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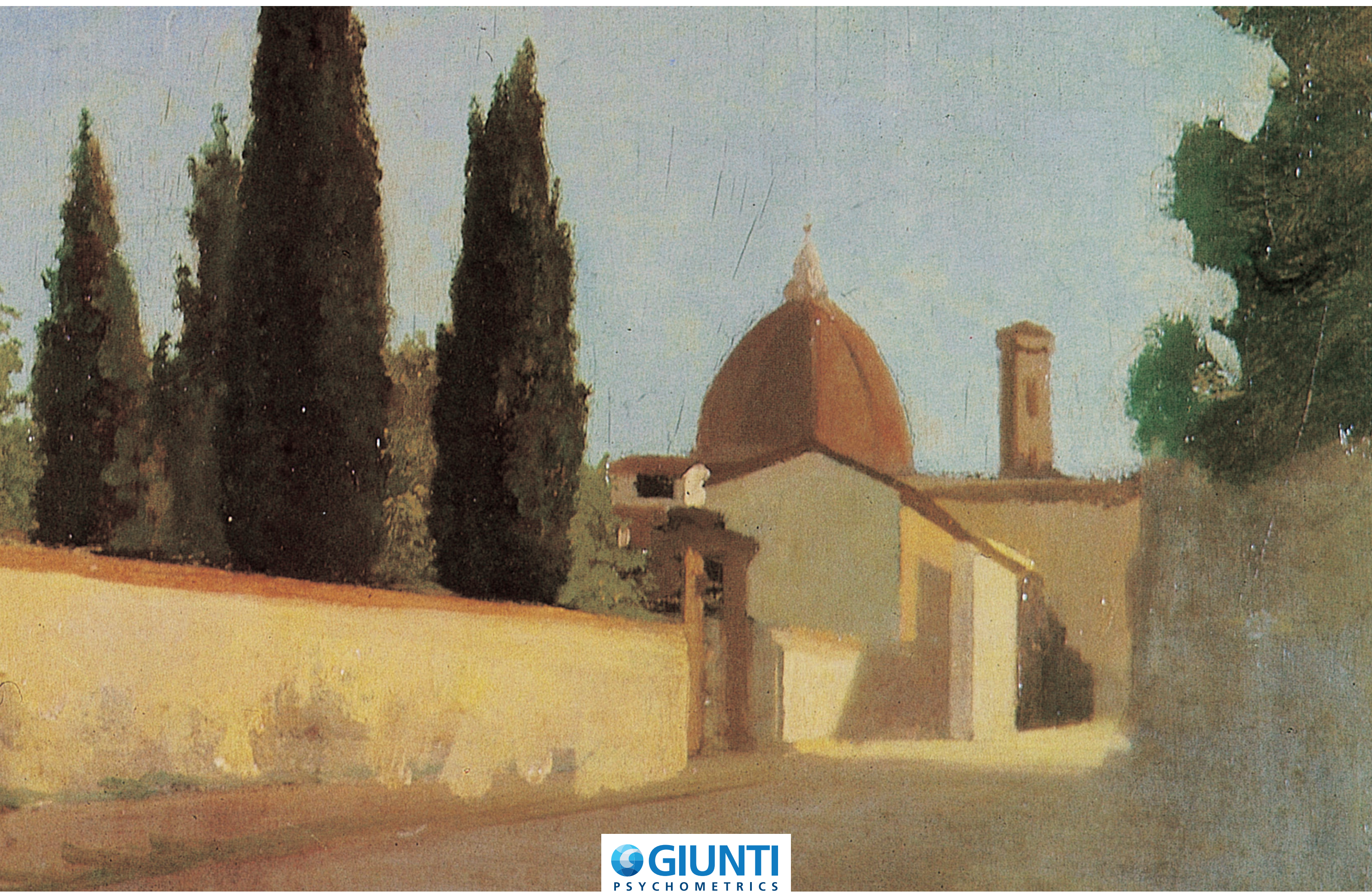
Experiences & Tools



GIUNTI PSYCHOMETRICS

Scientific Director Alessandro Zennaro

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Research

Experiences & Tools

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The visual perception of volume: Judgment and fixations for objects

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ABSTRACT. La presente ricerca ha esplorato, mediante tre esperimenti, quanto i pregiudizi del consumatore e la lunghezza o tipologia di una confezione influenzino le preferenze e l'attenzione nei confronti di un prodotto. I dodici partecipanti sono stati posti di fronte a due immagini di bottiglie posizionate una vicino all'altra sul monitor di un computer Dell Triniton e hanno valutato quale avesse il maggior volume. Sono stati monitorati anche i movimenti oculari, mediante il sistema Eyelink II. I risultati, ottenuti con l'analisi della varianza e il test *t* di Student, hanno confermato l'impatto dei pregiudizi.

SUMMARY. Understanding consumers' perception and judgments of product volume is critical for consumer researchers, package designers, and public health advocates. In this study, in a set of three experiments, observers chose which of two bottle images with different height-to-width ratios depicted greater volume. The elongation bias was replicated and a leftward bias was found. Eye movements were recorded as a measure of attention and pupil dilation was recorded as a measure of cognitive load. Fewer fixations were made to the chosen bottle; the last fixation was more often to the rejected bottle. The top halves of the bottles and the side nearest the alternative bottle receive more attention. There were more fixations, slower responses, and lower confidence for more visually complex bottles. Pupil dilation increased when judging the volume of more complex bottles. The context of a shelf increased confidence in some cases. Implications for packaging design are discussed. .

Keywords: *Eye movements, Decision making, Volume judgment, Left visual field bias, Packaging, Context*

INTRODUCTION

The perceived volume of a bottle or package has important implications for commercial package design, especially in the consumer goods industry. At the most basic level, if two products have similar attributes and price, then shoppers will generally select and purchase the product that is perceived as containing the larger volume. This larger perceived volume implies more product, and hence better perceived value.

There are also potential opportunities associated with influencing perceived volume of packages that go beyond this simple application. For example, there are numerous advantages for creating more concentrated, compact products in many consumer goods categories. Many liquid products, such as detergents, shampoos, and dishwashing liquids have historically contained quite high levels of water. More concentrated products reduce both the financial and environmental cost of packing, shipping and storing these products in a product manufacturing and supply chain. However, consumers can perceive smaller packages a poorer value, even if they contain the same quantity of active ingredient. If this can be lessened by strategic package design for the compacted version, consumers may be more willing to accept compacted products which use less energy and reduce waste, making them legitimate "green" alternatives (Bansal & Roth, 2000).

So there are several potential advantages associated with influencing perceived package volume. An opportunity in this respect lies in our understanding that people are not always accurate in their determination of volume, and that the shape of a package can impact perception of its volume. Many factors can potentially impact perceived volume of two different packages, including three dimensional effects such as body shape, asymmetry, handle shape, curvature, two dimensional effects such as pattern, label shape, geometric complexity, and even the number of displayed packages (Garber, Hyatt & Boya, 2009, 2014). One such factor that is of particular relevance to packaging is the elongation bias, where an increase in the ratio of height versus width creates a perception of greater apparent volume (Been, Braunstein & Piazza, 1964; Frayman & Dawson, 1981; Holmberg, 1975; Kerr, Patterson, Koenen & Greenfield, 2009; Pearson, 1964; Pechey et al., 2015; Raghubir & Krishna, 1999; Wansink & Van Ittersum, 2003; Yang & Raghubir, 2005). This is an effect that has been demonstrated repeatedly in packaging, and also in studies of everyday objects such as drinking glasses, where people repeatedly show a preference for tall, thin glasses over shorter, wider glasses of equal volume, and estimate that the tall, think glasses contain a greater volume (Wansink & Van Ittersum, 2003; Yang & Raghubir, 2005).

The elongation bias is of particular interest in the context of packaging because it appears to robustly and consistently operate across a range of relevant contexts. For example, it is not eliminated by reducing an observer's cognitive load or increasing an observer's motivation to be accurate during volume judgments, suggesting that it is at least in part an automatic process (Raghubir & Krishna, 1999). It is also at least partly robust in the face of expertise. For example, bartenders, when instructed to pour a precise amount into glasses, consistently pour less into elongated, highball glasses. Although the error rate was lower for bartenders than less practiced participants (Wansink & Van Ittersum, 2003), but still persisted. In a related study of purchasing behaviors, Yang & Raghubir (2005) categorized participants as non-drinkers, lighter drinkers and heavier drinkers to reflect their level of experience with buying beer. For all three groups, elongated containers (bottles) were perceived to contain more volume than shorter cans. The effect was strongest for the non-drinkers and weakest for the heavier drinkers. This suggests that this is a tenacious bias that will influence even experienced shoppers, albeit to a potentially lesser degree than less experienced ones.

In the experiments reported here, we have explored the impact of the elongation bias specifically in the context of packages similar to those found in the consumer goods industry. We have tested various prototypes in a context that models to some degree a retail environment such as a supermarket shelf, and evaluated how shape can influence preference as a proxy for shopper purchasing behavior. We expected to replicate the elongation bias, but we have also explored the role of shape, topological properties and holes in volume perception when varied in combination with the elongation bias.

In addition to this, we have also studied eye movements during judgments of relative volume. As mentioned previously, a study by Folkes & Matta (2004) reported that more attention leads to greater judged volume, suggesting that attentional mechanisms may impact volume perception. However, in their study the measure of attention was subjective: where observers reported, using questionnaires, which objects attracted more of their attention. By using eye tracking we expect to explore this hypothesis using a more direct measure of visual attention, and one that encompasses both explicit and implicit attentional effects. Eye tracking is a useful technique to apply in this context, as we know that fixations are often directed to the focus of attention (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher & Blaser, 1995). Observers more accurately identify simple objects when they are near saccade targets (Deubel & Schneider, 1996; Kowler et al., 1995). Prior to making saccades, observers orient their attention toward the intended target of the saccade (Hoffman & Subramaniam, 1995). Observers find it difficult to orient their attention to one location while making a saccade to a different location (Hoffman & Subramaniam, 1995; Kowler et al., 1995). These tight correlations make fixations a valuable measure of visual attention. When viewing scenes, observers fixate on more informative regions (Loftus & Mackworth, 1978). For instance, when viewing faces, observers fixate more on internal features than the rest of the face (Henderson, Williams & Falk, 2005; Stacey, Walker & Underwood, 2005). Particularly the eye region, which is the most informative region of a face, receives the highest proportion of fixations (Althoff & Cohen, 1999; Barton, Radcliffe, Cherkasova, Edelman & Intriligator, 2006; Walker-Smith, Gale & Findlay, 1977). Given these findings we planned to infer, from fixations, what regions are most informative during judgments of volume.

By exploring the impact of both elongation and topology on preference and attention, we hope to provide a foundation for package design that can increase perceived value between products of equal volume, but also to provide insights that can ultimately be adapted to increase the acceptance of environmentally advantageous ‘compact’ products.

EXPERIMENT 1

In this experiment, participants viewed two bottles placed side by side and judged which bottle had the greater volume while their fixations were recorded. Participants also made bets to indicate how confident they were in their judgments.

The stimuli were two-dimensional (2D) images of three-dimensional (3D) bottles. Previous studies found that the perceived volume of a 3D object can differ from the perceived volume of a 2D image of that object (Ekman & Junge, 1961; Frayman & Dawson, 1981). However, this is no problem for our experiment since our participants judged relative, not absolute, volume. Using 2D images gave us greater control of our bottle stimuli: we varied their elongation but kept constant their color, shape and area.

EXP. 1 - METHOD

Participants

Twelve participants (six males) with normal or corrected-to-normal vision participated in the study. Participants were paid $10 for their participation. Data from one female participant was excluded because she failed to comprehend the task, and data from one male participant was excluded because he was not naïve to the purpose of the study. The final data set contained data from 10 participants (five males) between the ages of 23 and 29 (M = 25.22, SD = 2.11).

Apparatus

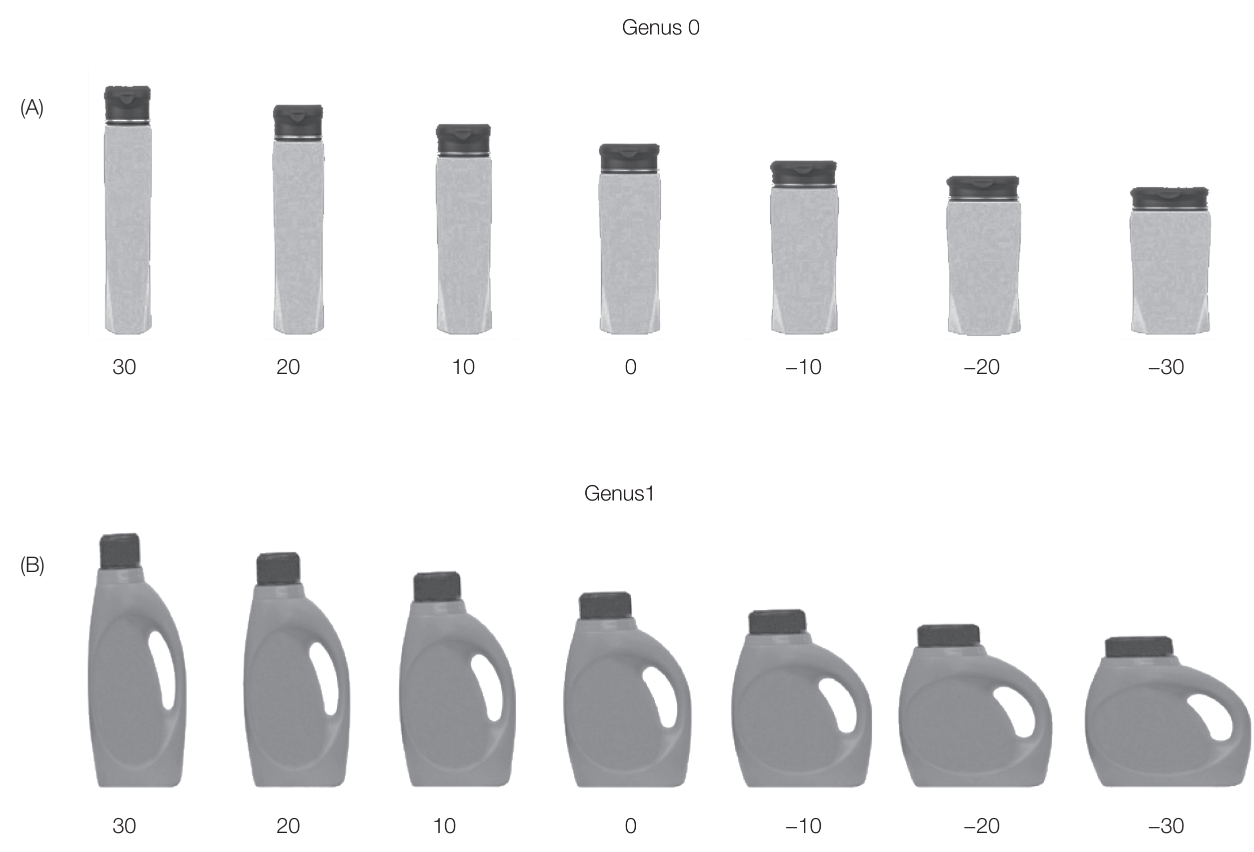
Stimuli were presented in color on a 19 inch Dell Trinitron monitor. Participants sat at about 60 cm from the computer monitor. Eye movements were monitored with the Eyelink II eye tracking system from SR Research.

Materials

The stimuli were created from one original image of a bottle having genus 0 and one original image of a bottle having genus 1, where genus is equivalent to the number of handles an object has. For each original image, three new images were created that had greater elongation: the height was increased by 10, 20 and 30 percent and the widths were decreased so that the surface area was kept constant. Likewise, three new images were created that were less elongated: The height was decreased by 10, 20 and 30 percent and the area kept constant. These six new images are the “altered bottles.” Thus there were a total of seven genus 0 images and seven genus 1 images used in the experiment. Figure 1 shows all images, arranged from tallest to shortest.

On each trial, two bottles of the same genus were presented side by side. One was the original and the other was one of the seven bottles of that genus. The original bottle was presented once to the left and once to the right of each of the seven bottles, for a total of 14 pairings for each bottle type.

Figure 1 – Genus 0 bottles used in Experiment 1 (A) and Genus 1 bottles used in Experiment 1 (B)



Note. The percentage of vertical elongation is indicated below each bottle. Genus 0 bottles were off-white, and Genus 1 bottles were red.

To study the effects of context, all 14 pairings were presented twice, once on a shelf and once on a gray background. In total, 28 trials were presented for each genus. The entire experiment consisted of 56 trials presented in random order.

Procedure

Participants sat about 2 feet from the display. They were fitted with the Eyelink II headset, and their fixations were calibrated using Eyelink software. Then a screen appeared with the following instructions: "On each trial, you will see two bottles. Please choose which bottle has the greater volume. If you choose the bottle on the left, press the left arrow key. If you choose the bottle on the right, press the right arrow key. After you press a key, you will be asked to make a bet on how confident you are in your choice. Your bet can be any amount from zero to 100 fake dollars. At the end of the experiment, you will receive real money, up to $10, depending on how well you bet and how accurate your volume choices are".

Participants then pressed any button to begin the experiment. Each trial was self-timed: each pair of bottles was displayed until the participant chose a bottle. A screen then appeared instructing participants to place a bet ranging from zero to 100, where zero indicated no confidence in their choice and 100 indicated the highest confidence. After a participant confirmed the bet amount, the next trial began. A drift-correction dot appeared before each trial to minimize errors in fixation measurements and to center the participant's gaze before the next trial.

After completing the experiment, each participant was told that their performance had earned the full $10 compensation. Participants were not told that there were, in fact, no incorrect answers.

EXP. 1 - RESULTS

Fixations, response times, volume judgments and bets were analyzed for effects of genus, context, elongation, participant gender, and relative bottle location. Fixations and bets for chosen and unchosen bottles were compared, and fixations to different portions of the bottles were analyzed. A four-factor (shelf/no shelf, location, genus, elongation), 2x2x2x7 within-subjects ANOVA was conducted for bets, fixations and response times. Gender was a between-subjects factor in all analysis.

Volume judgments and response times

Results showed that relative location of bottles affected volume judgments ($F_{(1,9)} = 8.758$, $p = .016$). Participants more often chose the bottle on the left as having greater volume ($t_{(9)} = 2.834$, $p = .020$). There were no other effects on volume judgments or response times.

Fixations

There were more fixations to the unchosen bottle in eight of the ten participants (significant for four participants, two-tailed $t_{(55)} = 4.066, 2.469, 2.030, 5.723$, all $p<.05$). On average, 33.5% of fixations were to the chosen bottle, and 38.07% were to the unchosen bottle. Total fixation time was also greater for the unchosen bottle for eight of the ten participants (significant for two, $t_{(55)} = 3.592, 4.486$, all $p<.05$). On average, 1975 ms were spent fixating on the chosen bottle, and 2116 ms on the unchosen bottle.

The last fixation was most often to the unchosen bottle ($t_{(9)} = 4.628$, $p = .001$). If this bottle was on the right, it received the last fixation on 70% of trials ($t_{(9)} = 4.651$, $p = .0012$). If on the left, it received the last fixation on 51% of trials ($t_{(9)} = .244$, $p = .81$).

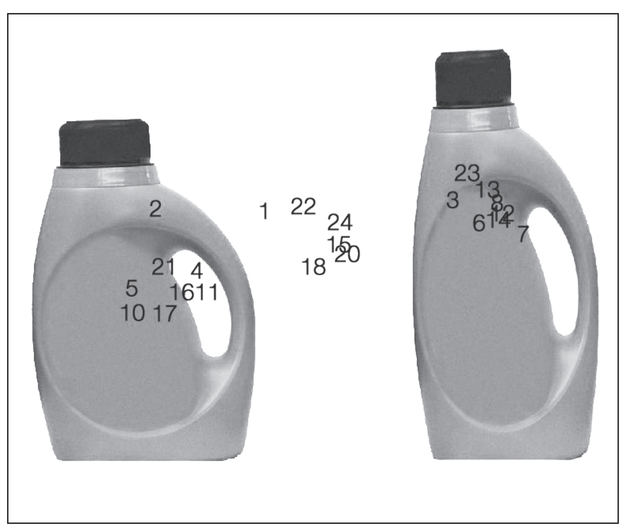
We analyzed the proportion of fixations to the inner side of each bottle, i.e., to the side closest to the other bottle. For all ten participants, two-tailed t-tests showed that the proportion of bottle fixations to the inner side was significantly above 50% ($t_{(55)} = 6.929, 9.438, 9.088, 9.365, 13.852, 9.305, 11.253, 13.618, 4.992, 10.951$, $p<.01$ for all participants). The proportion of bottle fixations to the top half of each bottle was also significantly above 50% for all ten participants ($p<.01$ for all participants). Within-subjects ANOVA showed that this top bias was greater for bottles of genus 0 ($F_{(1,7)}=5.703$, $p = .048$). Figure 2 shows typical fixations, numbered in sequence.

Bets

A bet was coded with positive sign if an altered bottle was chosen as having greater volume, and with negative sign otherwise. Results showed a significant effect of elongation ($F_{(6,24)} = 3.699$, $p<.01$), as shown in Figure 3. For elongations 30, 20 and 10, corresponding to bottles taller and thinner than the original, bets were coded with positive values, indicating that these elongated bottles were chosen. For elongations –10, –20 and –30, corresponding to bottles shorter and wider than the original, bets were coded with negative values, indicating that the original was chosen.

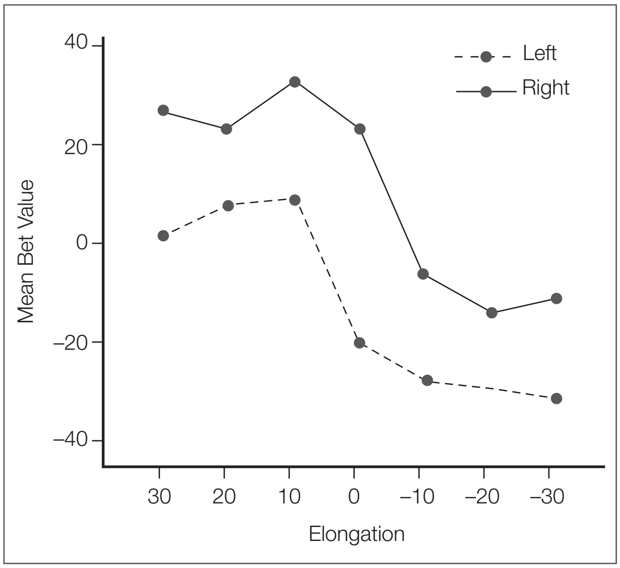
Bets indicate that participants were more confident when they chose the bottle on the left (see Figure 3). A bottle altered to be taller and thinner than the original was likely to be chosen as having greater volume regardless of its location,

Figure 2 – Fixations of one observer during one trial



Note. Fixations are numbered in sequence. There are more fixations to the upper half of the bottle, and to the side of the bottle nearest the other bottle.

Figure 3 – Mean bet values as a function of elongation and location of the original bottle (left or right)



but participants were more confident, as indicated by absolute values of bets, when it appeared on the left. A bottle altered to be shorter and wider was likely not to be chosen regardless of its location, but participants were more confident in rejecting it when it appeared on the right.

The genus of the bottle and the presence or absence of a shelf did not affect bets.

EXP. 1 - DISCUSSION

As expected, elongated bottles were judged to have greater volume. This replicates previous studies, as discussed in the introduction.

Bottle location also influenced judgments of volume. Participants more often chose the bottle on the left as having greater volume, and were more confident when they chose this bottle.

More attention, as measured by number of fixations and total fixation time, was allocated to the bottle that was not chosen as having greater volume.

Regardless of choice or bets, more fixations were made to the top halves of bottles than to the bottom halves. This might be due to the placement of the bottles. As seen in Figure 2, the bottoms of the two bottles are coplanar; however, if the bottles have different elongations then their tops have different heights. Thus the top halves provide more information about the relative heights of bottles, which can be used to estimate relative volumes. This top bias was greater for bottles of genus 0. However, these bottles are relatively cylindrical and have a fairly uniform width, whereas our genus 1 bottles have most of their bulk in the lower half. Thus the upper half of a genus 1 bottle may not be as useful in volume judgments and garners fewer fixations.

More fixations were made to the inner side of each bottle, i.e., to the side closest to the other bottle. This might reflect a strategy for acquiring visual information when making judgments of relative volume. But it might be an artifact of the large separation and spacing between bottles (see Figure 2). The next experiment addresses this issue.

EXPERIMENT 2

As seen in Figure 2, some fixations fell in the empty space between the bottles. Perhaps observers tended to look in the middle of the display and, in consequence, happened to fixate primarily the inner side of each bottle. Experiment 2 studies this issue.

EXP. 2 - METHOD

Participants

Ten observers (five males) with normal or corrected-to-normal vision participated in the study. Observers were paid $10 for their participation. Observers were between the ages of 20 and 30 (M = 24.2, SD = 3.12).

Apparatus

The apparatus was the same as in Experiment 1.

Materials

Half of the stimuli were those used in Experiment 1. The other half were the same bottle pairs with a decreased distance between bottles. This is illustrated in Figure 4, with

Figure 4 – Genus 0 bottles placed near to each other and in the context of a shelf

two genus 0 bottles placed in the context of a shelf. There were a total of 102 images used: 56 with the original between bottle distance, and 56 with the decreased distance.

Procedure

The procedure was the same as in Experiment 1, except that there were two blocks of trials, one with the original distance between bottles ("far") and one with a decreased distance between bottles ("near"). There were 56 trials in each block, and the order of the two blocks was counterbalanced across participants.

EXP. 2 - RESULTS

A five-factor (placement, shelf/no shelf, location, genus, elongation), 2x2x2x2x7 within-subjects ANOVA was conducted for bets, fixations and response times.

Volume judgments and response times

Bottle location significantly affected bets ($F_{(1,8)}$ = 9.440, p = .015). On average, the bottle on the left was chosen in 62% of the trials. Response times were longer during trials with genus 1 bottles ($F_{(1,8)}$ = 9.711, p = .014).

Fixations

As in Experiment 1, observers more often fixated the unchosen bottle, an effect significant for eight of the ten observers ($t_{(111)}$ = 3.912, 7.539, 4.927, 3.477, 3.713, 3.886, 4.136, 2.799, all p<.01). 33.1% of fixations were to the chosen bottle, and 40.79% were to the unchosen bottle. The total fixation time to the unchosen bottle was also greater for eight of the ten participants, significantly so for six ($t_{(111)}$ = 3.054, 4.637, 2.303, 3.418, 3.740, 2.840, all p<.01). On average, 1310 ms were spent fixating on the chosen bottle, and 1461 ms on the unchosen bottle.

More fixations were made during trials with genus 1 bottles ($F_{(1,8)}$ = 13.495, p = .006). This was not found in Experiment 1, perhaps because it had half as many trials as Experiment 2, and therefore less power.

As in Experiment 1, we found that more of the last fixations (64%) were made to the unchosen bottle, but only significantly so if it was on the right ($t_{(9)}$ = 9.239, p<.001). If observers chose the bottle on the left, 72% of the final fixations were to the unchosen bottle; if observers chose the bottle on the right, only 55% of the final fixations were to the unchosen bottle.

All ten observers made more fixations to the inner sides of the bottles ($t_{(112)}$ = 14.212, 18.838, 012.018, 17.816, 11.218, 13.174, 9.825, 15.619, 15.527, 9.783, all p<.001). This was affected by placement ($F_{(1,8)}$ = 9.263, p = .016). The proportion of inner fixations was greater when the bottles were near than when they were far.

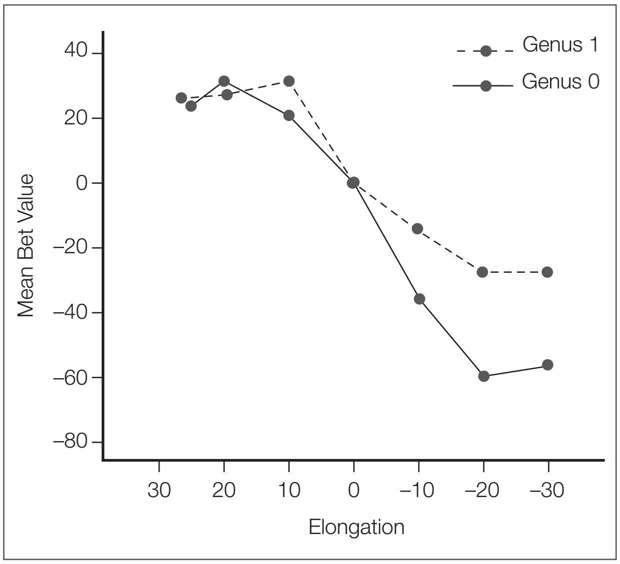
Bottle genus affected the proportion of inner fixations ($F_{(1,8)}$ = 6.031, p = .04), with this proportion being greater for bottles of genus 1 (see Figure 5). This effect was most pronounced for the shorter, wider bottles (elongations –10, –20, and –30).

More fixations (79%) were made to the top halves of bottles. This was significantly greater than 50% for all ten participants (all p<.05). There was a significant effect of bottle genus on the proportion of fixations to the top half of the bottle (p = .03): the proportion was higher for genus 0 bottles than for genus 1 bottles.

Bets

Elongation had a significant effect on bets ($F_{(6,48)}$ = 32.950, p<.001). As in Experiment 1, bets were higher when the original bottle appeared on the right ($F_{(1,8)}$ = 9.440, p = .015).

Figure 5 – Mean difference between number of inner and outer fixations, for Genus 0 and Genus 1 bottles



This pattern indicates greater confidence when the bottle on the left is chosen.

Bets were affected by bottle genus ($F_{(1,8)}$ = 21.037, p = .002). Bets were higher for genus 1 bottles for elongations –10, –20, and –30 (see Figure 6). This effect was not found in Experiment 1, perhaps because Experiment 1 had half as many trials as, and therefore less power.

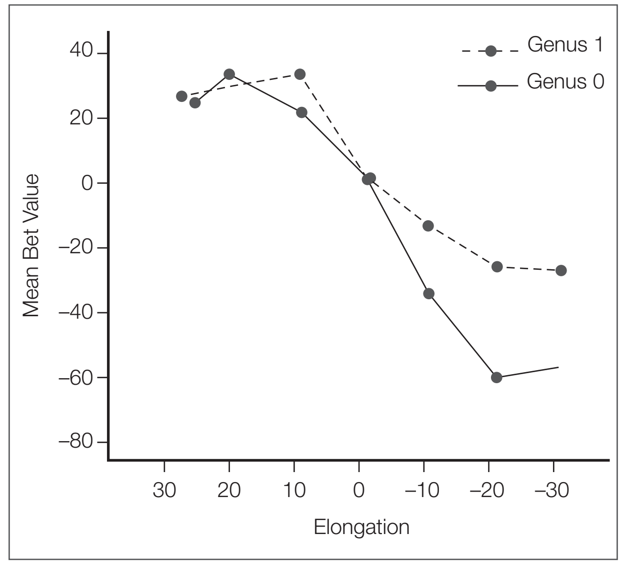
Context significantly affected bets ($F_{(1,8)}$ = 12.957, p = .007). For elongations 30, 20, 10, and 0, the bets were higher when there was a shelf present (see Figure 7). These are the taller elongations, and the tops of these bottles were in closer proximity to the shelf above them than were the tops of the shorter bottles.

EXP. 2 - DISCUSSION

Experiment 2 replicated many results found in Experiment 1. Observers showed an elongation bias. They more often chose the bottle on the left, and were more confident when they did. They more often fixated the unchosen bottle, and more often fixated the top halves of bottles.

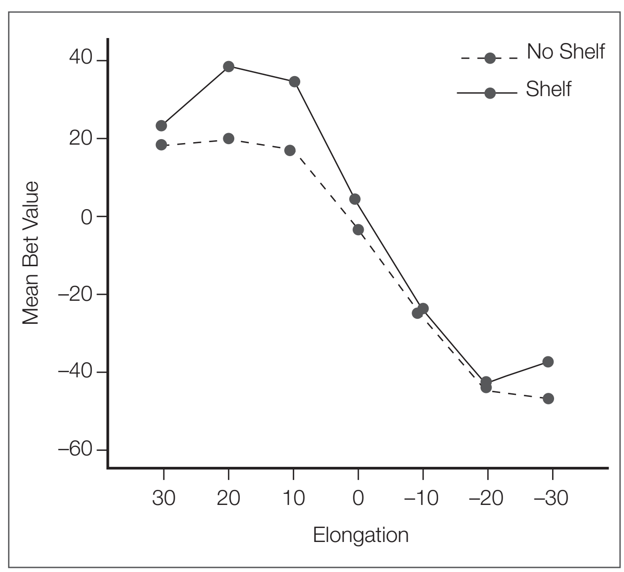
Observers more often fixated the side of a bottle nearest the other bottle when, as in Experiment 1, the bottles were widely separated. However when the bottles were close

Figure 6 – Mean bets at each elongation for Genus 0 and Genus 1 bottles



Note. Positive values indicate the altered bottle was chosen; negative values that the original bottle was chosen.

Figure 7 – Mean bets as a function of elongation and context (shelf or no shelf)



Note. Positive values indicate the altered bottle was chosen.

together, this effect was even stronger. Thus this fixation pattern cannot be dismissed as an artifact of wide separation between bottles. Instead it reveals an interesting strategy for gathering information when judging relative volume.

Perhaps because Experiment 1 had half as many trials and therefore less power, several effects found in Experiment 2 were not found in Experiment 1.

First, participants made more fixations and were slower to respond during trials with bottles of genus 1. These bottles are more irregularly shaped than the bottles of genus 0, and this extra geometric complexity might require more fixations and computations to judge their volumes. Second, genus affected bets. For the shorter, wider bottles (elongations −10, −20, −30), bets indicate that observers were less confident when choosing bottles of genus 1. This again could be due to the greater geometric complexity of these bottles.

Third, there was a new effect of context. Bets and confidence were higher for bottles with elongations 30, 20, 10 and 0 when they were viewed in the context of a shelf. These elongations correspond to taller bottles, and their height may have made it easier to use the upper shelf as a vertical reference point. Proximity to the upper shelf may have made the bottles look taller than they would without a shelf. The increase in perceived elongation could have increased observers' confidence that the bottles had greater volume.

EXPERIMENT 3

Experiments 1 and 2 studied judgments of relative volume when two objects are visible. However, observers must often judge relative volumes when more than two objects are visible. It is natural to ask whether the patterns of volume judgments found with two objects still holds when more than two objects are visible. Experiment 3 addresses this question, considering the case of four objects. It also investigates the resource demands of volume judgments, using measurements of pupil diameter.

EXP. 3 - METHOD

Participants

Ten observers (five males) with normal or corrected-to-normal vision participated in the study. Observers were paid $10 for their participation. Observers were between the ages of 20 and 34 (*M* = 23.0, *SD* = 4.22).

Apparatus

The apparatus was the same as in Experiment 1.

Materials

The stimuli were similar to those used in Experiment 2, with the bottles placed near each other, except that there were four bottles rather than two, and no shelf context was used. The two bottles on the left were identical to each other, as were the two bottles on the right. This is illustrated in Figure 8, with two genus 1 bottles. There were a total of 56 images: 28 with the genus 0 bottles and 28 with genus 1 bottles.

Procedure

The procedure and instructions were the same as the instruction in Experiment 1, except that observers were instructed to judge the relative volumes of the two middle bottles, and the block of 56 trials was presented twice. Trials were presented at random within each block. Two blocks allowed us to study practice effects on volume judgments and pupil diameter.

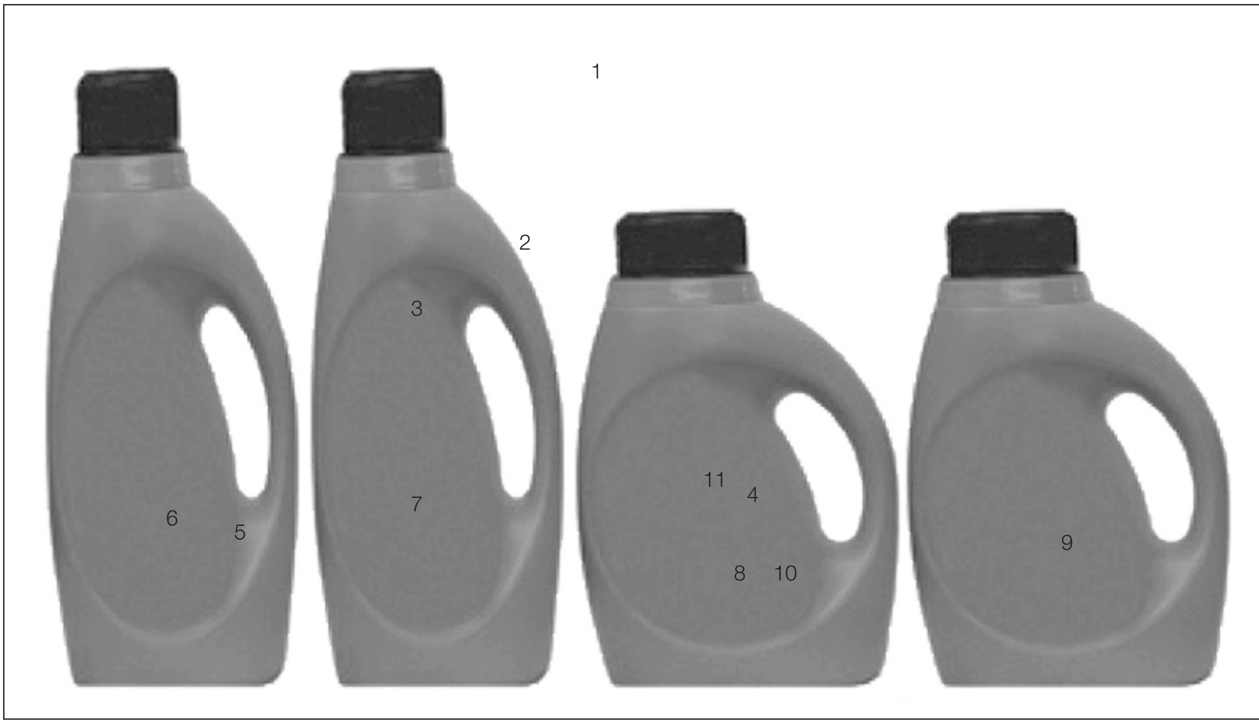
EXP. 3 – RESULTS

A four-factor (block, bottle location, bottle genus, elongation), 2x2x2x7 within-subjects ANOVA was conducted for bets, fixations and response times.

Volume judgments and response times

There was a main effect of block on bets ($F_{(1,8)}$ = 8.390, p = .020) and response times ($F_{(1,8)}$ = 8.815, p = .018); observers bet more confidently in the first block and responded more quickly in the second block. There was a marginal main effect of genus on bets ($F_{(1,8)}$ = 5.241, p = .051); observers bet more confidently on bottles of genus 0. There was a main effect of elongation on bets ($F_{(6,48)}$ = 4.650, p = .007); observers rated more elongated bottles as having greater volume. Notably, unlike Experiments 1 and 2, there was not a main effect of

Figure 8 – A sample stimulus used in Experiment 3, overlaid with fixations from one observer



bottle location on bets; observers no longer demonstrated a left field bias.

Fixations

As in Experiments 1 and 2, observers more often fixated the unchosen bottle; six of the ten observers showed this pattern, significantly so for three ($t_{(55)}$ = 2.422, 3.496, 3.196, all p<.02). On average, 25.95% of fixations were to the chosen bottle, and 28.60% were to the unchosen bottle. Also as in Experiments 1 and 2, observers more often fixated last on the unchosen bottle ($t_{(9)}$ = -3.074, p = .013); this effect was greater if the unchosen bottle was on the left. The total fixation time to the unchosen bottle was also greater for eight of the ten participants, significantly so for three ($t_{(55)}$ = 2.911, 3.613, 2.682, all p<.01). On average, 1580 ms were spent fixating on the chosen bottle, and 1760 ms on the unchosen bottle.

All ten observers made more fixations to the inner sides of the bottles than to the outer sides, significantly so for nine ($t_{(55)}$ = 3.202, 4.176, 5.022, 6.809, 6.148, 7.192, 5.216, 8.817, 6.862, all p<.002). Eight of ten observers made more fixations to the top halves of the bottles, significantly so for five ($t_{(55)}$ = 2.302, 3.488, 2.121, 2.763, 3.834, all p<.04). There was an interaction between top fixations and elongation ($F_{(6,48)}$ = 40.135, p<.001); observers did not preferentially fixate the tops in trials where the two bottles had precisely the same height.

Pupillometry

The mean pupil diameter was larger in the first block of trials than in the second ($F_{(1,8)}$ = 7.142, p = .028), as shown in Figure 9a; so also was the maximum pupil diameter ($F_{(1,8)}$ = 5.822, p = .042). The mean pupil diameter was larger for genus 1 bottles than for genus 0 bottles ($F_{(1,8)}$ = 27.424, p = .001), as shown in Figure 9b.

EXP. 3 - DISCUSSION

Experiment 3 replicated the elongation bias, and the bias found in Experiments 1 and 2 for more inner fixations and top fixations, and for more last fixations to the unchosen bottle.

Experiment 3, unlike Experiments 1 and 2, did not find a left field bias in volume judgments. This might be due to the presence of two extra bottles in each trial of Experiment 3. These extra bottles typically attracted a few fixations, as

Figure 9a – Mean pupil diameter in mm as a function of elongation and block

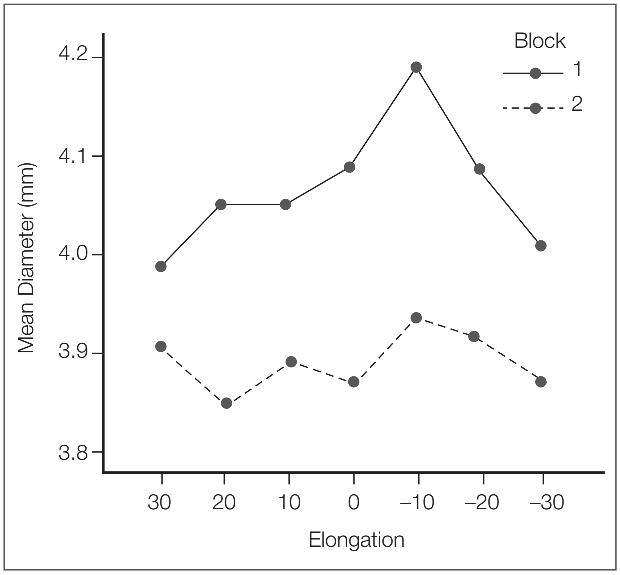
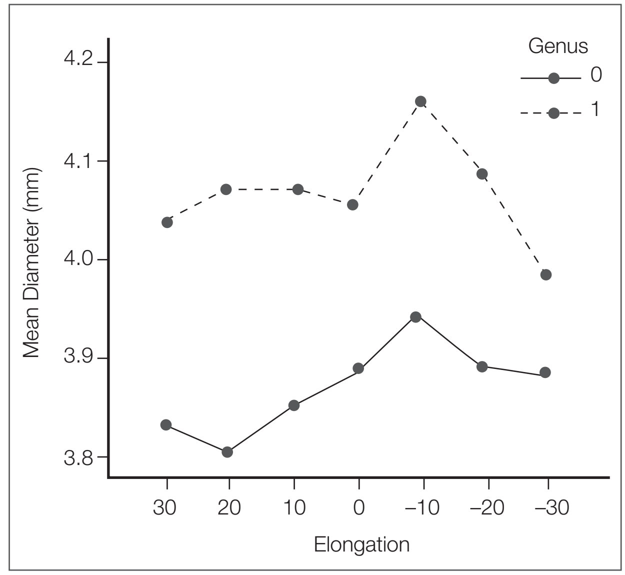


Figure 9b – Mean pupil diameter in mm as a function of elongation and genus of bottle



is seen in Figure 8. When an observer fixates the far left bottle, the middle left bottle is no longer in the left visual field. Similarly, when an observer fixates the far right bottle, the middle right bottle is no longer in the right visual field. This switching of visual fields could smear out the left field biakangs found in Experiments 1 and 2.

Pupil dilation is correlated with increases in attention and cognitive load (e.g., Beatty, 1982; Kang, Huffer & Wheatley, 2014; Peavler, 1974; Siegle, Ichikawa & Steinhauer, 2008). The greater pupil diameter in the first block of trials suggests that the volume judgment task became easier with practice. The greater pupil diameter for genus 1 bottles suggests that volume judgments were more difficult for the more complex bottles.

GENERAL DISCUSSION

Elongation

We replicated the well-known elongation bias: elongated bottles were seen to have greater volume. In addition, we found in Experiment 2 that the elongation effect can be enhanced by placing bottles in the context of a shelf. The shelf above the bottles may act as a vertical reference frame, improving the visual measurement of relative heights. This finding has obvious practical application in stores which display products on shelves.

Location

In Experiments 1 and 2, observers more often chose the bottle on the left as having more volume, and were more confident when they did. A left field bias has been found for other visual capacities, such as face perception (Barton et al., 2006; Gilbert & Bakan, 1973; Mertens, Siegmund & Grüsser, 1993; Phillips & David, 1997) and consumers' judgments of products price (Valenzuela & Raghubir, 2015). Our experiments are the first to suggest a left field bias in judgments of volume.

This bias might reflect hemispheric asymmetries in processing spatial relationships. Judgments of volume rely, one would expect, not just on categorical judgments such as "left of" or "above" but also on estimates of coordinates and distances. Kosslyn et al. (1989) found a left field advantage for processing such coordinate relationships.

The left bias might result from how we match objects to representations in memory. The right hemisphere appears to have an advantage for processing objects with the same basic features as a familiar object, but with an unfamiliar overall shape (Koivisto & Revonsuo, 2003). The altered bottles in our experiments have the same features as the original bottle, but are more or less elongated. Perhaps comparing the altered bottles to a representation in memory of a standard bottle could be done more quickly when the altered bottle is in the left visual field, thus leading to faster and more confident judgments of volume.

Or the left bias might be due to the functioning of two subsystems of visual working memory. One subsystem deals with specific exemplars and the other deals with abstract categories. Marsolek & Burgund (2008) found hemispheric differences in accuracy of judgments based on these subsystems. They presented a cue object followed by a probe object to participants and either asked "Is the probe object the same as the cue object?" or "Is the probe object in the same category as the cue object?". The first question taps into the specific subsystem and the second into the abstract subsystem. When participants were asked the first question, they were more accurate when the probe object was presented in the left visual field. Volume judgments also require a specific metrical comparison, not just a categorical classification. Thus a left field advantage for comparing specific exemplars might facilitate the computation of volume.

The left bias was eliminated in Experiment 3, which had four bottles on each trial rather than just two. The extra bottles attracted some eye fixations. When the far left bottle was fixated, the middle left bottle appeared, momentarily, in the right visual field; when the far right bottle was fixated, the middle right bottle appeared, momentarily, in the left visual field. This switching of visual fields might be responsible for the elimination of the left field bias. Thus, considering that in a real packaging environment, it is rare for two choices to be presented in isolation and shelves are usually crowded in super premium categories, the left visual field bias that was found in experiments 1 and 2 may have more mechanistic and technical value rather than real world potential applications.

Last fixation

More of the last fixations were made to the unchosen bottle. This result raise the question whether a last fixation on a rejected bottle suggest a deselection visual search mechanism. The answer to this question has implications for commercial application, and package design in the context of a shelf and could be explored further in additional studies, where a whole shelf is displayed, and designed to facilitate deselection of competitive or rival products.

Attention to unchosen bottle

Prior studies have found a correlation between greater attention and greater perceived size or volume (Folkes & Matta, 2004). We found the opposite: less attention was correlated with greater perceived volume. This is a surprising result deserving comment.

Folkes & Matta (2004) found that containers which attracted more attention were judged to have greater volume. Their study differs from ours in that their assessment of attention was subjective, based on the self reports of their observers, whereas ours was objective, based on measurements of fixations. Subjective reports might reflect how interesting an object is, rather than how long it holds attention. This is likely in the study by Folkes & Matta (2004), since their containers differed, intentionally, not only in elongation but also in other visual features that affect visual interest.

Anton-Erxleben, Henrich & Treue (2007) presented two moving patterns of random dots. A cue drew attention to one of the patterns, and the observer judged which pattern was larger. They found that the attended pattern was judged to be larger. Their study differs from ours in that their observers judged 2D sizes of dot patterns whereas ours judged volumes of bottles. Moreover, their stimulus presentation was too brief for observers to make a saccade. Our trials were self-timed so observers could fixate as they wished. Thus, Anton-Erxleben et al. (2007) found a correlation between *brief covert* attention and increased perceived size, whereas we found a correlation between *extended overt* attention and decreased perceived volume. This difference in types of attention and their impacts on perceived size or volume deserves further empirical study.

It also deserves further theoretical investigation. Extended overt attention might allow the observer to adopt more sophisticated computational and information-gathering strategies than are possible with brief covert attention. Observers might, for instance, tentatively select one bottle as having greater volume, and then recheck their assessment of the rejected bottle, leading to more fixations of that bottle. This result opens up doors for leveraging the balance between system 1 and 2 decision pathways. For example, could increasing overt attention increase opens to newer more innovative products, whereas decreased overt attention favor more familiar products which require less cognitive engagement, or are more prone to habit derived selection?

In summary, the observation that the chosen bottle has few fixations is surprising and counter intuitive finding for the packaging industry, as heat maps are often used as a proxy for preference. It has important real world implications, and worth further study.

Attention to regions of bottles

In both experiments, more fixations were made to the top halves of bottles than to the bottom halves. The tops of objects have been found to be more salient (Schiano, McBeath & Chambers, 2008). In a matching task, observers were more likely to match objects that had similarly shaped tops (Chambers, McBeath, Schiano & Metz, 1999). For many naturally occurring objects the more informative regions, such as the heads of animals, are at the top.

An alternative explanation is that observers base their judgments of volume on the most salient or reliable information they can gather. The bottles in our experiments stood side by side, with their bottoms coplanar, and with the tops varying in height. Thus the tops were the most informative regions for volume judgments.

Future experiments can test these two hypotheses. For instance, the bottles could be placed one above the other, rather than side by side. According to the first hypothesis, observers should still fixate the tops of bottles. According to the second, observers would fixate the top of the bottom bottle, and the bottom of the top bottle, where the geometry of the two bottles can most easily be compared. The second hypothesis also predicts that in this case there might not be an elongation bias. The widths, not the heights, are the most salient differences when the bottles are placed one above the other. Thus wider, not taller, bottles might be judged as having greater volume. If this were found, it would indicate that the elongation bias is not a fundamental principle in volume perception, but simply an artifact of the side-by-side presentation of the objects to be compared.

Attention to bottles was skewed not only in the vertical dimension. There was also a difference horizontally: most fixations were to the inner side of each bottle, i.e., to the side nearest the other bottle. We wondered if this was due to the large distance between bottles in Experiment 1. However, in Experiment 2, when the bottles were closer, inner fixations actually increased. So, rather than being an artifact of the distance between bottles, this fixation pattern appears to be a strategy that observers use to gather information when judging the relative volumes of two objects placed side by side.

This has important implications for asymmetrical objects. For example, our genus 1 bottles have a handle on one side and the bulk of the volume on the other. If the handle is placed on the side nearest the other bottle, then a strategy of inner fixations might bias observers to sample less from the portion of the bottle that contains most of the volume information. Placement could be a key factor in how volume is perceived for asymmetrical objects.

Bottle genus

More fixations were made to the top halves of genus 0 bottles than to the top halves of genus 1 bottles. The bulk of the genus 1 bottle, and thus most of its volume, is in the bottom half. This could draw the observer's attention downward in an attempt to get information necessary for a volume judgment. The genus 0 bottle is cylindrical, with no extra bulk at the bottom to draw attention.

The bias to inner fixations was greater for genus 1 bottles. These bottles are wider than the genus 0 bottles (for any given elongation), and they have a handle. Future experiments, using different combinations of widths and handles, could determine whether these features influence the bias to inner fixations.

Experiment 2 suggests that volume judgments are more difficult for irregularly-shaped bottles. Observers made more fixations to the irregularly-shaped genus 1 bottles, and took longer to respond to trials with genus 1 bottles. For more complex shapes, observers may need to gather more information to estimate volume. Response times may increase due to longer sampling and calculation times. Experiment 3 supports this interpretation. Pupil diameters were greater for genus 1 bottles, indicating greater cognitive load.

In Experiment 2, genus also affected bets. For the shorter and wider bottles, observers were less confident when choosing bottles of genus 1. This could be due to the greater geometric complexity of these bottles or an asymmetry effect with the handled bottles. In asymmetric bottles, the direct comparison point between the two bottles is a little different in terms of height and slope at the adjacent left/right edges of the bottles where they are directly compared. In this case, the right hand edge of the left bottle is lower and has greater slope than the left hand edge of the right bottle, while the negative space between them can also create an illusion of slope, and potentially height, similar to the Tower of Pisa illusion (Kingdom, Yoonessi & Gheorghiu, 2007). The differences between the symmetric and asymmetric legs would indicate that this might be an effect that is at play, and could open up an interesting direction for additional study with real world benefits.

CONCLUSION

The experiments presented here find that observers, when judging the volumes of bottles placed side-by-side, attend more to the top halves and inner halves of the bottles. This suggests that variations in shape in the top half of a bottle influence apparent volume more than the same variations in the bottom half; similarly, *mutatis mutandis*, for the inner half. This knowledge can be used to design products that optimize the perceived volume of a package.

Moreover, the insights from this research might have potential application in influencing relative choice between products in a category (share of the market), and to offset some of the challenges associated with 1) Compaction and 2) Direct relative comparison at the shelf.

1) *Compaction*. There is a potential to leverage the elongation bias effect in the service of compaction. This is important conceptually, as it has the potential to improve the ecological footprint of a product and package combination. Perceived value issues associated with reduced pack size is one of the biggest barriers to compaction. They are therefore a barrier to the environmental benefits it can bring in terms of reduced fuel, transportation, and storage. The experiments we propose infer this potential. Using the principles we have uncovered via these experiments, the compact package can be designed to maximize the perceived volume of the compacted product. Hence, the volume discrepancy can be lessened for the compacted version and consumers may be more willing to purchase compacted products (green alternatives), which foster a culture of environmental responsibility.
2) *Direct relative comparison at the shelf*. While compaction may have been a conceptual goal, because of the way the experiment is designed, it has even more relevance in influencing simple, relative choice between other similar competing products at the point of purchase. Shoppers can be quite sensitive to small differences when they compare competing packs at the shelf, where direct paired comparisons of relative value are made, and any differences magnified by direct side to side comparisons. All other attributes being equal, relative perceived size, and the perception that "I am getting more for my dollar" will influence value perception (big is better, more is better), and will likely drive choice and purchase towards the pack that is perceived as bigger in a consistent and relatively universal way, and drive market share. Because of its' simplicity, this will also likely be a decision metric that operates even in relatively time constrained, low engagement decisions that are common in a supermarket. The direct, real time choice is also what we are measuring, or at least modeling, in the research.

At the end, it is important to note that in all the experiments, participants were university students. It would be interesting to recruit a wider sample of participants, possibly with a variety in ages, educational background, job, shopping habits, and also to keep track of who is responsible for shopping, either when living with their families or independently.

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