). All plates (standard and test stimuli) had a standard rim of a 1/3 rim width-to-plate radius proportion. Because research shows that increasing color contrast between the circles enhances the differences between concentric circles (22), leading people to perceive the size of the inner circle as smaller than it actually is (22, 27, 28), we chose a dark rim color to create contrast against the white plate, highlighting the inner rim surrounding the food image. We also wanted the plate to look as realistic as possible and chose blue because it is one of the most popular plate colors in dishware catalogues. Rim coloring designs (highlighting the rim width as single line on the inner border; highlighting the rim around the inner and outer border of the rim; and coloring the entire rim) were chosen to provide visual cues and highlight the multiple concentric circles on a plate with a rim (Refer to images of plates in Figure 3).

Psychophysical Model of Food Portion Size

To examine how adults estimate food portion size based on plate rim design, we used a psychophysical research approach (31) that is frequently used to describe the relationship between subjective perceptions of objective differences. We created psychophysical response curves based on a participant's ability to correctly identify a larger food portion size when comparing images of plates with different food portion sizes and/or rim characteristics with a standard food portion size and design. Each point on the curve represents the probability of choosing a depicted food size compared to the standard stimulus for each rim design. The point of equivalence, or where each curve crosses 50% probability, marks the point where participants cannot distinguish the difference in food portion size between the test and standard stimulus, even when they truly exist; where there is an equal 50% chance that participants pick the standard stimulus versus the test stimulus. Comparing points of equivalence allows one to estimate the magnitudes of over- or under-estimating in perceived food portion sizes across the different rim characteristics by examining the horizontal shift of the response curve.

Statistical Analysis

Multi-level logistic regression examined the main effect of rim characteristic on the probability of choosing a depicted food size compared to the standard stimulus across rim characteristics, adjusting for the fixed effects of depicted test stimulus food size, food type, the rim characteristics by food size interaction, and a random effect for within person variation. We include the rim characteristics × food size interaction term in the primary analysis model, to obtain an unbiased estimate of the main effect of rim characteristics, as recommended in the statistical literature (32-35). The interaction between rim characteristic and depicted food portion size tested whether the probability of picking the test stimulus (i.e. rim characteristic) differed by the depicted food size. When interaction terms were significant, post-hoc analyses explored how food size differed by plate design. In all the analysis models, food portion sizes and rim characteristics were centered on their standard stimulus values (36). Descriptive statistics were used to calculate the magnitude of the relative difference in choosing the test stimulus using odds ratios with 95% confidence intervals, and the points of equivalence for each rim characteristic across food sizes, with the reference point being the standard stimulus. The Wald χ^2 test statistic tested the null hypothesis that there is no significant difference between rim characteristics. All tests were two-sided and conducted at the 0.05 level of significance. Data were analyzed with version 9.2 of the SAS statistical software package (SAS, Cary, NC).

Experiment 1: The Effect of Rim Width on Perceived Food Portion Size—338 participants (55% male; 74% Caucasian, 10% Asian, 6% Latino, 2% Black, 8% Other; Mean ± SD Age 29.8 ± 11.0 years) completed 42 trials each.

Results: Figure 3 illustrates the probability of choosing a depicted food size compared to the standard stimulus for each rim width-to-plate radius proportion. Table 1 presents a summary of the multi-level logistic model examining the effect of rim width on perceived food portion size. Depicted food portion size was significant in the model (*P*<0.0001), confirming that participants are able to discern larger food sizes as larger. Rim width (*P*<0.0001) was

also significant in the model, with participants overestimating food portion sizes on plates with greater rim width-to-plate radius proportions (i.e., wider rims) confirming Hypothesis 1. There was a significant rim width by depicted food portion size interaction ($P<0.0001$), indicating that the effect of rim width on perceived portion size is significantly greater with larger food portion sizes. Food type was not significant in the model ($P = 0.70$).

The odds ratios indicate that when comparing the same food size, people were 1.5 times as likely to pick the widest rim plate as having more food compared to the standard plate. Conversely, people were 0.6 times as likely to pick the plate with no rim as having more food. The point of equivalence values estimate the differences in perceived food portion sizes between plates with different rim widths and indicated that there is a 5.2% difference in perceived diameter of the food image when food is viewed on a plate with a very wide rim (1/2 rim width-to-plate radius proportion) compared to a plate with a very narrow rim (1/8 rim width-to-plate radius proportion).

Experiment 2: The Effect of Rim Coloring on Perceived Food Portion Size—
251 participants (51% female; 75% Caucasian% Caucasian, 8% Asian, 6% Latino, 6% Black, 5% Other; Mean ± SD Age 30.0 ± 10.3 years) completed 28 trials each.

Results: Figure 4 illustrates the probability of choosing a depicted food size compared to the standard stimulus for each rim coloring. Table 2 presents a summary of the multi-level logistic model examining the effect of rim coloring on perceived food portion size. Depicted food portion size was significant in the model ($P<0.0001$), again confirming that participants are able to discern larger food sizes as larger. Rim coloring ($P=0.01$) was also significant in the model with participants overestimating food portion sizes on plates with any type of rim coloring, confirming Hypothesis 2. There was a significant rim coloring by depicted food portion size interaction ($P=0.0003$), indicating that the effect of rim coloring on perceived portion size is greater with smaller food portion sizes. Food type was not significant in the model ($P = 0.47$).

The odds ratios indicate that with small food sizes, people were 2.3 times as likely to pick the rims with solid blue coloring as having more food compared to a plate with no rim coloring. However, with larger food sizes, people were only 0.6 times as likely to pick rims with solid blue coloring as having more food compared to a plate with no rim coloring. The point of equivalence indicated there is a 1.5-1.6% overestimation in diameter of food portion size when food is viewed on a plate with rim coloring compared to a plate without rim coloring.

DISCUSSION

We examined whether a plate's rim design, namely rim width and rim coloring affect perceived food portion size. Confirming that the Delboeuf illusion applies to plate rims surrounding food on a plate, these experiments found that wider and colored rims each exaggerate perceptions of the amount of food on a plate, making images of food look larger. Food type had no effect on the illusion, suggesting that the illusion persists regardless of the type of food depicted on the plate. The effect of rim width is greater with larger food portion

sizes consistent with our expectations from the Delboeuf illusion. However, the effect of rim coloring is greater with smaller food portion sizes. The color contrast illusion was inverted when food sizes were larger, resulting in rim coloring making food appear smaller on a plate.

The psychophysical response curve illustrated not only that wider rims and rim coloring exaggerate perceived food portion size, but illustrate how much more food is perceived on the plate. In Experiment 1, the point of equivalence illustrated that food on plates with wider rims looks approximately 5% larger in diameter than food on plates with a very thin rim. This difference in diameter is equivalent to a two dimensional area of 10% which would represent an even greater exaggeration in terms of three-dimensional food volume. In Experiment 2, food on plates with colored rims looks approximately 1.1% larger in diameter, equivalent to an exaggeration of 3% larger in area compared to food on plates with no rim coloring. Putting this into context, if these differences in visual perception translate into adults serving themselves less and eating less, because they perceive more food on plates due to rim design, the differences between eating off a wider rim versus a smaller rim plate could result in clinically-important reductions in energy intake (37, 38).

Besides the Van Ittersum study that tested the Delboeuf illusion with respect to plate size and plate coloring and serving behavior (17), and a study that tested the illusion on irregular objects (20), almost all past research on the Delboeuf illusion has been applied to circles and squares. This study extends this prior research on plate size by testing the application of the Delboeuf illusion to images of food and plate design characteristics. Jaeger et al had participants judge the size of a letter, either an "A" or an "S", which was surrounded by a circle. Similar to our experiments, Jaeger found that an outer circle resulted in people perceiving the letter size as larger. Larger surrounding circles (more space between letter and outer circle, similar to having no rims) diminished the illusion, making the letters look smaller. This study also found that decreasing the lightness contrast (similar to having no rim coloring) of the surrounding circle relative to the central letter diminished the illusion.

Our experiments examined the Delboeuf illusion using two-dimensional images of food and plates, rather than with real food and plates. The use of computers to present visual images of food limits the direct translation of our results to a real world setting. However, the effect of the Delboeuf illusion from a plate's rim width and coloring may be even greater when taking into account volume. The systematic methods of measuring food portion size and rim widths via visual images on a computer screen also provide a precise demonstration of the illusion in a way that reduces measurement errors. Because pictures were shrunk or enlarged to change the size of the food portion, it is possible that participants noticed the subtle differences in the size of the macaroni or fruit, potentially introducing a product-confound. However, we think this is unlikely because we purposely picked amorphous food images where small changes in the size of components of the images would be difficult to detect. No participants brought up these visual differences during extensive formative and pilot testing. Nevertheless, future studies are needed with real plates and food to validate these findings, to examine the effect of plate design on perceived food amounts and actual energy intake (18).

Previous research demonstrates that visual cues of portion size affect serving behavior and food intake. Wansink et al found that people eat more from self-refilling bowls than normal soup bowls (8). Adults also serve and eat more when given larger bowls and larger serving spoons (39). Research suggests that people cannot overcome these biases through awareness, knowledge or education (7). This suggests that even when people know about the bias created by packaging and portion sizes, it does not protect one from its effect. Therefore, if the findings from our experiment translate to real food on real plates, then plate design may represent a promising weight control strategy.

A strength of these experiments is the large sample size in each experiment, which enhances the generalizability of these findings. Because visual perception and perceptual bias are considered relatively hardwired and non-conscious (9), past studies that investigated the Delboeuf Illusion were conducted in smaller samples. The present findings also serve as an important first step to conduct this experiment in a real world setting, letting us define important parameters to inform the optimal plate design to influence perceived food portion size and, possibly, subsequent intake.

In conclusion, these experiments tested the Delboeuf illusion with food on plates with different rim characteristics. The results demonstrate that wider and colored plate rims exaggerate the perceived amount of food on a plate, making food look larger, compared to smaller rims, no rims or uncolored rims. The results of these experiments suggest that small changes in plate design have the potential to produce relatively larger effects on perceived food amounts and thus intake. If demonstrated to produce similar effects on actual food portion estimation and intake, plate design utilizing the Delboeuf illusion has the potential to be a simple and important weight loss and maintenance strategy.

ACKNOWLEDGEMENTS

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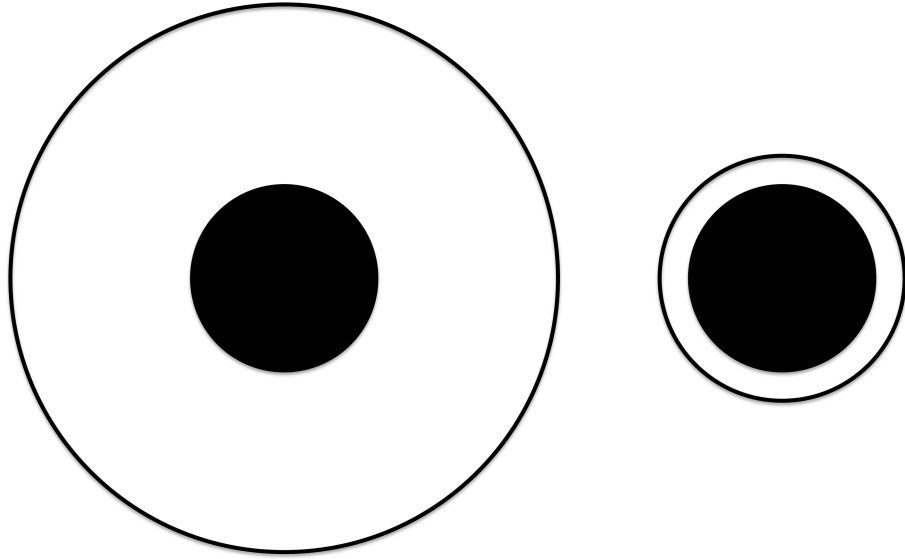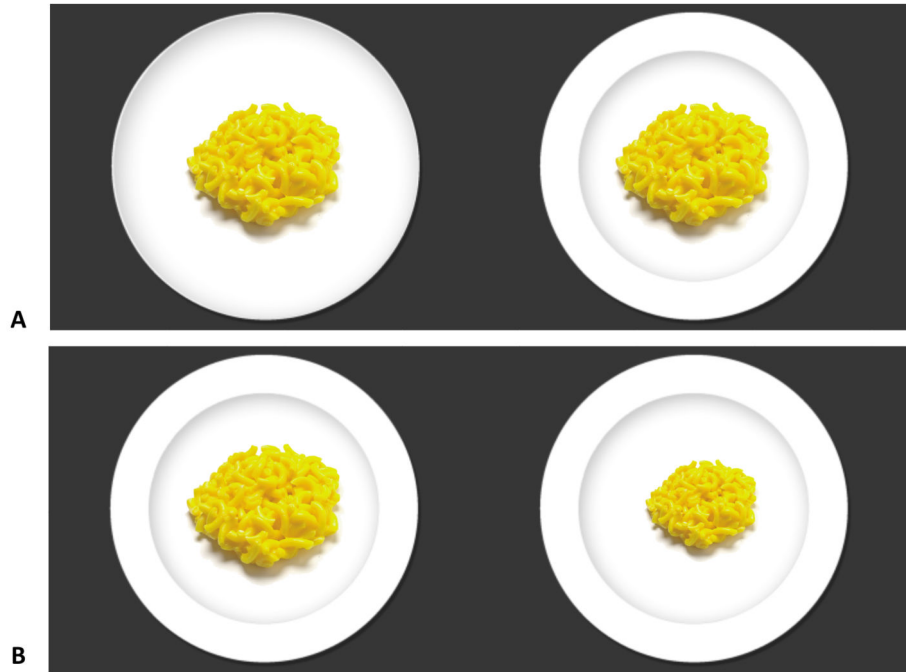
Figure 1.
The Delboeuf Illusion

Figure 2. Examples of pictures used as stimuli
A) Standard stimulus (i.e. food size of 185 pixels on a plate with a 1/3 rim width-to-plate radius proportion) is on right; Rimless plate with same food size is on left and B) Standard stimulus is on left; same rim size with smaller food size is on right
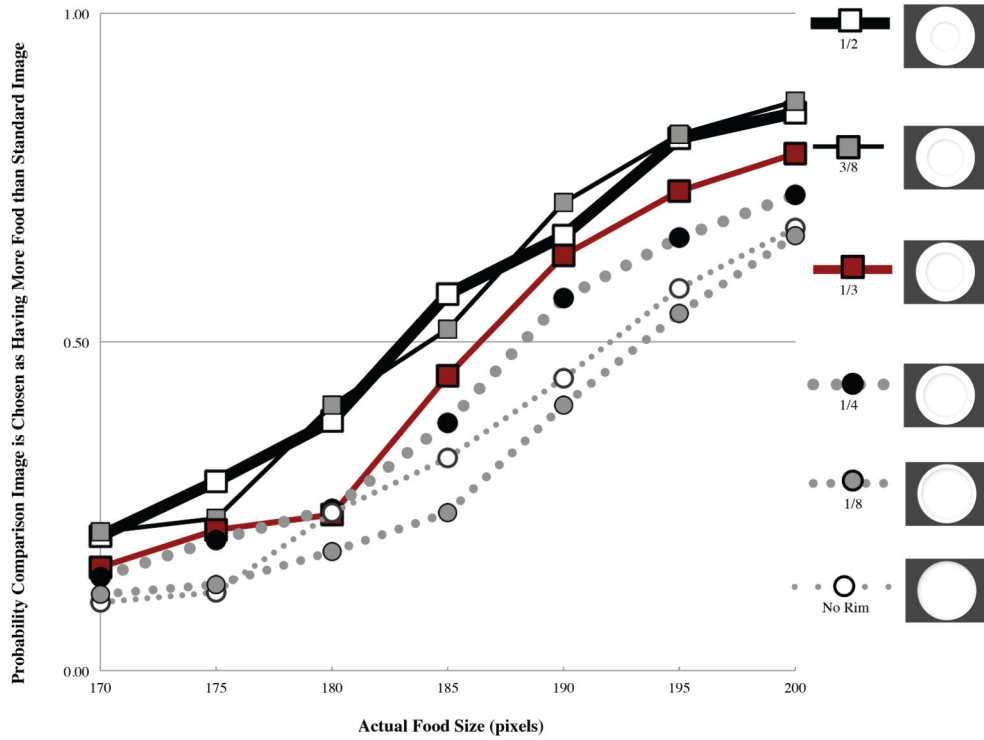
Figure 3. Psychophysical Response Curve, The Effect of Rim Width on Perceived Food Portion Size (Experiment 1)

Note: Every point on the graph is being compared to the standard stimulus: food size of 185 pixels on a plate with a 1/3 rim width-to-plate radius proportion
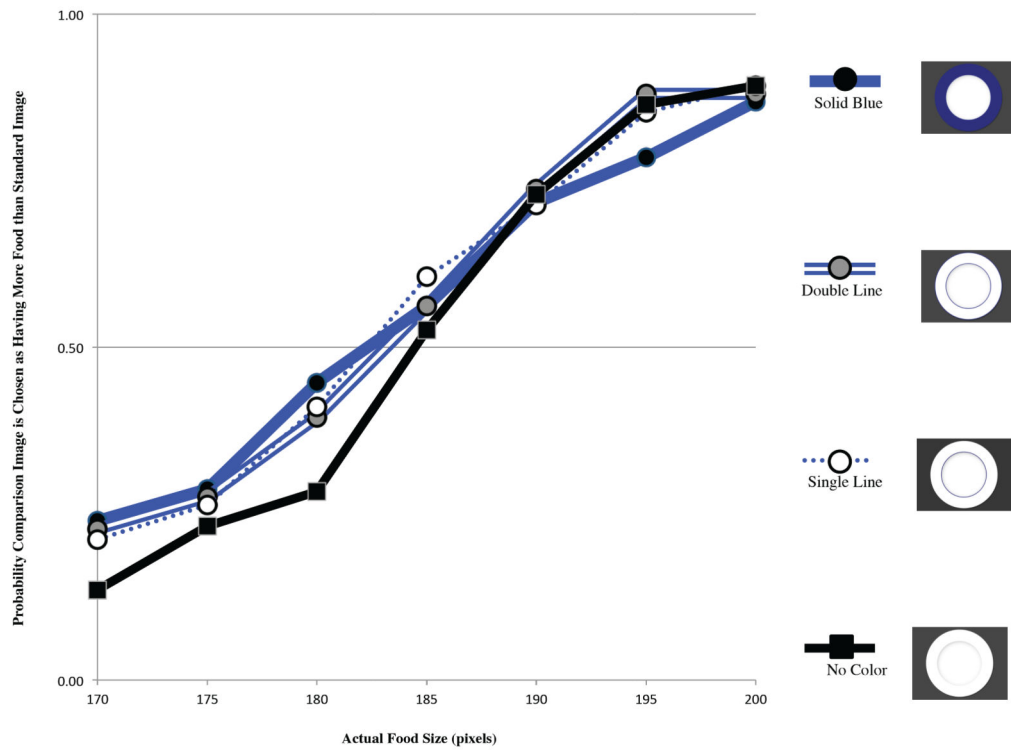
Figure 4. Psychophysical Response Curve – The Effect of Rim Coloring on Perceived Food Portion Size (Experiment 2)
Note: Every point on the graph is being compared to the standard stimulus: food size of 185 pixels on a plate with no rim coloring

Table 1

Multi-Level Logistic Regression Analysis: The Effect of **Rim Width** on Perceived Food Portion Size (Experiment 1)

	β (SE)	P value	Odds Ratios (95% Confidence Interval)			Point of Equivalence [a] (% Exaggeration)
			Small Food Size [b]	Medium Food Size [c]	Large Food Size [d]	
Intercept	0.46 (0.01)	<0.0001 *				
Food Size	0.02 (0.001)	0.007 *				
Food Type	0.001 (0.01)	0.96				
1/2 Rim	0.08 (0.01)	<0.0001 *	1.59 (1.23, 2.05) *	1.52 (1.33, 1.73) *	1.46 (1.13, 1.88) *	182.27 (1.5%)
3/8 Rim	0.08 (0.01)	<0.0001 *	1.39 (0.99, 1.97)	1.52 (1.33, 1.74) *	1.66 (1.22, 2.27) *	182.36 (1.4%)
1/3 Rim	Reference [e]					Reference = 185
1/4 Rim	−0.04 (0.01)	0.001 *	0.98 (0.69, 1.39)	0.82 (0.72, 0.94) *	0.68 (0.51, 0.92) *	187.91 (−1.6%)
1/8 Rim	−0.13 (0.01)	<0.0001 *	0.60 (0.45, 0.80) *	0.50 (0.44, 0.58) *	0.42 (0.33, 0.53) *	192.35 (−4.0%)
No Rim	−0.10 (0.01)	<0.0001 *	0.69 (0.48, 0.99) *	0.59 (0.52, 0.68) *	0.51 (0.38, 0.68) *	190.81 (−3.1%)
1/2 Rim × Food Size	−0.0004 (0.001)	0.75				
3/8 Rim × Food Size	0.001 (0.002)	0.62				
1/4 Rim × Food Size	−0.002 (0.002)	0.18				
1/8 Rim × Food Size	−0.004 (0.001)	<0.001 *				
No Rim × Food Size	−0.003 (0.002)	<0.05 *				

[a] Point of equivalence: Defined as the point where participants cannot distinguish the difference in food portion size between the two compared images, even when they exist, where there is an equal 50% chance that participants pick the standard vs. test stimulus.

[b] 170 pixel diameter;

[c] 185 pixel diameter;

[d] 200 pixel diameter:

[e] Reference: Food size of 185 pixels on a plate with a 1/3 rim width-to-plate radius proportion;

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*Denotes statistical significance

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Table 2

Multi-Level Logistic Regression Analysis: The Effect of **Rim Coloring** on Perceived Food Portion Size (Experiment 2)

	β (SE)	P value	Odds Ratios (95% Confidence Interval)			Point of Equivalence [a] (% Exaggeration)
			Small Food Size [b]	Medium Food Size [c]	Large Food Size [d]	
Intercept	0.52 (0.02)	<0.0001 *				
Food Size	0.03 (0.001)	<0.0001 *				
Food Type	0.01 (0.02)	0.47				
1/3 Rim	Reference [e]					Reference = 185
Solid Blue	0.03 (0.01)	0.01 *	2.26 (1.66, 3.07) *	1.18 (1.01, 1.39) *	0.62 (0.44, 0.87) *	182.3 (1.5%)
Double Lines	0.04 (0.01)	0.005 *	1.73 (1.09, 2.75) *	1.26 (1.06, 1.49) *	0.91 (0.59, 1.39)	182.0 (1.6%)
Single Line	0.04 (0.01)	0.006 *	1.71 (1.08, 2.71) *	1.25 (1.05, 1.48) *	0.91 (0.60, 1.40)	182.0 (1.6%)
Food Size × Solid Blue	−.006 (0.001)	<0.0001 *				
Food Size × Double Lines	−0.002 (0.002)	0.33				
Food Size × Single Line	−0.002 (0.002)	0.34				

[a] Point of equivalence: Defined as the point where participants cannot distinguish the difference in food portion size between the two compared images, even when they exist, where there is an equal 50% chance that participants pick the standard vs. test stimulus.

[b] 170 pixel diameter;

[c] 185 pixel diameter;

[d] 200 pixel diameter:

[e] Reference: Food size of 185 pixels on a plate with a 1/3 rim width-to-plate radius proportion;

* Denotes statistical significance