I, Trevor C Cessna, hereby submit this original work as part of the requirements for the degree of Doctor of Philosophy in Psychology.

It is entitled:
Do crossmodal correspondences found between marketed shampoo fragrances and the angularity of shapes transfer to the shape of 2-dimensional and 3-dimensional shampoo bottle designs?

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Do crossmodal correspondences found between marketed shampoo fragrances and the angularity of shapes transfer to the shape of 2-dimensional and 3-dimensional shampoo bottle designs?

A dissertation submitted to the
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Abstract

This study aimed to investigate whether crossmodal correspondences found between odors and visual shapes in the laboratory would also occur with marketed shampoo fragrances and bottle designs.

In Experiment 1, 160 participants rated each of the 12 marketed shampoo fragrances along three bipolar scales with the following anchor pairs: “bouba”/”kiki” shapes (Köhler, W. 1929. *Gestalt psychology*. New York: Liveright.), rounded/angular bottles, and rounded/angular labels. After completing all of these trials, participants smelled each fragrance again and provided a hedonic rating. The results revealed significant associations between two fragrances and all three angular shapes, bottles, and label designs, while additional significant associations were seen between two fragrances and all three rounded shapes, bottles, and label designs. Furthermore, these two ‘rounded’ fragrances were rated as more pleasant than the two ‘angular’ fragrances.

In Experiment 2, 151 participants were randomly presented one of two fragrances that were rated as the most extreme cases of a rounded fragrance (i.e., R1 – fragrance description: gourmand/aldehydic/creamy) and of an angular fragrance (i.e., A1 – fragrance description: fougere/green/musky) from Experiment 1. Participants were presented with a series of 2D shampoo bottle designs (i.e., bottle and label designs) and were told to select as quickly as possible the best overall design in a two-option forced-choice preference elicitation procedure using a conjoint analysis paradigm. Unlike previous research, participants were forced to decide which angular shape of the shampoo bottle and label best fits the presented fragrance when the degree of angularity was systematically manipulated with each new bottle and label design pairings. Finally, *MouseTracker* (Freeman & Ambady,
2010), a computer mouse tracking software, was used to record both the temporal (reaction time) and spatial (projection pathway of the mouse) response patterns during the reaction time tests as the participants decide which overall bottle design was best from two options. As predicted, participants preferred congruent bottle and label designs for both fragrances: R1 was best matched with the medium rounded bottle and the high rounded label design, while A1 was best matched with the low angular bottle but was matched incongruently with the high rounded label design (the low angular label design, however, was a close second). In addition, the MouseTracker results revealed that the predicted congruent bottle designs were selected via a more direct trajectory in comparison to the unpredicted bottle designs.

Following the similar preference elicitation procedure in Experiment 2, 153 participants in Experiment 3 were instead presented with a series of 3D shampoo bottle prototypes, while their dominant hand was tracked using a Kinect sensor for XBOX 360. As predicted, participants preferred congruent bottle designs for both fragrances: R1 was best matched with the medium rounded bottle, and A1 was best matched with the low angular bottle.

This set of experiments yielded strong evidence that crossmodal correspondence between fragrances and the angularity of shapes and bottle designs occurred. More importantly, the results reported here represent the first evidence that correspondences remained relatively consistent across different bottle design tasks and across multiple naïve participants.
Dedication

I dedicate this work to my family especially to my parents, who have demonstrated daily that through joyous perseverance – all things are possible. To my son, Brogan: May you always dream big and strive towards its achievement with a smile. Finally, to my wife, Tracy: Your love, patience, and support always illuminate why you are my better half! I love you.

*Ad Majorem Dei Gloriam.*
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Chapter 1: General Introduction

Our senses at any normal moment are stimulated by many different external stimuli. From these numerous stimuli, which each may stimulate just one sense or several senses simultaneously, some researchers have argued that humans need to solve the crossmodal correspondence problem (Ernst, 2007; Spence, 2011), in that we have to categorize which of these stimuli are relevant to a particular environmental object via multisensory integration. For example, how do we integrate the sight, crunch, texture, and flavor of a delicious red apple?

Two important factors that contribute to multisensory integration of different unisensory stimuli are their relative temporal and spatial relationship to one another (Calvert, Spence, & Stein, 2004; Spence & Driver, 2004). To elaborate, as the temporal span between different sensory stimuli decreases, the overall likelihood that multisensory integration would occur increases (Jones & Jarick, 2006; van Wassenhove, Grant, & Poeppel, 2007). Similarly, the spatial congruency of different sensory stimuli (e.g., an auditory and a visual stimulus) that originated from a similar location may also lead to the integration of these stimuli (e.g., Frens, Van Opstal, & Van der Willigen, 1995). Conversely, stimuli that are temporally asynchronous or spatially incongruent are unlikely to be integrated.

Recently, researchers have observed that multisensory integration occurs in very specific ways through the combination of different unisensory features. For example, high auditory pitches tend to be associated with small visual objects (Mondloch & Maurer, 2004). This type of multisensory integration is called *crossmodal correspondence* (Gilbert, Martin, & Kemp, 1996; Spence, 2011). As
defined by Spence, crossmodal correspondence is “a tendency for a feature, or attribute, in one sensory modality to be matched (or associated) with a sensory feature, or attribute[,] in another sensory modality” (2012, p. 37). A key assumption made in crossmodal correspondence research is that these effects are experienced by a large sample of the population or are even, in some cases, universal (Spence, 2011).

Köhler (1929) is cited as demonstrating one of the first examples of crossmodal correspondence. He found a non-arbitrary relationship between speech sounds (i.e., “baluba” and “takete”) and visual shapes (see Figure 1.1). Participants would generally match the “baluba” with curvy, rounded shapes and “takete” with sharp, angular shapes. Using slightly different speech sounds than Köhler (i.e., “bouba” instead of “baluba” and “kiki” instead of “takete”), researchers have replicated these findings across languages and cultures (Bremner et al., 2013; Imai, Kita, Nagumo, & Okada, 2008) and even with children as young as 2.5 years old (Maurer, Pathman, & Mondloch, 2006). This salient example of crossmodal correspondence is called the “Bouba-Kiki effect.”
Evans and Treisman (2010) demonstrated another example of crossmodal correspondence. They found a consistent relation between auditory pitches and visual black and white gratings. In a reaction time experiment, if a grating was presented either above or below a fixation target and simultaneously paired randomly with either a high or low pitch sound, then participants responded faster to the congruent stimulus pair (e.g., a grating presented “above” paired with a high pitch sound).

It is important to note that much of the early work in crossmodal correspondence was conducted between visual and auditory stimuli. Only recently has the focus shifted to examining crossmodal correspondences in other sensory domains, in particular olfaction. Evidence for crossmodal correspondence has been reported between odors and auditory stimuli. Belkin and colleagues (1997), for example, had participants smell an odor and then presented a series of pitches using a staircase procedure until participants stated that the pitch matched the odor. They
reported that birch tar (i.e., smoke odor) and civet (i.e., pungent and fecal odor) were associated with low-pitched tones in comparison to bergamot (i.e., woody, orange-citrus odor), which was associated with high-pitched tones.

Those findings were later replicated by Crisinel and Spence (2012). They presented participants with a series of odors to smell. For each odor, participants judged which digital musical scale from four types of instruments (i.e., piano, strings, woodwind, and brass) and which auditory pitch from the selected instrument best matched the odor. The authors demonstrated that regardless of the instrument selected smoked and musk odors were rated between the range of 131 and 262 Hz, while a lemon odor was rated at approximately 523 Hz. They also noted that the selection of a pitch was strongly linked by both the odor’s hedonic value and its complexity (e.g., odors that were rated as “complex”, “intense”, “earthy”, “nutty”, “spicy”, “woody”). Furthermore, odors matched with congruent, realistic sounds (e.g., potato chip odor paired with the sounds of eating potato chips) or pleasant sounds (e.g., a baby laughing) significantly increased the overall odor pleasantness rating in comparison to both incongruent or unpleasant sounds, respectively (Seo & Hummel, 2011).

Crossmodal correspondences have also been reported with odors and visual stimuli. One of the most robust findings of crossmodal correspondences is the relationship between some odors and color hues. For example, if participants were presented with a series of bottles containing odorous mixtures that were either clear or dyed via food coloring, then participants typically rated odor intensity as more intense when odors were presented in congruent odor and color mixtures (e.g., mint
and green color or strawberry and red color) (Zellner & Kautz, 1990; Zellner & Whitten, 1999). When participants were asked to match odors and a color on the color wheel, nearly half of the associations (9 out of 20 odors) were consistent among participants from their initial evaluation to the follow-up evaluation 2 years later (Gilbert et al., 1996). Gottfried and Dolan (2003) used pictures instead of color hues and revealed that participants would detect the presence of an odor (e.g., orange) faster and more accurately when the odor was paired with a congruent picture (e.g., a picture of oranges) instead of an incongruent picture (e.g., a picture of a bus).

Within the field of crossmodal correspondence research pertaining to odors and visual stimuli, the link between odors and visual shapes is very sparse. Seo and colleagues (2010) were the first to evaluate whether crossmodal correspondence occurred between odors and abstract symbols. In their Experiment 1, for each odor participants were presented with a series of abstract symbols and asked, “Does this odor fit to this symbol?” Using the correspondence analyses from XLSTAT (Addinsoft, New York, USA) to evaluate the association between the odors and abstract symbols presented, they found that the overall pleasantness of the odor was the main driver in selecting the shapes. In particular, odors that were typically regarded as pleasant (e.g., vanilla, banana, violet) were matched with rounded-shaped symbols, while odors that were typically regarded as unpleasant (e.g., pepper, truffle, parmesan cheese) were matched with angular-shaped symbols (see Figure 1.2). Thus, their Experiment 1 revealed that participants selected rounded-shaped symbols more often with the violet odor and selected angular-shaped symbols more
often with the parmesan cheese odor. In their Experiment 2, the authors selected 2-phenyethanol (PEA; violet odor) and 1-butanol (as a substitute for actual parmesan cheese) odors and their corresponding congruent abstract shape based on their spatial approximation revealed in the correspondence analysis. The authors first asked participants to evaluate how appropriate each abstract symbol (see Figure 1.3) was when paired with the two odors to assess their congruency. In a series of presentations that involved receiving visual stimuli for 3 s prior to the odors, participants were instructed to rate the odor intensity and pleasantness. Using olfactory event-related potentials (ERPs) data, the authors determined that 1-butanol had a significantly shorter N1 peak latency for congruent abstract symbol and odor pairs. Since N1 peaks are associated with both odor quality and intensity (Pause & Krauel, 2000), these results suggest that detection sensitivity was enhanced when congruent abstract symbols were presented prior to the odors (Bulsing, Smeets, Hummel, & van den Hout, 2007).
Similar to Seo and colleagues (2010), Hanson-Vaux and colleagues (2013) conducted a study examining the crossmodal correspondence between odors and shapes. In that study, however, participants matched odors to the “Bouba-Kiki” shape scale (a bipolar scale with the “bouba” rounded-shape and “kiki” angular-
shape as endpoints; see Figure 1.4). Participants smelled 20 different wine odors and rated each odor on the Bouba-Kiki shape scale. When comparing the overall mean scores of each odor to the midpoint of Bouba-Kiki shape scale, the results revealed that only vanilla and raspberry were rated as significantly more rounded “bouba” shaped, while only lemon and pepper were rated as significantly more angular “kiki” shaped.

![Bouba-Kiki shape scale](image)

Figure 1.4 The “Bouba-Kiki” shape scale used by Hanson-Vaux et al. (2013).

The overall conclusion from both the work of (Seo, Arshamian, et al., 2010) and Hanson-Vaux and colleagues (2013) is that crossmodal correspondence does occur between some odors and visual stimuli. One of the questions that motivated the present research project was whether these congruent, crossmodal associations would carry over into consumer products. Presently, this question—and broader questions about the importance of crossmodal correspondence outside the laboratory—remains unanswered (Spence, 2012). The effects between visual-odor crossmodal correspondences found in a controlled laboratory setting could be either weakened or absent when incorporated into sensory-rich marketed products.

Previous research found that consumers tend to evaluate products as more pleasant when they integrated congruent multisensory associations (Seo & Hummel, 2011). With the ubiquitousness of both fragrances and visual design elements in consumer products, the need to systematically evaluate the effectiveness of
olfactory-visual crossmodal correspondences beyond the laboratory setting could help improve product acceptance and influence consumer decision making. Consequently, this could improve product sales. Take, for example, the global sale of shampoo products, for which both fragrance and visual elements (e.g., product color, bottle shape, and label designs) are important. Companies like Procter & Gamble (P&G) and Unilever each recently had over $20 billion in annual net sales in their beauty/shampoo departments (P&G, 2013; Unilever, 2012). If the incorporation of crossmodal correspondences was found to improve shampoo sales by even just 0.5%, this would amount to an increase of $100 million.

The first aim of the present study was to determine whether crossmodal correspondences found between odors and visual shapes in the laboratory would occur when marketed shampoo fragrances (judged as either “angular” or “rounded” fragrances via the Bouba-Kiki shape scale) were paired with their congruent angular/rounded bottle and label designs. It is unknown whether these crossmodal (olfactory-visual) correspondences would be maintained when the products are scaled up to 2-dimensional or 2D (i.e., an image of a 3-dimensional shampoo bottle and label) and 3-dimensional or 3D (i.e., an actual shampoo bottle) stimuli that more closely resemble actual consumer products. For example, would a “rounded” shampoo fragrance be matched to rounded bottle and label designs? Crossmodal correspondences between visual shapes and odors were previously reported using either a list of abstract visual shapes (Seo, Arshamian, et al., 2010) or the Bouba-Kiki shape scale (i.e., Hanson-Vaux et al., 2013). In this study, it was hypothesized that similar crossmodal correspondences found between the marketed shampoo
fragrances and the Bouba-Kiki shape scale would be maintained as the shampoo bottle and label designs were scaled up in 2D and 3D products.

The second aim of the present study was to determine if naïve participants would match a shampoo fragrance that was previously judged as either a “rounded” or “angular” with its congruent bottle and label shape design determined by an overall preference elicitation method. An overall preference elicitation method was designed to force participants to select the best overall shampoo bottle design from two options when the degrees of shape angularity for both the shampoo bottle and label designs vary. For example, when participants are presented with a “rounded” fragrance, would they also select the best overall bottle design that has the most “rounded” features from various degrees of bottle and label shape angularity? It is currently unknown how participants would respond when both the angularity of the bottle and label designs are systematically presented ranging from rounded to angular. It was hypothesized in this study that the shampoo bottle and label design would be selected based on how well they fit to the congruent fragrances (i.e., those that were previously judged as either a rounded or angular fragrance).

The third aim of the present study was to better understand the mental processes that occur during the “first moment of truth” (FMOT) (Hui, Huang, Suher, & Inman, 2013; Inman, Winer, & Ferraro, 2009; Nelson & Ellison, 2005) experience in which a consumer in a retail store notices a shampoo bottle, opens the lid of the bottle, smells the fragrance, and compares the fragrance perception to his or her expectations. To simulate the FMOT, the current study employed a preference elicitation method in which participants were instructed to smell and match a
fragrance with the best bottle and label designs from two options as quickly as possible. In an attempt to measure the mental processes of selecting the best bottle preference, two measurement tools were used: reaction times and mouse/hand tracking. Reaction times, traditionally, was used a discrete measurement tool to assess preference (Freeman, Dale, & Farmer, 2011). For example, if a participant was presented with two pictures and told to select the mammal, then a pairing with a clear right answer (e.g., a dog and an ant) should result in a quicker reaction time than a pairing with an ambiguous answer (e.g., a whale and a kangaroo). Unlike reaction time, mouse/hand tracking allows for a continuous stream that captures the interaction between the mental processes and the motor outputs. One of the key features of mouse/hand tracking is the evidence of spatial attraction towards the alternative option before picking the correct option. Using the previous example about selecting the mammal picture, the spatial attraction to select the ant when paired with the dog should be low; conversely, the spatial attraction to select the kangaroo when paired with the whale should be high (Spivey, Dale, Knoblich, & Grosjean, 2010; Spivey, Grosjean, & Knoblich, 2005). By analyzing both the reaction time and the mouse/hand trajectories when determining the best overall bottle design, the data could reveal additional evidence of the influence of the angularity of the bottle and label design in the participants’ decision based on the smelled fragrance. It was hypothesized that there would be significantly quicker reaction times and a more direct trajectory when a shampoo fragrance was paired with very different shampoo bottle and label design from one another. For example, if both a rounded bottle and a rounded label were paired with an angular bottle and
an angular label, then there should be a quicker and a more direct trajectory for selecting the best overall bottle design. Conversely, when a shampoo fragrance is paired with two similar bottle and label designs, participants would have slower reaction times and a more indirect trajectory for selecting the best overall bottle design.

If the hypotheses from these three aims are confirmed, it could demonstrate the usefulness of using the Bouba-Kiki shape scale as a relatively simple and cost-effective predictive tool for selecting the best visual shape design of a future marketed product that involves concurrent olfactory and visual stimulus features.
Chapter 2: Experiment 1 – Three Bipolar Line Scales

In Experiment 1, participants smelled a series of marketed shampoo fragrances. The aim of the first experiment was twofold: 1) to replicate and extend previous findings of crossmodal correspondences between odor and visual stimuli and 2) select two fragrances (judged as either “angular” or “rounded” fragrances) to be used in the remaining experiments. First, Experiment 1 evaluated whether there were crossmodal correspondences between some of the fragrances and the angularity of shapes using the Bouba-Kiki shape scale. In addition, would there be any evidence of crossmodal correspondences between the fragrances and the angularity of both shampoo bottle and label designs judged on bipolar scales? It was hypothesized that these three scales (Bouba-Kiki shape scale, rounded/angular bottle scale, and rounded/angular label scale; see Figure 2.1) would significantly correlate between one another. Second, if crossmodal correspondence occurred, then the two best fragrances would be selected to be used in the remaining experiments by being rated as the most opposite based on the Bouba-Kiki shape, rounded/angular bottles, and rounded/angular label scales. It was hypothesized that the shampoo fragrances that are typically judged as floral and/or fruity would be rated as being significantly more rounded, while shampoo fragrances that are typically judged as musky or citrus would be rated as being significantly more angular (Crisinel & Spence, 2012b; Hanson-Vaux et al., 2013; Seo, Arshamian, et al., 2010).
Figure 2.1  a) the Bouba-Kiki shape (adopted from Hanson-Vaux et al., 2013), b) rounded/angular bottles, and c) rounded/angular label scales.

Method

Participants.

Due to the small effect sizes reported in previous research (Crisinel & Spence, 2012b; Hanson-Vaux et al., 2013), an a priori power analysis indicated that 160 participants would be needed to have 80% power for detecting a small effect size (Cohen’s $g = .10$) when employing a 0.10 alpha criterion for statistical significance. One hundred sixty adults (124 women and 36 men with an age range of 18-65 years) were recruited from an consumer acceptance screening research pool that consisted of consumers from the Greater Cincinnati region. All participants provided written informed consent and filled out a brief questionnaire providing basic demographic information (i.e., gender and age), shampoo usage history, and olfactory function history. Participants were included if they reported being generally healthy, normosmic, and used shampoo more than once a month. Participants were excluded if they noted as being allergic to cosmetic or fragrance ingredients, had asthma, were
not willing to smell multiple fragrances, or did not use a shampoo at least once a month.

**Fragrance stimuli and test apparatus.**

Sixteen marketed shampoo fragrances were initially selected in an attempt to create a wide variety of fragrant characteristics (e.g., floral, fruity notes) and included fragrances targeted to both men and women consumers. Twenty pilot participants completed a fragrance sorting task and were asked to sort each fragrance into one of three possible groups: rounded, angular, and neither/equal. Each pilot participant was presented with the Bouba-Kiki shape scale as reference for what a “rounded” and “angular” fragrance represented visually. An overall percentage association of 55% or more was used to classify each fragrance as either in the rounded or angular group. The data revealed that four fragrances met this criterion for the rounded group and four fragrances for the angular group. Four additional fragrances were included because they were found to not meet this criterion for either the rounded or angular group, and they are considered the “neither” group (see Table 2.1 for the pilot data. Note: Only the description of the fragrances are listed. In addition, each fragrance rated as either rounded or angular was ranked with the highest sorted labeled with a 1, e.g., R1 or A1, respectively).
Table 2.1  The sorted frequency (shown in percentages) among the angular, neither/equal, and rounded groupings for the 12 best fragrances from the sorting pilot test.

<table>
<thead>
<tr>
<th>Fragrance Label</th>
<th>Fragrance Description</th>
<th>Angular (%)</th>
<th>Neither/Equal (%)</th>
<th>Rounded (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>gourmand / aldehydic / creamy</td>
<td>10%</td>
<td>20%</td>
<td>70%</td>
</tr>
<tr>
<td>R2</td>
<td>fruity red / berry / floral</td>
<td>10%</td>
<td>30%</td>
<td>60%</td>
</tr>
<tr>
<td>R3</td>
<td>oriental / spicy / gourmand</td>
<td>20%</td>
<td>20%</td>
<td>60%</td>
</tr>
<tr>
<td>R4</td>
<td>fruity red / berry / floral</td>
<td>25%</td>
<td>15%</td>
<td>60%</td>
</tr>
<tr>
<td>N1</td>
<td>fruity orchard / peach / creamy</td>
<td>35%</td>
<td>20%</td>
<td>45%</td>
</tr>
<tr>
<td>N2</td>
<td>watery / ozone / floral</td>
<td>40%</td>
<td>25%</td>
<td>35%</td>
</tr>
<tr>
<td>N3</td>
<td>fruity lush / melon / green</td>
<td>40%</td>
<td>25%</td>
<td>35%</td>
</tr>
<tr>
<td>N4</td>
<td>citrus / lime / green</td>
<td>45%</td>
<td>20%</td>
<td>35%</td>
</tr>
<tr>
<td>A4</td>
<td>floral soft / aldehydic / floral</td>
<td>55%</td>
<td>25%</td>
<td>20%</td>
</tr>
<tr>
<td>A3</td>
<td>fougerie / green / musky</td>
<td>60%</td>
<td>15%</td>
<td>25%</td>
</tr>
<tr>
<td>A2</td>
<td>floral soft / aldehydic / woody</td>
<td>65%</td>
<td>10%</td>
<td>25%</td>
</tr>
<tr>
<td>A1</td>
<td>fougerie / green / musky</td>
<td>65%</td>
<td>15%</td>
<td>20%</td>
</tr>
</tbody>
</table>

The 12 fragrances were presented in a small plastic sealable tube (called a sorberad) that contains a cotton wick to which the fragrance oil was directly applied. Participants were instructed to position their noses approximately 1.0 cm away from the sorberad when smelling each fragrance. In addition, participants were prompted to both smell the fragrances and evaluate the fragrances by responding using custom software described below.

The test evaluation of the three scales was conducted using EyeQuestion® v3.12.0 (Logic8, The Netherlands). For each scale (see Figure 2.1), the angular and rounded shapes/bottles/labels anchored the ends of a 9-point scale. Each scale also included the option for participants to select a “Does Not At All Match” button if they thought neither anchor best matched the overall characteristics of the fragrance.

Procedure.

After completing the consent, demographic, and olfactory function history forms, participants sat in front of a computer screen and were instructed as follows:

Today, you are going to smell a series of fragrances and rate each fragrance on three different line scales. For each fragrance, sniff the fragrance for only
3 seconds and then answer the three line scales based on your gut reaction. After answering all three line scales, there will be an automatic 10 second wait before moving one to the next fragrance in an attempt to avoid smelling fatigue.

Figure 2.2 Depiction of the line scale.

The participants were then shown a demonstration line scale (see Figure 2.2) and told the following:

Mark on the line scale below where you think the scale best matches the overall characteristics of the fragrance you just smelled. If the fragrance best matches the “WOMAN” image on the left side of the screen, then mark on the line scale to the LEFT of center of the scale. If the fragrance best matches the “MAN” image on the right side of the screen, then mark on the line scale to the RIGHT of center of the scale. The closer the mark is to either side, the more you think the fragrance best matches the corresponding image. If the fragrance matches both images EQUALLY, then place a mark in the middle.
of the scale or at “5”. If the fragrance DOES NOT MATCHES EITHER image, then mark the “Does Not At All Match” box ONLY.

After answering any questions, participants started the experiment by smelling the assigned fragrance ad libitum for up to 3 s before answering all three scales serially. After answering the three scales with the first fragrance, the procedure repeated until all 12 fragrances were presented. The presentation order of the fragrances, scales, and which side (left or right) each bipolar pair was anchored on the scale was counterbalanced across participants. Finally, after smelling and evaluating all of the fragrances, the participants smelled each fragrance again and rated its hedonic characteristic on a 5-point Likert scale. The evaluation of the hedonic rating was necessary to ensure that the matching of the fragrances to the different types of angularity of the shapes/bottles/labels was not solely a consequence of how pleasant the fragrances were judged, e.g., all fragrances rated as unpleasant were also judged to be angular (Hanson-Vaux et al., 2013; Yeshurun & Sobel, 2010; Zarzo, 2008). This rating also ensured that the two fragrances selected for the remaining experiments would have similar hedonic ratings. The duration of Experiment 1 per participant was about 30 minutes.

**Data Analyses**

To determine if participants would rate each fragrances similar on the Bouba-Kiki shape scale as they would on the rounded/angular bottle and label scales, Pearson correlation tests were performed to determine if the three bipolar scales as a whole were related to one another. Significant correlations between all three scales would suggest that participants could transfer the same angular association seen
among the fragrances and the Bouba-Kiki scale to the 2D rounded/angular bottle and label designs. In addition, Pearson correlation tests were performed to identify the relationship between the three bipolar scales separately for each fragrance. The alpha level was set at 0.05.

To evaluate how each fragrance was rated on each of the three bipolar scales separately, the data was analyzed using one-sample $t$-tests. These $t$-tests determined if each fragrance was rated significantly different from the scale’s midpoint of “5”. A Bonferroni-corrected alpha value of 0.004167 (0.05/12 fragrances) was used. Finally, a two-sample $t$-test was used to determine whether the two fragrances revealed to be the most different from one another on all three bipolar scales also had similar hedonic scores.

**Results**

The Pearson correlation tests revealed that overall the three bipolar scales were significantly related to each other. The Bouba-Kiki shape scale was significantly related to rounded/angular bottle scale and rounded/angular label scale $r(1711) = .25, p < .01$, and $r(1707) = .67, p < .01$, respectively. The rounded/angular bottle scale was significantly related to the rounded/angular label scale, $r(1716) = .27, p < .01$. Additional Pearson correlation tests were conducted between the three bipolar scales across fragrances in an effort to see the impact of how each fragrance affected the relationship between the three scales (see Table 2.2). The correlations revealed that R1, R2, R3, and R4 (the four fragrances sorted as “round” in the pilot study) were all evaluated as significantly related across the 3 scales. Conversely, all three scales were significantly related to each other for A2 and A4, while A1 (the
fragrance sorted as “angular” most often in the pilot study) was evaluated as significantly related between the Bouba-Kiki shape and rounded/angular label scales only.

Table 2.2  Correlations between the three bipolar scales across fragrances. Note: * p ≤ .05, ** p ≤ .01.

One-way t-tests were conducted to assess which fragrances were significantly different from the scale’s midpoint (i.e., scale value of 5) for the Bouba-Kiki shape, rounded/angular bottles, and rounded/angular label scales. For the Bouba-Kiki shape scale, the following fragrances were judged significantly “Bouba”: R1 [t(146) = -4.80, p < .001, d = 0.40]; R4 [t(142) = -4.65, p < .001, d = 0.39]; N1 [t(146) = -4.39, p < .001, d = 0.36]; N3 [t(143) = -3.09, p = .002, d = 0.26]; and R2 [t(155) = -3.16, p = .002, d = 0.25]. The following fragrances were judged significantly “Kiki”: A1
\[ t(143) = 6.43, p < .001, d = 0.54 \] and A3 \[ t(150) = 5.04, p < .001, d = 0.41 \] (see Figure 2.3).

For the rounded/angular bottle scale, the following fragrances were judged significantly “rounded”: R1 \[ t(144) = -6.20, p < .001, d = 0.52 \]; N1 \[ t(149) = -4.50, p < .001, d = 0.37 \]; and N3 \[ t(146) = -4.10, p < .001, d = 0.34 \]. The following fragrances were judged significantly “angular”: A1 \[ t(143) = 5.90, p < .001, d = 0.49 \] and A3 \[ t(154) = 4.24, p < .001, d = 0.34 \] (see Figure 2.4).

Finally, for the rounded/angular label scale, the following fragrances were judged significantly “rounded”: R1 \[ t(146) = -4.40, p < .001, d = 0.36 \]; N1 \[ t(152) = -4.96, p < .001, d = 0.40 \]; and R4 \[ t(147) = -3.90, p < .001, d = 0.32 \]. The following fragrances were judged significantly “angular”: A3 \[ t(154) = 3.81, p < .001, d = 0.31 \] and A1 \[ t(140) = 3.41, p = .001, d = 0.29 \] (see Figure 2.5).

Figure 2.3 Bouba-Kiki shape scale results with five signifying the scale’s midpoint. Error bars represent the standard errors of the mean.
Figure 2.4  Rounded/angular bottle scale with five signifying the scale's midpoint. Error bars represent the standard errors of the mean.

Figure 2.5  Rounded/angular label scale with five signifying the scale's midpoint. Error bars represent the standard errors of the mean.

The hedonic ratings of each fragrance were recorded on a five-point scale with the endpoints of Dislike Very Much (-2) and Like Very Much (2). The results
show that all of the fragrances were rated as favorably liked with the exception of A1 and A2 being rated just below the neutral rating of Neither Like nor Dislike (0) (see Table 2.3).

<table>
<thead>
<tr>
<th>Fragrance Label</th>
<th>M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R4</td>
<td>0.97 (1.01)</td>
</tr>
<tr>
<td>R2</td>
<td>0.68 (1.10)</td>
</tr>
<tr>
<td>N1</td>
<td>0.64 (1.03)</td>
</tr>
<tr>
<td>R1</td>
<td>0.60 (1.17)</td>
</tr>
<tr>
<td>A3</td>
<td>0.44 (1.13)</td>
</tr>
<tr>
<td>N2</td>
<td>0.41 (1.08)</td>
</tr>
<tr>
<td>N4</td>
<td>0.34 (1.23)</td>
</tr>
<tr>
<td>R3</td>
<td>0.24 (1.13)</td>
</tr>
<tr>
<td>N3</td>
<td>0.19 (1.30)</td>
</tr>
<tr>
<td>A4</td>
<td>0.06 (1.32)</td>
</tr>
<tr>
<td>A1</td>
<td>-0.08 (1.35)</td>
</tr>
<tr>
<td>A2</td>
<td>-0.14 (1.39)</td>
</tr>
</tbody>
</table>

Table 2.3  Average fragrance hedonic score using a five point scale: Dislike Very Much (-2), Dislike Moderately (-1), Neither Like nor Dislike (0), Like Moderately (1), and Like Very Much (2).

Discussion

The results from Experiment 1 replicated and extended the previous findings of crossmodal correspondences between odors and visual stimuli. As previously demonstrated, certain fragrances were rated as being either angular or rounded based on the Bouba-Kiki shape scale, mirroring the previous results by Hanson-Vaux and colleagues (2013). They used 20 odors and found that only two odors were rated significantly different than the midpoint on the Bouba-Kiki shape scale for both the Bouba and Kiki shapes. The findings from Experiment 1 were able to also find significant differences from the midpoint on the Bouba-Kiki shape scale for five fragrances rated as Bouba or rounded and two fragrances rated as Kiki or angular. As demonstrated in other studies using the Bouba-Kiki shape scale (Crisinel & Spence,
2012b; Hanson-Vaux et al., 2013), not all the tested fragrances were rated significantly as either Bouba or Kiki. These findings reinforce the idea that certain fragrances, but not all, could consistently be segmented into groups as either “rounded” or “angular”. Furthermore, as predicted, the three scales correlated with one another suggesting that participants were willing to evaluate the fragrances similarly on the Bouba-Kiki shape scale as they would with both the rounded/angular bottle and label scales. This outcome suggests that participants could transfer the same angular association seen among the fragrances and the Bouba-Kiki scale to the 2D rounded/angular bottle and label designs.

Based on the results from Experiment 1, A1 and R1 fragrances were chosen to represent the angular and rounded fragrances, respectively, in Experiments 2 and 3. These choices were based on a number of reasons. First, based on the three scales, R1 was rated as the most rounded on all three scales. A1 was rated the most angular for the Bouba-Kiki shape and rounded/angular bottle scales, while it was the second most angular on the rounded/angular label scale. This outcome mirrors exactly the pilot results with these same two fragrances sorted the most often into their respective angularity category (see Table 2.1). Second, in terms of the correlations per fragrance, participants’ ratings for R1 were significantly correlated with all three scales, that is, participants rated R1 as rounded on all three scales. Participants’ ratings for A1, however, were only significantly correlated between the Bouba-Kiki shape and rounded/angular label scales. In order to test the impact of selecting the “Does Not At All Match” button on any one of the three bipolar scales, the correlations were re-run with each fragrance trial only included into the analysis if
participants rated the fragrance on all three scales. The Pearson $r$ values were only marginally affected with most decreasing their overall values. One downside to selecting these two fragrances is that A1 ($M = -0.08$, $SD = 1.35$) was rated significantly different than R1 ($M = 0.60$, $SD = 1.17$) based on their hedonic scores, $t(159) = 4.59, p < 0.001, d = 0.36$. Although A1 was rated overall as neutral, R1 was rated significantly more positive. Upon closer inspection, participants in this experiment rated the rounded fragrances more positively than the angular fragrances suggesting the possibility that hedonics could be a driver in selecting the angularity of the fragrances.

The two fragrances selected as either rounded or angular met the hypothesis that the rounded fragrance would be judged as floral and/or fruity and the angular fragrance would be judged as musky or citrus. The description of the dominant fragrance notes for R1 is gourmand/aldehydic/creamy, but the fragrance subjectively smelled like a vanilla-creamy and floral fragrance. Again, the description of the dominant fragrance notes for A1 is fougère/green/musky, but the fragrance smelled like equal parts musky and woody-grassy (see Table 2.1 for each fragrance’s description). With the previous research examining the crossmodal correspondence between visual stimuli and odors found in a wine training kit (e.g., blackberry, lemon, mushroom, etc. see Hanson-Vaux et al., 2013) or artificial odors (e.g., banana, parmesan cheese, pepper, etc. see Seo, Arshamian, et al., 2010), it is interesting that complex fragrances containing some essence of floral or musky notes can still drive the crossmodal correspondence relationships between the angularity of visual stimuli and odors.
Chapter 3: Experiment 2 – MouseTracker CA Procedure with 2D Bottles

The aims of Experiment 2 were to determine (1) whether the individual crossmodal correspondences found between R1 and A1 fragrances and the angularity of the shampoo bottle and label designs from Experiment 1 were still present when combined in 2D shampoo bottle designs, and (2) if the selection of the best overall bottle design, reaction times, and mouse trajectories were impacted by crossmodal associations between the shampoo fragrances and the angularity of the shampoo bottle and label designs. For both the R1 and A1 fragrances, naïve participants were presented with a series of 2D shampoo bottle designs (i.e., bottle and label designs) and were told to select as quickly as possible the best overall design in a two-option forced-choice preference elicitation procedure using a conjoint analysis (CA) paradigm. Unlike previous research, participants in Experiment 2 were forced to decide which angular shape of the shampoo bottle and label best fits the presented fragrance when the degree of angularity was systematically manipulated with each new bottle and label design pairings. The hypotheses were that crossmodal correspondences seen in Experiment 1 would again be observed, with participants preferring the best overall congruent bottle design relative to the presented fragrance, and with the congruent bottle design weighted more strongly than the congruent label design in the preference decision. For example, a combination of a rounded bottle with an angular label would be predicted as the preferred overall bottle design when paired with an angular bottle with a rounded label for the R1 fragrance. Furthermore, the matching of the fragrance with the overall congruent bottle design would result in quicker reaction time and a more direct response trajectory.
Method

Participants.

Using the same inclusion and exclusion criteria from Experiment 1, a new sample of 151 adults (85 women and 66 men with an age range of 18-65 years) was recruited from an early acceptance testing research panel that consisted of participants from the greater Cincinnati region. In order to conduct a CA, a minimum of 150 participants was needed (Orme, 2010b).

Fragrance stimuli and test apparatus.

The A1 and R1 fragrances from Experiment 1 were again presented in the sorberad tubes.

The 2-dimensional depictions of shampoo bottle and label designs were created from the Cubify® Design™ v15.0.2.15088 (3D Systems, Inc., Rock Hill, SC, U.S.A.), a 3D design software package (see Figure 3.1 for the bottle designs and see Figure 3.2 for the label designs). The bottle designs varied in similar incremental degrees of angularity, that is, the maximum widths (measured at 3.5 cm above the bottle’s base) for both the rounded and angular low, medium, and high bottle designs were 6 cm, 8 cm, and 10 cm, respectively. Likewise, the label designs varied in similar incremental degrees of angularity, that is, the maximum widths for both the rounded and angular low, medium, and high label designs were 3 cm, 4 cm, and 5 cm, respectively. Note that the high rounded and angular bottle and label designs were the anchors from the rounded/angular bottle and label scales from Experiment 1.
Figure 3.1  Shape of the bottles varying from rounded to angular: A) high rounded, B) medium rounded, C) low rounded, D) low angular, E) medium angular, & F) high angular.
Figure 3.2 Shape of the labels varying from rounded to angular: I) high rounded, II) medium rounded, III) low rounded, IV) low angular, V) medium angular, & VI) high angular.
MouseTracker (Freeman & Ambady, 2010), a computer mouse-tracking software package, was used to record both the temporal (reaction time) and spatial (trajectory of the mouse) response patterns as participants decided as quickly as possible which overall shampoo bottle design best fit the fragrance.

Due to time constraints, a full-profile conjoint analysis, in which participants evaluated every possible fragrance, bottle, and label combinations, was not feasible. Instead a fractional factorial design was employed which reduced the number of combinations into an orthogonal array, which is the optimal number of combinations that can best evaluate the main effects between the bottle and label designs for each fragrance. Using SPSS® v22.0 (IBM Corporation, Armonk, NY, U.S.A.), an orthogonal array was created based on fragrance (A1 vs. R1), presented side of the computer screen (left vs. right), bottle design (high angular, medium angular, low angular, low rounded, medium rounded, high rounded), and label design (high angular, medium angular, low angular, low rounded, medium rounded, high rounded). The orthogonal array output from SPSS yielded 15 pairings for the angular fragrance and 11 pairings for the rounded fragrance. In addition, four holdout pairings were created for each fragrance. The holdout pairings were included into the procedure to be evaluated by the participants but were not included in the CA. These holdout pairings were later used to measure how well the part-worth utilities from the CA model predicted the actual selections of the holdout pairings. For each fragrance, two holdout pairings were created by SPSS and two additional holdout pairings were created in order to assess the extreme design differences between bottle and label designs. For both fragrances, the first pairing was the high angular bottle and label
designs shown with the high rounded bottle label design, while the second pairing was the high angular bottle and high rounded label shown with the high rounded bottle and high angular label design. The resulting design had the participants evaluate 34 bottle pairings: 19 pairings for the angular fragrance and 15 for the rounded fragrance. These 34 bottle pairings were randomly presented to each participant. A limitation to the MouseTracker software was that the bottle design presented on the left side of the screen could not be randomly assigned to the bottle design presented on the right side of the screen by default. To rectify this, 6 different versions were created so that the bottle and label designs on the left side of the screen were randomly paired with bottle and label designs on the right side.

**Procedure.**

After completing the consent, demographic, and olfactory function history forms, participants sat in front of a computer screen. They were instructed that their task was to quickly decide which overall design (out of two options) best matched the overall characteristics of the smelled fragrance. The procedure for each trial started with participants prompt to “Get Ready” for 2000 ms. They were then prompt to “Sniff” for 3000 ms when participants sniffed ad libitum one of the two randomly assigned fragrances. Following the sniff cue, the bottle design pair was displayed. Participants used the MouseTracker software to make their selection of the overall bottle design (which included the bottle presented with a label) that they believed matched the fragrance best. Participants started with their mouse on the bottom center of the screen and then moved the mouse cursor to one of two bottle designs in either of the two top corners (see Figure 3.3). Finally, participants smelled each
fragrance again and rated its hedonic rating on a 5 point Likert scale. Each trial took about 10 s to complete. In an attempt to minimize sniffing fatigue and fragrance adaptation, researchers told the participants that they could take a break from smelling at any point during the experiment.

Figure 3.3  A screenshot of the start of a MouseTracker trial.

**Data Analyses**

**Conjoint analysis.**

As a preference elicitation method, CA allows researchers to examine the presumed dominant attributes (e.g., bottle and label designs) that could influence participants’ overall preference of the bottle design. Each dominant attribute (e.g., bottle design) is subdivided into different levels (e.g., high rounded, …, high angular), and participants are asked to select which of these different combinations of attribute levels are preferred. Based on participants’ selections, researchers can make inferences on preferences per attribute of a product that the participants experienced,
and can model estimated preferences for products that were not presented to the participants (Hensher, Louviere, & Swait, 1998).

Due to a small number of sample pairings per participant, a Hierarchical Bayes (HB) model was used for utility estimation using Choice-Based Conjoint (CBC)/Hierarchical Bayes software from Sawtooth Software, Inc. v8.4.4 (Orem, Utah, U.S.A.). The power of the HB model is that it has two levels: the lower level estimates the part-worth utilities of the participant, while the higher level incorporates the participant’s part-worth utilities with the population parameters. The assumption of the lower level is that the probability of part-worth utilities of each participant for selecting a particular attribute level conforms to the multinomial logit model (Orme, 2013). The HB model can be written as the following:

\[ p_k = \frac{\exp(x_k' \beta_i)}{\sum_j \exp(x_j' \beta_i)} \]  

(1)

where \( p_k \) equals the probability of a participant selecting the \( k^{th} \) concept of a particular choice task, \( x_k \) equals the selected concept, \( x_j \) equals the vector values of all remaining alternative concepts of the particular choice task, and \( \beta_i \) equals the vector of part-worth utilities for the \( i^{th} \) participant. This equation, phrased simply, captures what a participant’s probability would be when the selected concept utility is divided by all of the possible alternative concepts’ utilities (Orme, 2013).

The HB higher-level model assumes that the part-worth utilities of each participant has a multivariate normal distribution (Orme, 2013), and it can be written as the following:

\[ \beta_i \sim \text{Normal}(\mu, \Sigma) \]  

(2)
where $\mathbf{a}$ equals a vector of means of the distribution of the part-worth utilities of all participants and $\mathbf{D}$ is the matrix of variances and covariances of the distribution of the part-worth utilities of all participants (Orme, 2013).

The CBC/HB software performed 10000 preliminary draws in an attempt to find data convergence, then an additional 10000 draws were used to ensure stable part-worth utilities for each participant. These results were then imported into Sawtooth Software, Inc.’s SMRT (Suite of Marketing Research Tools) program to calculate the utility values of each attribute. To examine preferences, the purchase likelihood simulation was used as a measure to see how participants relatively ranked each bottle combination within the study. The optimization method used was exhaustive search which examines every possible combination of the different levels among the attributes (Orme, 2003).

The CA results were reported in terms of two different values. First, the average part-worth utilities demonstrate the contribution each level has within an attribute. Part-worth utilities are zero-centered differences scaled so that the sum of each level within an attribute equals zero, and part-worth utilities are interval data. Thus, as the magnitude of a positive part-worth utility value increases, it signifies a greater utility effect for that particular attribute level in comparison to the other alternative levels of that same attribute. Conversely, as the magnitude of a negative part-worth utility value decreases, it denotes a smaller utility effect for that particular attribute level in comparison to the other alternative levels of that same attribute (Orme, 2005).
The relative importance of each attribute, which is a percentage score, was calculated by taking the range of each attribute’s utility values and summing them to get the utility range total. Then, the utility range for each attribute is divided by the utility range total and multiplied by 100. Relative importance is ratio-scaled and should only be used to compare attribute relative to each other within the study. The relative importance of each attribute was calculated for each participant individually first before averaging the values across all participants (Orme, 2005).

**MouseTracker.**

The MouseTracker data focused on the four holdout pairings per fragrance for analyses since these were the only pairings that every participant evaluated across the six different test versions. All trajectories were rescaled onto a standard coordinate space with [-1.0, 0.0] corresponding to the bottom left corner and [1.0, 1.5] corresponding to the top right corner. The starting location of the mouse pointer was at [0.0, 0.0]. In order to compare trajectories fairly, all trajectories were remapped rightwards about the midline of the display area, resulting in the leftward trajectories being overlaid on top of the rightward trajectories. Since every trajectory varied in duration, each trajectory was normalized into 101 time steps using linear interpolation, i.e., creating the same 101 (x,y) coordinate pairs regardless of whether a participant’s trial lasted 800 ms or 3000 ms (Freeman & Ambady, 2010).

For each holdout pairing, a predicted preferred overall bottle design was determined based on how congruent its bottle and label combination was to the presented fragrance. A congruent bottle design was also given more weight than a congruent label design in the prediction. Furthermore, if neither of the overall bottle
designs were congruent with the presented fragrance (e.g., the bottle and label combinations for the pairings were angular when the presented fragrance was R1), then the bottle design that was closest to the congruent angularity (e.g., a medium angular bottle would be the predicted preferred design when paired with a high angular bottle for the R1 fragrance) would be selected as the predicted preferred overall bottle design. The following analyses were conducted based on the averaged trajectories across all participants between the predicted and unpredicted overall bottle designs for each holdout pairing.

In addition to capturing the mouse trajectory for each trial, the MouseTracker software was used to report the average spatial attraction and reaction times. Spatial attraction (i.e., the mouse trajectory towards the unselected alternative bottle design before clicking the selected bottle design) was measured by computing the maximum deviation (MD) and area under the curve (AUC). MD was calculated from the largest perpendicular deviation between the idealized straight trajectory (i.e., the straight trajectory from the start to the selected bottle design) and the actual trajectory out of all time steps. For example, as the MD value increases, the mouse trajectory would also increasingly bend towards the unselected bottle design. AUC was computed by the geometric area created between the mouse trajectory and the idealized straight trajectory (Freeman & Ambady, 2010). The MD and AUC values between the predicted and unpredicted overall bottle designs were compared by first submitting to Levene’s test for equality of variances and then followed by independent t-tests. The alpha level was set at 0.05.
Finally, the reaction times were calculated based on the total time between the start of the trial and clicking on the selected bottle design. Again, the reaction times between the predicted and unpredicted overall bottle designs were compared by first submitting to Levene’s test for equality of variances and then followed by independent \( t \)-tests. The alpha level was set at 0.05.

**Results**

**Hedonic ratings.**

The fragrances were recorded on a five-point scale with the endpoints of *Dislike Very Much* (-2) and *Like Very Much* (2). In this experiment, the hedonic ratings for A1 and R1 were rated overall as positive. Unlike in Experiment 1, A1 was rated as liked \((M = 0.44, SD = 1.34)\) instead of just below the neutral rating; while R1 was again rated as liked \((M = 0.95, SD = 0.89)\).

**CA results.**

The CA results were calculated from the 26 test pairings for each of the six different test versions. The remaining eight holdout pairings (four pairings with R1 fragrance and four pairings with A1 fragrance) were saved to test the HB model produced from the CA.

**Part-worth utilities.**

The average part-worth utilities are reported in Table 3.1. For the R1 fragrance, the best bottle design was the medium rounded with the high rounded a close second having only about 3 utility points difference between the two. The remaining bottle designs were not preferred when presented with the rounded fragrance. The worst performing bottle design was the high angular. The part-worth utilities linearly
increased at a similar rate for the bottle label designs starting with the low rounded, then medium rounded, and stopping with the high rounded label designed being the most preferred. Like the high angular bottle design, the high angular label design was the least preferred out of all of label bottle designs.

For the A1 fragrance, the best bottle design was the low angular and then linearly decreased at a similar rate to the medium angular and then the low rounded bottle design. The worst performing bottle design was the high rounded. The part-worth utilities for the label design was mixed in that the best label design were the high rounded label with the low angular label design as a close second. The only other preferred label design was the high angular. The medium rounded label design was the least preferred label design.

<table>
<thead>
<tr>
<th>Bottle Design</th>
<th>R1</th>
<th>A1</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Rounded</td>
<td>42.24</td>
<td>-51.99</td>
</tr>
<tr>
<td>Medium Rounded</td>
<td>45.31</td>
<td>-26.37</td>
</tr>
<tr>
<td>Low Rounded</td>
<td>-3.29</td>
<td>11.34</td>
</tr>
<tr>
<td>Low Angular</td>
<td>-27.40</td>
<td>36.75</td>
</tr>
<tr>
<td>Medium Angular</td>
<td>-12.24</td>
<td>23.14</td>
</tr>
<tr>
<td>High Angular</td>
<td>-44.62</td>
<td>7.14</td>
</tr>
<tr>
<td><strong>Importance</strong></td>
<td><strong>75.12%</strong></td>
<td><strong>76.94%</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Label Design</th>
<th>R1</th>
<th>A1</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Rounded</td>
<td>5.20</td>
<td>6.65</td>
</tr>
<tr>
<td>Medium Rounded</td>
<td>4.29</td>
<td>-9.84</td>
</tr>
<tr>
<td>Low Rounded</td>
<td>2.62</td>
<td>-3.46</td>
</tr>
<tr>
<td>Low Angular</td>
<td>-3.40</td>
<td>5.30</td>
</tr>
<tr>
<td>Medium Angular</td>
<td>-1.44</td>
<td>-0.39</td>
</tr>
<tr>
<td>High Angular</td>
<td>-7.28</td>
<td>1.75</td>
</tr>
<tr>
<td><strong>Importance</strong></td>
<td><strong>24.88%</strong></td>
<td><strong>23.06%</strong></td>
</tr>
</tbody>
</table>

Table 3.1 Average part-worth utilities and attribute importances for the R1 and A1 fragrances: Zero-centered differences. N = 151 participants.
**Attribute importance.**

To quantify the overall impact of an attribute on participants’ preferences of the best overall bottle design when presented with the assigned fragrance, the attribute’s importance was calculated from the attribute’s part-worth utilities. The attribute importance values reported for both R1 and A1 were very similar. As seen in Table 3.1, the bottle design attribute captured about 75% in the decision for both fragrances, while the label design attribute only captured about 25%. This outcome suggests that the bottle design has three times the impact in matching of the overall bottle design to the presented fragrance than does the label design.

**Choice likelihoods.**

Using overall bottle selections of each participant within the study, a prediction of the best bottle and label design combination can be computed. For the R1 fragrance, the best overall bottle and label design combination in predicting fragrance match preferences of participants was the medium rounded bottle and the medium rounded label combination with a choice likelihood of 83.01%. In fact, the top five best bottle and label design combinations all had the medium rounded bottle as the best bottle design choice, and all had the choice likelihood ranging from 83.01% to 80.86%.

For the A1 fragrance, the best overall bottle and label design combination in predicting fragrance match preferences of participants was the low angular bottle and the high rounded label combination with a 79.91%. Similar to the R1 fragrance, the top five best bottle and label design combinations all had the same bottle design of the low angular bottle, and all had the choice likelihood ranging from 79.91% to 73.95%. 
**CA model results.**

For each holdout pairings, a simulated overall bottle preference was conducted based on the created CA model using the remaining non-holdout pairings. The simulation results, called shares of preference, are typically reported as percentages that total 100 percent and are ratio scaled. For example, if 200 participants reported their bottle preference between two bottles and Bottle 1 had 45% shares of preference and Bottle 2 had 55% shares of preference, then the simulated results would suggest that 90 participants would prefer Bottle 1 and 110 participants would prefer Bottle 2. For this study, to compare the simulated results with the actual preference seen for each holdout pairings, the shares of preference was multiplied by the total number of participants (151) to get the simulated preferences (Orme, 2010a).

As seen in both Figure 3.4 (for R1 fragrance) and Figure 3.5 (for A1 fragrance), the CA model was only able to correctly predict the actual bottle preference selection half the time (i.e., the actual preference fell within
the 95% confidence interval), while the remaining predictions fell just outside of the confidence interval (with the noted exception of R1 Holdout 2). For R1, the model was able to correctly predict the two extreme holdout pairings (i.e., R1 Holdout 3 and R1 Holdout 4); however, for A1 the model was only able to correctly predict congruent extreme holdout pairing of A1 Holdout 3.

Figure 3.4 The actual preference count for each overall bottle design within each holdout pairing for R1 fragrance. In addition, the shares of preferences transformed into an estimated frequency count with the 95% confidence interval were included.
MouseTracker results.

The MouseTracker results focused on the eight holdout pairings (four pairings with R1 fragrance and four pairings with A1 fragrance) since these were the only pairings that every participant saw across the six different versions. For each holdout pairing, a predicted preferred overall bottle design was determined based on how congruent its bottle and label combination was to the presented fragrance with the congruent bottle design weighted more than the congruent label design in the prediction. Furthermore, if neither of the overall bottle designs was congruent with the presented fragrance (e.g., the bottle and label combinations for the pairings were angular when the presented fragrance was R1), then the bottle design that was closest to the congruent angularity (e.g., a medium angular bottle would be the predicted preferred
design when paired with a high angular bottle for the R1 fragrance) would be selected as the predicted preferred overall bottle design.

*Mouse trajectories.*

Figure 3.6-Figure 3.13 illustrate the averaged trajectories for both the *predicted* preferred overall bottle design (shown as green circles) and the *unpredicted* preferred overall bottle design (shown as red squares) for all eight holdout pairings. In addition, for both the predicted and unpredicted trajectories, each figure displays the total number of participant who selected the overall bottle design and the average reaction time in the inset.
Figure 3.6 Fragrance R1 Holdout Pairing 1: Green trajectory was medium rounded bottle and low angular label and red trajectory was low angular bottle and medium angular label. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).

Figure 3.7 Fragrance R1 Holdout Pairing 2: Green trajectory was low angular bottle and low rounded label and red trajectory was high angular bottle and low angular label. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).
Figure 3.8  Fragrance R1 Holdout Pairing 3: Red trajectory was high angular bottle and high angular label and green trajectory was high rounded bottle and high rounded label. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).

Figure 3.9  Fragrance R1 Pairing Holdout 4: Green trajectory was high rounded bottle and high angular label and red trajectory was high angular bottle and high rounded label. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).
Figure 3.10  Fragrance A1 Holdout Pairing 1: Red trajectory was high rounded bottle and medium rounded label and green trajectory was low angular bottle and low angular label. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).

Figure 3.11  Fragrance A1 Holdout Pairing 2: Green trajectory was low rounded bottle and high angular label and red trajectory was medium rounded bottle and medium angular label. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).
Figure 3.12  Fragrance A1 Holdout Pairing 3: Green trajectory was high angular bottle and high angular label and red trajectory was high rounded bottle and high rounded label. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).

Figure 3.13  Fragrance A1 Holdout Pairing 4: Red trajectory was high rounded bottle and high angular label and green trajectory was high angular bottle and high rounded label. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).
**Spatial attraction.**

To compare attraction of the predicted congruent bottle responses to the unpredicted congruent bottle responses, independent *t*-tests were conducted for both MD and AUC data. The MD for unpredicted bottle responses (*M* = 0.25, *SD* = 0.48) was not significantly different than for the predicted bottle responses (*M* = 0.20, *SD* = 0.38), *t*(531.91) = 1.64, *p* = .10, *d* = 0.14. The AUC for unpredicted bottle responses (*M* = 0.51, *SD* = 1.14) was significantly larger than for the predicted bottle responses (*M* = 0.35, *SD* = 0.84), *t*(500.83) = 2.41, *p* = .02, *d* = 0.22 (the MD and AUC values per holdout pairing are reported in Figure 3.14 for the R1 fragrance and in Figure 3.15 for the A1 fragrance). Even though the MD was not significantly different between the predicted and unpredicted bottle designs, the AUC was larger for unpredicted bottles. This outcome suggests that participants were attracted to the other bottle option to some degree and yet still selected the unpredicted bottle. Conversely, the lower AUC value for those who selected the predicted bottle design were less influenced by the other bottle design and moved the mouse directly towards the predicted bottle design.
Figure 3.14  The MD and AUC values for each bottle within each holdout pairing for the R1 fragrance. Error bars indicate the standard errors of the mean.

Figure 3.15  The MD and AUC values for each bottle within each holdout pairing for the A1 fragrance. Error bars indicate the standard errors of the mean.
**Reaction times.**

In a traditional bottle selection procedure, reaction time is the primary tool to assess if there was any interference between the angularity of the bottle/label designs and the presented fragrance in the selection of the best overall bottle design. An independent *t*-test was conducted to compare the predicted and unpredicted bottle selections. Although the expected trend was observed, the reaction time for unpredicted bottle responses ($M = 2380.72$ ms, $SD = 1045.90$ ms) was not significantly different than for the predicted bottle responses ($M = 2248.99$ ms, $SD = 1126.48$ ms), $t(1206) = 1.87$, $p = .06$, $d = 0.11$. The average reaction times per bottle per holdout pairing can be seen in Figure 3.6-Figure 3.13.

**Discussion**

The primary goal of Experiment 2 was to assess the strength of the crossmodal correspondences found in Experiment 1 between fragrances and the three line scales when using various degrees of angularity of bottle and label designs. As seen in Experiment 1, A1 and R1 were highly rated on the three line scales as either “angular” or “rounded,” respectively. Using an all-new pool of participants and only prompting them to match fragrances to the best overall bottle designs, the results revealed some supporting evidence that the crossmodal correspondences demonstrated in Experiment 1 also appeared in Experiment 2 via the CA and AUC results.

First, as predicted, participants best matched the R1 with a rounded bottle and a rounded label design. Based on the part-worth utilities from the CA, participants preferred only rounded bottle and label designs for R1 while none of the part-worth
utilities for either the angular bottle or label designs were positive. This outcome suggests that R1 was clearly preferred with a rounded bottle and label design. Conversely, the part-worth utilities results for A1 suggest that preferences of participants were mixed (see Table 3.1 for part-worth utilities). Focusing only on the bottle designs, the top two bottle designs preferred were angular (low and medium, respectively), but unlike R1, A1 had one rounded bottle (low) rated positively. This pattern continued as the most preferred label design preferred was the high rounded with the low angular a close second. Even with the original prediction that A1 would be matched best with both an angular bottle and label design, the fact that A1 was preferred best with the low angular bottle supports the existence of crossmodal correspondence for this fragrance given that the bottle design itself accounted for about 77% of the importance in the overall bottle design selection. Although not perfectly consistent, the CA results from Experiment 2 demonstrated that participants in general matched R1 and A1 with their respective congruent bottle and, to a lesser extent, label designs.

Second, as stated previously, the mouse trajectories can be seen as a proxy to a continuous stream of interaction between the mental processes and the motor outputs involved in decision making (Spivey et al., 2010, 2005). This interaction was best seen in the AUC results in particular for Holdout 4 for both R1 (see Figure 3.14) and A1 (see Figure 3.15). The Holdout 4 for both fragrances were the same in that the high rounded bottle and high angular label design was paired with the high angular bottle and high rounded label design. Since the CA confirmed the prediction that congruent bottle designs and fragrances would have more weight in selecting the
best overall bottle design than congruent label designs and fragrances, the large AUCs for the unpredicted bottles suggest that participants were influenced by the congruent bottle design and incongruent label design. Nevertheless, they selected the incongruent bottle and congruent label designs. For both A1 and R1, the AUCs for Holdout 4 were significantly larger for the unpredicted bottle design versus the predicted bottle design. Thus, the presence of crossmodal correspondence in the mouse tracking data is not evident in participants having a small AUC value for matching the fragrance with the congruent bottle design; rather it is evident in participants having a large AUC value for matching the fragrance with the incongruent bottle design. The large AUC value suggests that participants were drawn to selecting the congruent bottle before picking the incongruent bottle. This influence would not have been apparent by merely considering the choice response or reaction time data, which reinforces the utility of using the mouse-tracking protocol. Interestingly, when both bottle and label designs were either completely congruent or incongruent in their most extreme form, as is the case for Holdout 3 for both A1 and R1, the significant differences between the AUCs for the two bottle designs disappeared. These results, which include the CA outcome as stated above, can be considered as evidence that crossmodal correspondences occurred between the two fragrances and their congruent bottle and label designs.

A somewhat surprising result from this experiment was that reaction time and MD were not significantly different between the predicted and unpredicted overall bottle designs for the holdout pairings. Even under a variety of different bottle pairings, the differences in reaction times and MDs between the predicted and the
unpredicted overall bottle designs were not significant for the holdout pairings. There was one exception for the A1 Holdout 2 pairing. This pairing contained two rounded bottles (predicted design: low rounded bottle/high angular label; unpredicted design: medium rounded bottle/medium angular label), and the reaction time for the unpredicted design was greater than for the predicted design. This outcome suggests that participants who selected the unpredicted bottle design had a difficult time choosing the best overall bottle design though this only occurred with the A1 fragrance.

Finally, it is important to consider why some participants struggled to match the A1 fragrance to the angular bottle and label design. It could be possible that participants made their choices based on the bottle’s overall functionality (i.e., affordances; Gibson, 1979) and not on its angularity. For example, the angular bottle designs were potentially too novel and impractical of a design to be used as a shampoo bottle. If so, participants selected a rounded bottle more out of familiarity or usability traits rather than pairing the “angular” fragrance to an angular bottle. In the results of both the pilot study and Experiment 1, the bimodal nature of the A1 data being classified as both rounded and angular bottle and label designs was not evident. It is unclear if this was merely a result unique to this participant pool; it was therefore important to determine if that result persisted in Experiment 3, when participants were presented with these same bottle designs as 3D-printed bottles rather than as 2D pictures.
Chapter 4: Experiment 3 – Kinect Maximum Difference Procedure with 3D Bottles

The aims of Experiment 3 were to determine (1) whether the crossmodal correspondences found between R1 and A1 fragrances and the overall bottle designs from Experiment 2 would persist when implemented in 3D shampoo bottle designs, and (2) if the selections of the best overall bottle design, reaction times, and hand trajectories were impacted by crossmodal associations between the shampoo fragrances and the angularity of the shampoo bottle designs. Similar to Experiment 2, naïve participants were presented with a series of shampoo bottle designs (3D bottle prototypes were used rather than 2D images, however) and were told to select as quickly as possible the best overall design based on the presented fragrance in a two-option forced-choice preference elicitation procedure using a maximum difference scaling (MaxDiff) paradigm. A Kinect sensor for XBOX 360 was used to track the participants’ hands and captured their hand trajectories as they selected their preferred bottle design. The hypotheses were that crossmodal correspondences seen in Experiment 2 would continue in that participants would prefer the medium/high rounded bottle designs best for the R1 fragrance, while they would prefer the low angular bottle design best for the A1 fragrance. Furthermore, the hand trajectories, as seen with the mouse tracking trajectories, would be more direct to the predicted preferred bottle design than for the unpredicted preferred bottle design as captured in the AUC value. The execution of Experiment 3 was important to determine if the assumption that the effects found in 2D bottle designs would translate when incorporated into 3D bottle designs.
Method

Participants.

Using the same inclusion and exclusion criteria from Experiment 1, a new sample of 153 adults (106 women and 47 men with an age range of 18-65 years and 12 participants in total were left handed) was recruited from an employee acceptance screening research panel that consisted of employees from the Greater Cincinnati region.

Fragrance stimuli and test apparatus.

The two fragrances used in Experiment 2—R1 and A1—were again presented in the sorberad tubes.

In addition, the same shampoo bottle designs used in Experiment 2 were utilized, but in Experiment 3 the author used actual bottles printed by a 3D Systems, Inc. (Rock Hill, SC, U.S.A.) 3D printer. The printer utilized the stereolithography process in which a laser “prints” each layer of the bottle on the surface of the resin vat. After the creation of each bottle layer, the printer lowers the bottle slightly into the resin vat to make room for the next layer. The finished bottles are shown in Figure 4.1.

![Figure 4.1](image)

**Figure 4.1** Shape of the bottles varying from rounded to angular (order from left to right): high rounded, medium rounded, low rounded, low angular, medium angular, and high angular.
Finally, instead of tracking movements of a mouse, the Kinect for Windows camera sensor for XBOX 360 and SDK 2.0 software were used to track the hands of participants as they reached to grab the bottle design that they believed best matched the overall characteristics of the smelled fragrance. A basic Kinect program was written to record both the temporal (reaction time) and spatial (projection pathway of the mouse) response patterns as participants decided as quickly as possible which overall shampoo bottle design best fit the fragrance.

The Kinect software allowed the researcher to capture not only the x-, y-, and z-coordinate of participants up to 30 frames per second, but it also captured picture stills of the participant completing the task. In addition, the Kinect shows the researcher a skeleton representation of the participant to allow the researcher to see if the Kinect system is capturing the participant’s movement properly. Figure 4.2 illustrates what the researcher saw during each trial. Participants were deliberately pixelated in order to conserve computing processing power and memory to capture the task with the best frame rate possible.

Figure 4.2  Screenshot of the Kinect Software in action with the skeleton figure on the left mirrors the movement of the participant on the right.
Like Experiment 2, a fractional factorial design was again employed and the orthogonal array was created based on fragrance (A1 vs. R1), presented side of the participant (left vs. right), and bottle design (high angular, medium angular, low angular, low rounded, medium rounded, high rounded). The current study used only 6 bottle designs to reduce the experiment’s duration. The orthogonal array yielded 5 pairings for each of the two fragrances. In addition, 2 constant pairings were created for each fragrance: One pairing was high angular and high rounded bottles and the other pairing was low rounded and low angular bottles. Similar to the holdout pairings in Experiment 2, these constant pairings were given to every participant in the experiment. These constant pairings were used in the MaxDiff analysis. Thus, in total, participants evaluated 14 bottle pairings. These 14 bottle pairings were randomly presented to each participant using six different assigned orders.

Procedure.

The procedure was similar to Experiment 2. Instead of selecting the bottle designs on a computer, however, participants actively reached for one of the two bottles.

After completing the consent, demographic, and olfactory function history forms, participants sat down at the experimental table (see Figure 4.3 for the exact dimensions of the study setup and bottle positions). They were instructed that their task was to decide quickly which bottle design (out of two options) best matched the overall characteristics of the smelled fragrance. One of the two fragrances was presented per trial. The bottles were positioned on the table in front of the participants, one to the right and one to the left. Participants were prevented from
seeing the bottles between trials by a partition. The two bottles were switched after each trial by the experimenter positioned on the opposite side of the table next the Kinect camera.

![Setup from the participant’s point of view.](image)

Each trial started with participants being told to place their dominant hand on the taped rectangle at the edge of the table and to hold the edge of the partition with their non-dominant hand. Participants were then told to “Get Ready” and “Sniff” for up to 3 s during which they sniffed ad libitum. After sniffing, participants used their non-dominant hand to lower the partition in front of them and reached out to touch the best bottle design with their dominant hand. After the trial was over, participants
raised the partition, and the experimenter changed the bottles without the participants seeing the bottles.

The Kinect recording was initiated once the partition was completely lowered and was stopped after participants touched their bottle selection. In an attempt to minimize sniffing fatigue and fragrance adaptation, researchers told the participants that they could take a break from smelling at any point during the experiment.

Data Analyses

MaxDiff analysis.

The MaxDiff analysis was chosen because it could handle data that compared paired comparisons along one factor, as in this case, bottle designs. The CA used in Experiment 2 needed to have at least two factors to conduct the analysis; however the results from the MaxDiff analysis yield similar results to the CA. The MaxDiff algorithm is an analytic component, implemented using Sawtooth Software, Inc., that calculates the preference/importance scores across different bottle designs. Thus, for Experiment 3, the higher the importance scores were for a particular bottle design the more likely that participants preferred that bottle design when paired with the presented fragrance.

To calculate estimated participant-level scores, the MaxDiff algorithm used HB techniques via the multinomial logit model with the following equation:

\[ P_i = \frac{e^{U_i}}{\sum e^{U_{ij}}} \]  

where \( P_i \) equals the probability of a participant selecting the \( i^{th} \) item as best in an item set ranging from \( i \) through \( j \) items, and \( e^{U_i} \) equals the antilog of the utility of item \( i \).
Similar to the CBC/HB software in Experiment 2, the MaxDiff software performed 20000 preliminary draws in an attempt to find data convergence. Then, an additional 20000 draws were used to ensure stable average estimate for each participant’s score.

The MaxDiff results were reported in terms of three different values: Best count proportion, estimated best count proportion, and importance score. First, the best count proportion is the likelihood that an item when presented was selected as the best among the alternative options. For example, if the high rounded bottle was presented 10 times with the A1 fragrance and selected only twice, then the best count proportion would be 0.2.

To calculate the estimated best count proportion, the raw weights from the multinomial logit estimation were transformed using the following equation:

\[ \frac{e^{U_i}}{e^{U_i} + a - 1} \]  

(4)

where \( e^{U_i} \) equals the antilog of the zero-centered raw logit weight for item \( i \) and \( a \) equals the number of items per set shown (i.e., 2 bottle designs). Then, the transformed scores per participant per bottle design were averaged.

Finally, the importance scores were calculated using equation 4 above, but instead of averaging the individual scores, the transformed scores were rescaled to sum to 100, enabling ratio scaling. Thus, if the high rounded bottle design had a score of 5 and the low angular bottle design had a score of 10, then participants preferred the low angular bottle design twice as much as the high rounded bottle design (The MaxDiff System Technical Paper, 2013).
Hand tracking.

The hand tracking data focused on the two constant pairings per fragrance for analysis since these were the only pairings that every participant evaluated across the six different test versions. In order to visually compare the hand trajectories from Experiment 3 to the mouse trajectories from Experiment 2, the hand trajectories were normalized into 101 time steps and rescaled initially following the exact procedure described in Experiment 2.

After evaluating the initial results, two problems were identified with the collection of the Kinect data. First, the Kinect software used for this experiment used an interface that made it difficult to tell when the software was recording the trial. This unfortunately led to some trials not being fully captured, and for that reason 68 of the 612 the Kinect data trials were excluded from this experiment. Second, the Kinect camera occasionally experienced interference from other body segments when trying to track the motion of the reaching hand. The pattern of interference depended on the participant’s handedness and which bottle was selected. For example, if a right-handed participant reached (with the dominant right hand) for the bottle positioned to their left, the Kinect software would temporarily lose track of the right hand as it would pass in front the left hand. This interference resulted in the data suggesting that right-handed participants initially moved their hands to the right and then quickly back to the left after the camera re-acquired the right hand after resolving the interference. This interference did not occur for these same participants when selecting the bottle positioned to their right. The same type of interference occurred for left-handed participants when their left hand passed in front of their
right hand. Thus, this interference resulted in artifacts in the initial time steps of the trajectories for each bottle of each constant pairing (e.g., see Figure 4.4).

Since the initial trajectories for each of the bottle responses per bottle pairing per handedness were unreliable, the trajectories were processed in two ways. First, the trajectories were separated into only right-handed or left-handed participants to control for differences in interference based on handedness. The separation of the data based on handedness was needed since the Kinect camera could capture up to a 4 cm difference in the average starting x-coordinate position for left- and right-handed participants. In the Results, only data from the right-handed participants were presented because there was too few left-handed participants (12 in total).

In addition, as seen in Figure 4.4, some of the averaged trajectories did not start at zero on the x-axis. To correct for this, for each constant pairing the initial raw
time steps were deleted one time step at a time. Then, the new time steps were recoded again following the procedure stated in Experiment 2. The deletion of the initial time step was repeated until the averaged recoded x- and y-axis trajectories all had zeros within the first five time steps. These corrections eliminated the interference and maintained an equal number of time steps for all trials among each constant pairings; however, since the total number of recoded time steps varied between the right- and left-handed participants within the same constant pairings, the trajectory results were reported separately for each right- and left-handed participants.

For determining the predicted bottle per pairing, it was hypothesized that participants would select the angular bottle when the A1 fragrance was presented and select the rounded bottle when the R1 fragrance was presented. Both the AUC and MD were again reported using the same technique described in Experiment 2. The MD and AUC values between the predicted and unpredicted overall bottle designs were compared by first submitting to Levene’s test for equality of variances and then followed by independent t-tests. Finally, reaction times were calculated based on the total time between the partition being completely lowered and the touching of the bottle. Again, the reaction times between the predicted and unpredicted overall bottle designs were compared by first submitting to Levene’s test for equality of variances and then followed by independent t-tests. The alpha level was set at 0.05 for all statistical tests.
**Results**

**MaxDiff analysis results.**

For each of the six different test versions, the MaxDiff results were calculated from the 14 test pairings which included the four constant pairings (two pairings with R1 fragrance and two pairings with A1 fragrance) that all of the participants saw.

**Attribute-level importance.**

The MaxDiff model assessment reported very similar results to Experiment 2. To quantify the overall impact of the bottle design on participants’ preferences of the best bottle design when presented with the assigned fragrance, the bottle design attribute’s importance was calculated from the raw logit weights (*The MaxDiff System Technical Paper, 2013*). Table 4.1 reports the bottle design importance for both the R1 and A1 fragrance. An importance percentage of 16.7% for all 6 bottle designs would be the result if they were selected randomly. Thus, a percentage greater than 16.7% would signify participants preferred that particular bottle design greater than chance. When the R1 fragrance was presented, the medium rounded was the most preferred bottle with high rounded bottle a close second. In fact, these two bottle designs were preferred more than twice as much as any of the angular bottles when paired with R1 fragrance. For the A1 fragrance, the most preferred bottle design was low angular. The remaining bottle preferences for the A1 fragrance are captured first with the medium angular and then high angular bottle designs. Unlike Experiment 2, A1 results does not suggest some bottle preference spilling over in the rounded bottle design when using a percentage greater than chance as a preference threshold marker.
Table 4.1  Bottle design importances for the R1 and A1 fragrances. N = 153 participants.

<table>
<thead>
<tr>
<th>Bottle Design</th>
<th>R1</th>
<th>A1</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Rounded</td>
<td>24.72%</td>
<td>11.51%</td>
</tr>
<tr>
<td>Medium Rounded</td>
<td>25.34%</td>
<td>13.69%</td>
</tr>
<tr>
<td>Low Rounded</td>
<td>16.77%</td>
<td>15.62%</td>
</tr>
<tr>
<td>Low Angular</td>
<td>12.07%</td>
<td>23.34%</td>
</tr>
<tr>
<td>Medium Angular</td>
<td>11.13%</td>
<td>19.19%</td>
</tr>
<tr>
<td>High Angular</td>
<td>9.96%</td>
<td>16.65%</td>
</tr>
</tbody>
</table>

MaxDiff model result.

Similar to the shares of preference from Experiment 2, the MaxDiff analysis calculates the estimated best count proportion which allows the researcher to model the data with the actual results (The MaxDiff System Technical Paper, 2013). In Figure 4.5 and Figure 4.6, both the best count and estimated best count proportions are reported for R1 and A1 fragrances, respectively. Similarly to what was reported with the shares of preference in Experiment 2, the MaxDiff model was only able to correctly predict the actual bottle design preferences less than half of the time (i.e., the actual preference fell within the 95% confidence interval), although the estimated best count proportion does capture the overall trend in the data. For R1, the estimated best count proportions were close to the 95% confidence interval for the low rounded and all of the angular bottle designs, but overestimated the two most preferred bottle designs (the medium rounded and high rounded bottle designs). For A1, the estimated best count proportions were overall either within the 95% confidence interval or close to it for each of the bottle designs.
Figure 4.5  The best count proportions of each bottle design for R1 fragrance. In addition, the estimated best count proportions for each bottle design with the 95% confidence interval were included.

Figure 4.6  The best count proportions of each bottle design for A1 fragrance. In addition, the estimated best count proportions for each bottle design with the 95% confidence interval were included.
Hand tracking results.

As in Experiment 2, the hand tracking results focused on the 4 constant pairings (two pairings with R1 fragrance and two pairings with A1 fragrance) since these were the only pairings that every participant saw across the six different versions. The following hand tracking results only focused on the results from right-handed participants (for the left-handed participants’ results, see Appendix A for the trajectories of the constant pairings and Appendix B for the AUC and MD values).

Hand trajectories.

Figure 4.7-Figure 4.10 illustrate the averaged trajectories for both the predicted preferred bottle design (shown as green circles) and the unpredicted preferred overall bottle design (shown as red squares) for all four constant pairings. In addition, for both the predicted and unpredicted trajectories, each figure displays the total number of participants who selected the overall bottle design and the average reaction time in the inset.
Figure 4.7  Fragrance R1 Constant Pairing 1 (right-handed participants): Red trajectory was high angular bottle and green trajectory was high rounded bottle. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).

Figure 4.8  Fragrance R1 Constant Pairing 2 (right-handed participants): Green trajectory was low rounded bottle and red trajectory was low angular bottle. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).
Figure 4.9  Fragrance A1 Constant Pairing 1 (right-handed participants): Green trajectory was high angular bottle and red trajectory was high rounded bottle. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).

Figure 4.10  Fragrance A1 Constant Pairing 2 (right-handed participants): Red trajectory was low rounded bottle and green trajectory was low angular bottle. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).
**Spatial attraction.**

To compare attraction of the predicted congruent bottle responses to the unpredicted congruent bottle responses, independent *t*-tests were conducted for both MD and AUC data. The MD for unpredicted bottle responses (*M* = 0.08, *SD* = 0.06) was not significantly different than for the predicted bottle responses (*M* = 0.08, *SD* = 0.06), *t*(496) = 0.07, *p* = .95, *d* = 0.00. The AUC for unpredicted bottle responses (*M* = 0.24, *SD* = 0.17) was not significantly different than for the predicted bottle responses (*M* = 0.24, *SD* = 0.17), *t*(496) = 0.17, *p* = .86, *d* = 0.00 (the MD and AUC values per constant pairing are reported in Figure 4.11 for the R1 fragrance and in Figure 4.12 for the A1 fragrance). Unlike Experiment 2 where AUC for predicted bottle designs were statistically more direct to the bottle selection than the unpredicted bottle designs, no overall differences were found for the predicted and unpredicted responses based on the spatial attraction measures.
Figure 4.11  The MD and AUC values for each bottle within each constant pairing for the R1 fragrance for right-handed participants. Error bars indicate the standard errors of the mean.

Figure 4.12  The MD and AUC values for each bottle within each constant pairing for the A1 fragrance for right-handed participants. Error bars indicate the standard errors of the mean.
Reaction times.

An independent t-test was conducted to compare the predicted and unpredicted bottle selections. The reaction time for unpredicted bottle responses ($M = 1759.83$ ms, $SD = 719.22$ ms) was significantly slower than the predicted bottle responses ($M = 1604.22$ ms, $SD = 719.22$ ms), $t(496) = 2.29$, $p = .02$, $d = 0.22$. Upon closer inspection, the significant difference in reaction time between the predicted and unpredicted bottle designs was because of the A1 constant pairing 2 in which participants selected the low angular bottle faster than the low rounded bottle for the A1 fragrance. The average reaction times per bottle per constant pairing can be seen in Figure 4.7-Figure 4.10.

Discussion

The primary goal of Experiment 3 was to determine whether crossmodal correspondences found between R1 and A1 fragrances and the bottle designs from Experiment 2 would persist when implemented in 3D shampoo bottle designs. The overall results from the MaxDiff analysis suggest that indeed the crossmodal correspondences seen in Experiment 2 continued with participants again preferring rounded bottle designs for the R1 fragrance while preferring angular bottle designs for the A1 fragrance. What was remarkable about Experiment 3 was how similar the preferred bottle designs for each fragrance were to Experiment 2. An independent sample of participants clearly matched R1 with either the medium or high rounded bottle, while participants matched A1 with either the low or medium angular bottle (see Table 4.1), closely replicating the results of Experiment 2 (see Table 3.1).
However, unlike in Experiment 2 where the results suggested that there was some preference among participants for the low rounded bottle with A1, participants in Experiment 3 did not show any preference for any rounded bottle designs. This could be due to a number of factors. First, this experiment utilized a different set of participants, so this difference (despite the other similarities in the results) could merely reflect idiosyncrasies of the two samples. Second, as proposed in the Discussion of Experiment 2, the preference for the low rounded bottle for the A1 fragrance could be the result of participants’ sensitivity to the functional properties or affordances (Gibson, 1979) of the bottles as determined by their shapes. To elaborate, the bottle’s angularity could make it harder to grasp the bottle. This usability argument, however, was not supported in Experiment 3 because participants were able to actually grasp the bottle when selecting their preferences. Given that participants were able to grasp their preferred bottle design for each bottle trial, this explanation would lead to the expectation that participants would have selected the low rounded bottle more often as their preferred bottle design. However, this did not occur for the A1 fragrance. Furthermore, upon closer examination of the choice likelihoods from the CA in Experiment 2, the results did show that the 12th-best bottle design was the low rounded bottle and the low angular label combination when paired with the A1 fragrance. This was the first bottle/label combination that did not include either the low or medium angular bottle design as the best. Therefore, in the absence of any evidence that participants preferred the low rounded bottle design with A1 in Experiment 3, the speculation that participants selected the low rounded bottle design for A1 based on the bottle’s functional properties may not be supported.
by the data; it may have instead occurred because the low rounded bottle design was paired with angular labels.

The second aim of Experiment 3 was to determine if the crossmodal associations between the shampoo fragrances and the angularity of the shampoo bottle designs impacted the selections of the best overall bottle design, reaction times, and hand trajectories. The results based on the Kinect data were unclear. The interference observed in the trajectories when the reaching, dominant hand passed in front of the resting, non-dominant hand complicated the interpretation of results, and suggests that the Kinect methodology may not be robust enough to use in consumer research of this type without further investigation of the experimental task and procedure. The Kinect was utilized in Experiment 3 as a quick and cost-effective hand tracking sensor, but it may be more error-prone than other, more expensive motion capture hardware. It has been reported that the typical spatial error of skeletal tracking for general poses with the Kinect is about 10 cm (Han, Shao, Xu, & Shotton, 2013). Considering that the maximum width between the two bottles was only 16 in, this relatively low degree of resolution could have a profound impact on the accuracy and precision of the hand trajectory measurements.

The interference of the dominant hand with the non-dominant hand occurred during the initial decision process in which the dominant hand moved from rest to either the left or right as participants reached for the preferred bottle. Having to delete the initial time steps may have limited the sensitivity of the hand tracking method in this experiment. Most of the spatial attraction to the unselected bottle occurred in the beginning to middle time steps of the trajectories in Experiment 2.
Furthermore, unlike the mouse tracking procedure in Experiment 2, participants in Experiment 3 were more deliberate in their selection of their preferred bottle. Even with the participants repeatedly told to make a bottle selection as quickly as possible during the instructions, they were not willing to start reaching for a bottle until they had seemingly selected their preferred bottle first. This procedural characteristic led to very few deviations from participants’ initial preferred bottle selections mid-reach. These mid-reach switches were more common in Experiment 2. Despite that, the overall reaction times between the predicted and unpredicted bottles in Experiment 3 were significantly different with participants selecting the predicted bottles faster than the unpredicted bottles. With only A1 constant pairing 2 showing evidence of this difference and with Experiment 2 showing no statistical difference between the predicted and unpredicted bottles, the exact nature of how reaction times play a role in crossmodal correspondence between these fragrances and visual cues remains unclear. Despite these issues with the Kinect system and unclear reaction time results, crossmodal correspondences between the fragrances and the bottle designs were still evident in the MaxDiff analysis.
Chapter 5: General Discussion

The results of the three experiments expand our understanding of how crossmodal correspondences occur between olfactory and visual stimuli throughout the shampoo packaging design stages. In particular, this series of experiments provides evidence of crossmodal correspondence remaining relatively constant over a variety of different tasks using the same fragrances. First, evidence of crossmodal correspondence between the fragrances and visual stimuli was seen in the pilot study prior to Experiment 1. Twenty participants on the basic sorting task were able to agree that some of the presented fragrances were either “rounded” or “angular” when using the Bouba-Kiki shape scale as a visual reference for what a “rounded” and “angular” fragrance represented. In Experiment 1, the fragrances—R1 and A1—that were sorted most often as either rounded or angular in the pilot study were again judged as being rounded or angular, respectively, via bipolar line scales anchored by either shapes, bottles, or labels. In Experiment 2, participants consistently paired the R1 and A1 fragrances with their congruent (i.e., rounded and angular, respectively) 2D bottle designs on a forced-choice preference elicitation task. In Experiment 3, participants again paired the R1 and A1 fragrances with their congruent 3D bottle designs. Thus, these three experiments illustrated four different methods that assessed crossmodal correspondences among a set of fragrances and visual stimuli either explicitly (i.e., sorting task and bipolar line scales) or implicitly (i.e., preference elicitation with 2D and 3D bottle designs) where participants in general preferred the R1 fragrance as rounded and the A1 fragrance as angular in each experiment.
The results from these three experiments add additional support to previous findings regarding the existence of crossmodal correspondence between some fragrances and visual stimuli (i.e., shapes, pictures, and designs) (Crisinel & Spence, 2012b; Demattè, Sanabria, & Spence, 2006, 2009; Deroy, Crisinel, & Spence, 2013; Gottfried & Dolan, 2003; Seigneuric, Durand, Jiang, Baudouin, & Schaal, 2010; Seo, Roidl, Müller, & Negoias, 2010; Stevenson, Rich, & Russell, 2012). In particular, the outcome that participants matched R1 (a vanilla-creamy and floral fragrance) to rounded shapes and bottle designs while they matched A1 (a musky and woody-grassy fragrance) to angular shapes and bottle designs align with previously reported results from Seo and colleagues (2010) and Hanson-Vaux and colleagues (2013). These two different research teams each reported evidence that a vanilla odorant was evaluated as rounded with Seo and colleagues (2010) reporting that participants paired vanilla to circle- or curve-shaped abstract symbols and with Hanson-Vaux and colleagues (2013) reporting that participants significantly judged vanilla as rounded based on the Kiki/Bouba line scale. Their findings that a vanilla odorant was perceived as being rounded were replicated in each of these three experiments even though R1 contained other distinctive fragrance notes in addition to vanilla. Furthermore, Hanson-Vaux and colleagues (2013) evaluated a musk odorant, which was evaluated as angular based on the Kiki/Bouba line scale, but the mean score was not significantly different than the scale’s midpoint. Their finding of evidence that participants tend to rate a musk odorant as angular was supported in the current series of experiments since A1 also contained a musky fragrance note.
In addition the fragrance preference elicitation procedure in all experiments, Experiment 2 and 3 captured reaction times and included a mouse/hand tracking manipulation as an alternative methodology to investigate whether crossmodal correspondence would occur between the fragrances and the bottle designs. As seen in other crossmodal correspondence research for some time now, reaction times can be impacted negatively when one sensory stimulus is paired with another inconsistent stimulus. For example, reaction times increase when participants have to quickly determine the elevation of a visual stimulus in conjunction with a task-irrelevant low pitch sound (e.g., Bernstein & Edelstein, 1971; also see, Evans & Treisman, 2010) or when participants have to read a series of color printed words (e.g., “red”) with inconsistent ink-colors (e.g., “blue”) (i.e., Stroop effect, Stroop, 1935). The reaction times reported for the predicted and unpredicted bottles were not found to be significantly different in Experiment 2 but were in Experiment 3. However, when looking at each individual bottle pairing, participants selected the predicted, low angular bottle faster than the unpredicted, low rounded bottle for the A1 constant pairing 2 which was the reason for the difference in the overall reaction times for the predicted and unpredicted bottles.

Unlike the evidence illustrated in the fragrance preference elicitation tasks, there are at least two possibilities on why reaction times were not an important predictor of the occurrence of crossmodal correspondence in Experiment 2 and 3. One possible reason was that holdout bottle pairings in Experiment 2 and the constant bottle pairings in Experiment 3 were fairly different from one another (e.g., a holdout pairing in Experiment 2: the high rounded bottle and high rounded label
combination paired with the high angular bottle and high angular label combination; and a constant pairing in Experiment 3: the high rounded bottle paired with the high angular bottle). If the bottle pairings were very similar to one another (e.g., the high rounded bottle paired with the medium rounded bottle) then perhaps the reaction times would be different between the predicted and unpredicted bottle designs particularly if the degree of differences between the two bottles occurred on a transitional boundary of what is a preferred bottle design. In fact, there is some evidence that this may be true. The one significant constant pairing 2 for A1 in Experiment 3 had a low angular bottle paired with a low rounded bottle, and one holdout pairing 2 for A1 in Experiment 2 had the low rounded bottle and high angular label combination paired with the medium rounded bottle and medium angular label combination.

Another possibility why reaction times were not strongly predictive of crossmodal correspondence was that reaction times in those earlier studies were more dependent on the interaction of a strong mismatch with previously learned associations, resulting in interference between controlled and automatic processing. For example, as noted earlier, the Stroop effect is seen when there is a mismatch between a color hue paired with the color word, thus increasing reaction times because participants must ignore the visual attribute (hue) and engage slower, more controlled processing to read the color words. The connections between color hue and color name are probably much stronger than associations of certain odors or fragrances to visual stimulus attributes such as shapes, although there is some
evidence of strong associations between odors and other visual attributes such as color (e.g., Demattè et al., 2006).

The AUC values between the predicted and unpredicted bottle designs were significant in Experiment 2 but not the MD values. The fact that the AUC values were overall significantly smaller for the predicted bottle designs than for the unpredicted bottle designs points to additional evidence that crossmodal correspondence occurred—participants who selected the unpredicted bottle were attracted slightly to the predicted bottle design during the response but not with sufficient magnitude to alter the MD values between the two bottle designs. Furthermore, the differences in AUC values were not the result of only one holdout pairing as seen in the reaction time results but resulted from three different pairings. What is interesting about this finding was that the significantly different AUC values occurred with very different bottle designs. Out of hindsight and similar to what was discussed in the reaction time section above, I would assume that any differences seen between bottle designs on AUC would occur when there were only subtle differences between the two bottles. When the most extreme examples of each bottle were presented (e.g., holdout pairing 1 for A1 in Experiment 2: the high rounded bottle and medium rounded label combination paired with the low angular bottle and low angular label combination), then participants should quickly select their preferred bottle design without being influenced by the opposite bottle (i.e., in angularity). This, however, was not always the case based on the Experiment 2 data. AUC values were sensitive enough to see the attraction participants had for the unselected predicted bottle designs. That some participants were attracted to the
unselected predicted bottles would suggest that there were some sort of attribute design that competed with participants’ bottle selections (Freeman et al., 2011; Spivey et al., 2005). The implication of this finding is that differences in AUC values could work in tandem with the preference elicitation tasks in Experiment 2 and 3 to better understand the crossmodal correspondences. The preference elicitation task illustrates which overall bottle design participants preferred between two options, while a significant difference in AUC values between the two options would suggest that there might be competing attributes that require further investigation.

The present results have some important implications in terms of marketing particular fragrance-scented products. For example, the fragrance preference elicitation tasks from Experiment 2 and Experiment 3 clearly suggest that participants preferred A1 in a low angular bottle. Knowing that A1 fragrance is a combination of musky and woody-grassy notes, the author was able to find other examples of the similar fragrances in the marketplace and subjectively determine if their bottle designs matched the reported expectations. Focusing on fragrances with a predominate musk note, Old Spice® and AXE® both have a men’s 2-in-1 shampoo and conditioner and a men’s body wash with a musk fragrance note (see Figure 5.1).
The Denali fragrance from Old Spice® and the Dark Temptation fragrance from AXE® both incorporate a musky note just as the A1 fragrance did. (Note: The Old Spice® shampoo/conditioner bottle example (A) should be depicted as containing the Denali fragrance and not Wolfthorn. Old Spice® does not currently sell this fragrance variation although this current bottle design is an accurate representation of what is sold in store presently.) The shampoo/conditioner designs from Old Spice® and AXE® incorporate few angular elements and their overall bottle designs are rounded/curvy. Both body wash designs contain some angular accent lines either on the front bottom of the bottle (i.e., Old Spice®) or lines on the sides of the bottle (i.e., AXE®), yet the overall bottle designs for both body washes are rounded/curvy. If in fact the main perceived fragrance driver for both the consumers of these Old Spice® and AXE® products and the participants of these experiments is the musky note, then this presents an opportunity for both brands to incorporate a more angular bottle design in order to potentially increase the consumer’s experience with the product as a coherent one. Based on the present results, however, the amount or degree of angularity to incorporate is unclear. Perhaps the correct amount is between the rounded shampoo/conditioner bottle designs that incorporated no angular lines or accent and the rounded body wash bottle designs that incorporated some angular
accent lines. Having a better understanding of whether or not these bottle designs present a mismatch in consumers’ expectations needs further research. Rectifying this potential mismatch could increase consumers’ overall hedonic preference and desire to purchase the product (Spence, 2012).

It is important to acknowledge that the research presented here is just one facet in understanding how crossmodal correspondences impact consumers’ product expectations. The current results suggest that companies should take a holistic approach into selecting the best packaging design (i.e., shape, texture, weight, color, label font, etc.) in order to aid consumers in understanding the essence of the brand (Calder & DuPuis, 2010; Walker, 2012). It would be interesting to utilize this holistic approach with the same two fragrances—R1 and A1—following the same procedural design from the present project but with other sensory modalities. Would similar significant crossmodal correspondence result occur, for example, when evaluating these fragrances along with various textures (Demattè, Sanabria, Sugarman, & Spence, 2006), hues (Demattè, Sanabria, & Spence, 2006; Gatti, Bordegoni, & Spence, 2014; Gilbert et al., 1996), labels (Becker, van Rompay, Schifferstein, & Galetzka, 2011; Crisinel & Spence, 2012b), typefaces (Velasco, Salgado-Montejo, Marmolejo-Ramos, & Spence, 2014), and brands integrated in the bottle designs? It may be an idea in designing the best bottle to incorporate as many congruent crossmodal correspondences to maximally align with consumers’ overall expectations of what the product is.

In conclusion, the results from the current series of experiments yielded strong evidence that crossmodal correspondence between fragrances and the
angularity of shapes and bottle designs occurred. More importantly, the results reported here represent the first evidence that correspondences remained relatively consistent across different bottle design procedures and across multiple naïve participants.
References


Appendix A: Hand trajectories for the left-handed participants

Figure 0.1  Fragrance R1 Constant Pairing 1 (left-handed participants): Red trajectory was high angular bottle and green trajectory was high rounded bottle. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).

Figure 0.2  Fragrance R1 Constant Pairing 2 (left-handed participants): Green trajectory was low rounded bottle and red trajectory was low angular bottle. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).
Figure 0.3  Fragrance A1 Constant Pairing 1 (left-handed participants): Green trajectory was high angular bottle and red trajectory was high rounded bottle. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).

Figure 0.4  Fragrance A1 Constant Pairing 2 (left-handed participants): Red trajectory was low rounded bottle and green trajectory was low angular bottle. The averaged reaction time per bottle is reported in the inset (error bars indicate the standard errors of the mean).
Appendix B: Spatial Attraction for the left-handed participants

Figure 0.5  The MD and AUC values for each bottle within each constant pairing for the R1 fragrance for left-handed participants. Error bars indicate the standard errors of the mean.

Figure 0.6  The MD and AUC values for each bottle within each constant pairing for the A1 fragrance for left-handed participants. Error bars indicate the standard errors of the mean.