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Do Visual-Olfactory Associations Strengthen the Real-Object Preference?

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Abstract

Current knowledge of human object perception relies heavily on studies using images as proxies for real objects. However, real objects are fundamentally different from images. For example, real objects have multisensory properties while images do not. Given that research shows that people look longer at real objects than images of objects, known as the *real object preference*, and that people look longer at objects when they are presented along with an associated smell, the present pilot study aimed to assess whether visual-olfactory associations contribute to the *real-object preference.* The present study used a within-subjects design including four participants. Participants viewed a real object alongside an identical image of the object while presented with either a congruent odor (e.g., viewed orange and smelled orange), incongruent odor (e.g., viewed orange and smelled coffee), or neutral odor (e.g., viewed orange and smelled odorless air). Participants' eyes were tracked using an eye tracker as they viewed the objects, and the percent looking time at the real object was analyzed. Preliminary results suggest that participants looked more at the real object than the image in the neutral odor condition, replicating the *real-object preference*. Further, the results demonstrated a trend in which congruent odors maintained the *real-object preference* while incongruent odors decreased the *real-object preference.* Prior to future data collection, researchers should focus on refining the current experimental design.

Keywords:

real-object preference, real-object advantage, vision, olfaction, visual-olfactory associations, eye-tracking

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Do Visual-Olfactory Associations Strengthen the *Real-Object Preference*?

Human perception evolved in an environment comprised of real objects (Norman, 2002). Despite this, our current knowledge of human object perception relies heavily on studies using images as proxies for real objects. Recent research has revealed that people process and behave toward real objects differently than images of objects (e.g., Bushong et al., 2010; Carver et al., 2006; Gerhard et al., 2016; Gomez et al., 2018; Marini et al., 2019; Schumacher, 2017; Snow et al., 2001; Snow et al., 2014). This research suggests that there is a *real-object advantage* and that images are not ecologically valid stimuli. Nonetheless, the reason why real objects elicit an advantage over pictures remains uncertain.

There are at least three fundamental distinctions between real objects and images that may contribute to this *real-object advantage*. First, real objects are tangible and, therefore, provide the potential for interaction. In contrast, images of objects do not afford the potential for interaction—for example, one would not expect to grasp a coffee cup that is pictured in a magazine. Second, real objects provide binocular depth cues. Each eye receives slightly different information regarding the location of an object; the disparity in location perceived by each eye is referred to as binocular disparity (Blake & Wilson, 2011). Through this disparity, the brain processes the depth of an object (Blake & Wilson, 2011). Images are two-dimensional, and therefore, through binocular disparity, are recognized as flat. Finally, and most pertinent to the present study, real objects can be explored with each of our senses. For example, many real objects emit odors and sounds, and can be touched and tasted. Images of objects, however, can only be explored visually and do not have other multisensory properties. Therefore, the broad purpose of the present study was to evaluate whether the multi-sensory properties of real objects contribute to the *real-object advantage*.

The *Real-Object Advantage*: Neural Processing of Real Objects and Images

Neural differences in the processing of images and real objects can be seen early in development (Carver et al., 2006). Specifically, one study found that 18-month-old infants differentiated between novel and familiar objects faster when the objects were presented as real objects than as images (Carver et al., 2006). The researchers suggested that the visual richness of real objects makes them easy to process. Images, however, need to be represented as real objects with multisensory properties, which take longer for the brain process (Carver et al., 2006).

Moreover, a gradual decrease in brain activation has commonly been found after the recurrent presentation of uniform images—a phenomenon known as functional magnetic resonance imaging (fMRI) adaptation (Grill-Spector et al., 1999). In contrast, FMRI adaptation does not similarly occur with the repetitive presentation of uniform real objects (Snow et al., 2001). This lack of adaptation might be due to the fact that real objects are more visually interesting than images, have a richer range of multisensory properties, or afford interactions (Snow et al., 2001). Indeed, the potential to interact with real objects may be one factor that contributes to differences in the processing of real objects and images (Marini et al., 2019). Based on the idea that real objects afford the potential for interaction, researchers recorded electroencephalography (EEG) while participants viewed real graspable objects compared to images of objects. They found that viewing real objects resulted in stronger and prolonged action-related brain responses compared to viewing images of objects (Marini et al., 2019).

In sum, real objects and images are processed differently at the neural level. This research suggests that studies using images of objects to investigate human vision are not equivalent to those using real objects.

***The Real-Object Advantage*: Behaviour Toward Real Objects and Images**

Not only do people process real objects and images differently, but they also behave toward them differently. Specifically, people are willing to pay more for an object when it is displayed as a real item compared to when it is displayed as an image (Bushong et al., 2010; Romero et al., 2018). Similarly, people pay more attention to real objects than images of objects (Gomez et al., 2018). Further evidence of a distinct advantage for real objects over images is apparent in our memory performance (Snow et al., 2014). When people are presented with everyday household items, they show superior recall for items that had been displayed as real objects as opposed to images (Snow et al., 2014). Thus, the format an object is presented in plays a substantial role in our value judgments, in capturing our attention, and in our memory performance.

Another component of the *real-object advantage* (the neural processing and behavioural advantages of real objects) and the most important to the present study, involves looking preferences. Previous research has discovered that infants tend to spend more time looking at real objects than they do images (Gerhard et al., 2016). To determine whether this effect was also present in adults, Schumacher (2017) used a preferential looking paradigm which examined participants' eye movements in an eye tracker. Schumacher presented adults with one image and one real object in pairs of stimuli (orange and peach, coffee and hot cocoa, or vanilla and cinnamon). She found that participants spent more time looking at the real object than the image, regardless of the stimuli. Schumacher concluded that people prefer real objects to images, or in other words, that her results were an indication of a *real object preference.*

What Factors Contribute to the *Real-Object Preference*?

Each of the three fundamental differences between real objects and images – the potential for interaction, binocular depth cues, and multisensory properties – could contribute to the *real-object preference.* Previous research has demonstrated that the potential for interaction plays a role in the *real-object advantage* and therefore, likely would play a role in the *real-object preference* (Bushong et al., 2010; Gomez et al., 2018; Marini et al., 2019). For example, when a real object is placed behind a transparent barrier, such that there is no potential for interaction, people's willingness to pay for a real object becomes comparable to images (Bushong et al., 2010). Similarly, when a real object is placed behind a transparent barrier, people pay equal attention to real objects and images (Gomez et al., 2018).

Research also suggests that binocular depth cues play a role in the *real-object advantage*. When a patient with visual agnosia was presented with a real object and a line drawing within arm's reach (enabling binocular disparity to convey depth), he was able to identify the real object better than the line drawing (Chainay & Humphreys, 2001). However, when the real object was presented beyond arm's reach (to reduce binocular depth cues), the patient was no better able to identify the real object than the line drawing. Based on this research, binocular depth cues may play a role in the *real-object preference.*

There is limited knowledge, however, as to whether the multisensory properties of objects also impact our preference for real objects. When we interact with real objects, we combine information from each of our senses to create a coherent and holistic perception of our experience – this is multisensory integration. Our sense of vision interacts with our other senses to help us identify what we are experiencing. Recently, research has highlighted the interactive nature between vision and olfaction (e.g., Gottfried & Dolan, 2003; Seigneuric et al., 2010; Seo et al., 2010; Zhou et al., 2010). This research suggests that olfactory cues may contribute to the *real-object preference.*

The Impact of Vision on Olfaction

Early research on the cross-modal integration of vision and olfaction focused on the effect of visual cues on associated odors. This focus was based on the belief that vision is a dominant sense which contributes more to our perceptual experience than our other senses (Ackerman, 1991). Indeed, visual cues can change people's perception of an odor (Morrot et al., 2001). Research shows that visual cues associated with an odor can result in superior recognition of an odor (Gottfried & Dolan, 2003). For example, people are faster and more accurate at identifying the presence of an odor when presented with an image and related odor (e.g., image of a bus and smell of diesel) than when presented with an image and an unrelated odor (e.g., image of cheese and smell of fish; Gottfried & Dolan, 2003).

Although this study (Gottfried & Dolan, 2003) and various others (Demattè et al., 2009; Gilbert et al., 1996; Sakai et al., 2005) illuminated the impact of vision on olfaction, the role of olfaction on vision was still largely unexplored in the early 2000s.

Impact of Olfaction on Vision

Recently, researchers have found that the presentation of odors related to images facilitates visual attention and identification (Seigneuric et al., 2010; Seo et al., 2010; Zhou et al., 2010). In one study, participants were presented with a visual scene, including various images of objects, one of which was an object naturally associated with the odor presented, the "odor-related image" (Seigneuric et al., 2010). Participants fixated on the odor-related image faster and for a shorter amount of time compared to the other images in the visual scene. The researchers suggested that the odor facilitated rapid identification of the odor-related image, whereas the other objects required more time to identify.

The impact of odor on vision has similarly been investigated using binocular rivalry (Zhou et al., 2010). Binocular rivalry occurs when two distinct images are presented separately to the two eyes (Blake & Logothetis, 2002). Instead of perceiving both images, perception alternates between the two (Blake & Logothetis, 2002). Studies using binocular rivalry to investigate the impact of olfaction on vision have found that an image related to an odor is perceived for a longer amount of time and suppressed for a shorter length of time in comparison to a competing image (Zhou et al., 2010). These two studies (Seigneuric et al., 2010; Zhou et al., 2010) were some of the first to illustrate the ability for olfactory information to impact visual perception. Nonetheless, neither study included a control condition, which limits the reliability of their results. Perhaps participants attended to the image related to the odor for reasons other than the presentation of the odor, such as the colour or size of the image.

Seo and colleagues (2010) provided stronger support for the impact of olfaction on vision by including an odorless control condition. In their study, participants' eye movements were recorded as they looked at a display with four images (e.g., orange, apple, pepper, onion). Simultaneously, they were presented either with an odor congruent with one of the images (e.g., odor of an orange), or odorless air. Participants fixated on the image significantly longer when a congruent odor was present than when no odor was present. These results indicated that olfactory cues enhanced visual attention toward congruent images.

One major limitation of past studies of visual-olfactory interactions is that most have used images instead of real objects, even though images typically do not have any odor. Only a limited number of studies have used real objects to examine the effect of olfaction on vision. For example, one study had participants smell an odor and then grasp a real object (Castiello, Zucco, Parma, Ansuini, & Tirindelli, 2006). When the odor belonged to an object incongruent with the size of the object to be grasped, participants' hand apertures mimicked the odor object's size as opposed to the real object's size. This study provided valuable information regarding real-world effects of olfaction on vision, as it suggests olfactory cues can override visual information in our action-related responses.

Despite knowledge that olfactory cues can influence our visual responses (when both images or real objects are used), no study to date has examined the impact of olfaction on vision when both images and real objects are used in the same study. Thus, it remains unclear whether olfactory cues contribute to the *real-object preference*.

The Present Study

In sum, real objects are processed differently (Carver et al., 2006; Marini et al., 2019; Snow et al., 2011), more highly valued (Bushong et al., 2010; Romero et al., 2018), more memorable (Snow et al., 2014), and are looked at more (Gerhard et al., 2016; Schumacher, 2017) than images. Further, real objects have multi-sensory properties and when people are presented with objects and odors simultaneously they tend to fixate on the object to which the odor belongs (Seo et al., 2010). Taken together, these results suggest that multi-sensory properties may play a role in the *real-object preference.* Drawing on the preferential looking paradigm used in Schumacher's (2017) study and the use of odors used in Seo et al.'s (2010) study, I investigated whether visual-olfactory associations strengthen the *real-object preference.* Given that this was a pilot study, the primary purpose was to determine whether the experimental design used in the present study would be successful in testing the effects of odors on the *real-object preference*.

In the current study, participants were presented with a real object and an image of the same object, along with a congruent, incongruent, or neutral odor. Participants' eye movements were tracked using an eye tracker to determine the percent of time fixated on the real object. Four visual stimuli (orange, peach, coffee, and hot cocoa) and five odors (orange, peach, coffee, hot cocoa, and odorless air) were used. Participants were presented with a real object and its corresponding image (e.g., a picture of an orange side by side with a real orange) along with a congruent odor (e.g., orange) or an incongruent odor (e.g., coffee or hot cocoa). The fruit odors were incongruent to the drink odors and vice versa. In a neutral trial, participants were presented with a real object and its corresponding image along with odorless air, to enable us to determine if there were looking preferences in the absence of odors.

Two hypotheses were proposed. First, replicating Schumacher's (2017) findings, we hypothesized participants would look longer at the real object than the image in the neutral odor condition. Second, since congruent odors enhance visual attention toward the same object (Seo et al., 2010), and since images do not have a smell, we hypothesized participants would look longer at the real object than the image in the congruent odor condition compared to the incongruent or neutral odor condition.

Method

Participants

Participants for the pilot study (curtailed prematurely due to the COVID-19 situation) were four undergraduate students (2 females, 2 males) from the University of Western Ontario, ranging in age from 18 to 21 (M = 19.25, SD = 1.26). Participants were eligible for the study if they were between the ages of 18 and 35, had normal or corrected-to-normal vision, normal depth perception (<60 arcseconds, as tested by the Randot Stereotest), and a normal sense of smell (correctly identified at least four out of five smells, as tested by the Burghart "Sniffin' Sticks" test). Participants were ineligible for the study if they had a history of strabismus ("lazy eye"), any visual or neurological disorders, or health issues that may affect their sense of smell. Participants were recruited through the Psychology Department's Research Participation Pool and received one course credit for their participation. An additional two participants were recruited but due to technical problems with the odors, were excluded from the study. The present study was conducted in accordance with the Western University Non-Medical Research Ethics Board (NMREB; see Appendix A), consistent with the Declaration of Helsinki (2013), and informed consent was obtained prior to the experiment. All participants received course credit regardless of whether or not they completed the full study.

Materials

Visual Stimuli

The visual stimuli consisted of four real objects and four identical images. The real objects were realistic plastic food and drink items (orange, peach, coffee, and hot cocoa, from Two Hot Peppers Inc., Toronto, Ontario, see Appendix B). The stimuli were each glued to white foam-board platforms (16.5 cm x 12.3 cm x 12.3 cm) on a wooden base (17.0 cm x 19.0 cm x 2.0 cm). Plastic items were used to eliminate the natural odor associated with real food and drink items and to avoid the rotting of real food. Some items were modified to reduce glossiness and enhance realism. The images were photographs of the real objects in the experimental set-up taken using a digital camera (Canon EOS Rebel T5 DSLR) from the viewpoint of the participant. The images were then matched to the real objects on the dimensions of brightness, contrast, and colour using an editing software (Adobe® Photoshop Lightroom). A color card was used to ensure the colors of the images were as true to real life as possible. The images were then resized to match the size of the real object using in-house software made by a member of our lab.

Olfactory Stimuli

An olfactometer was used to deliver odorless air or one of four scented oils: orange peel, market peach, coffee, and hot cocoa (from Candora Soap Inc., London, Ontario). To limit adaptation over trials, four different odors were chosen and the same odor never followed itself in an experimental trial. The familiarity, intensity, and pleasantness of the odors were taken into consideration, as more familiar, intense, and pleasant odors tend to attract more attention than less familiar, intense, and pleasant odors (Bensafi et al., 2002). Through olfactory piloting, these four odors were found to match on familiarity, intensity, and pleasantness.

Screening Form

A screening form was created for this study to ensure participants had no health issues or injuries that would affect their sense of smell (see Appendix C). The form contained a total of 19 items in which participants responded yes or no. If participants checked "yes" to any of the 11 health complications listed under question 1, they were to be excluded from the study. If they had any visual problems, suffered severe head trauma, been hospitalized due to a toxin, or underwent treatment for cancer within the last six months, they were to be excluded from the study. Further, if participants were taking medications such as steroids, antidepressants, or anti-epileptics, they were to be excluded from the study. If they ever had any nose, mouth, or taste problems, they were included in the study, but the information was to be recorded.

Screening Test for Sense of Smell

A shortened version of the Burghart "Sniffin' Sticks" test (Mueller & Renner, 2006) was used to test participants' sense of smell. Participants were presented with five felt-tip pens filled with everyday odors. They had to successfully identify at least four out of the five odors from a list of 22 options to be included in the study.

Screening Test for Depth Perception

The Randot Stereotest (Wang et al., 2010) was used to test participants' stereoacuity (depth perception when using both eyes). For this test, participants wore polarized 3D glasses and viewed 10 sets of three circles. They had to identify which of three circles (left, right, or middle) in each set "popped" out at them. Each set represents a different level of stereoacuity. Participants needed to have a stereoacuity of less than 60 arcseconds to be included in the study

Rating of Odors

An olfactory rating form was created for participants to rate the odors used on intensity, familiarity, and pleasantness after the experimental trials (see Appendix D). Ratings ensured that participants were familiar with the smell, and the intensity was strong enough to be noticeable. Intensity was rated on a scale from 0 (*no sensation)* to 100 (*strongest imaginable*). Familiarity was rated on a scale from 0 (*extremely unfamiliar*) to 10 (*extremely familiar*). Pleasantness was rated on a scale from -5 (*extremely unpleasant*) to 5 (*extremely pleasant*). Participants were also asked to name the real objects the odors were associated with.

Apparatus

Figure 1 depicts an overview of the apparatus in the experimental set-up. A tower-mounted eye-tracker (EyeLink 1000, SR Research Ltd., Ottawa, ON, Canada) was used to record the total number and time of fixations (samples treated as a unit due to similar positions) at a sampling rate of 1000 Hz. The eye-tracker tracked the right eye and identified both the center of the pupil and the corneal reflection to minimize drift. A chin rest set was used to ensure participants' heads were stabilized throughout the experiment. In front of the eye-tracker were two identical 24 inch monitors (Acer GN246HL), occluded by a large board (62 cm x 116 cm) with two 15 cm x 18 cm viewing windows separated by 4 cm through which participants could view the stimuli.

On an experimental trial, one monitor displayed the image superimposed on a grey background through MATLAB® software. The other monitor displayed the same grey background, with the real object placed in front of the monitor. A color calibration tool (Spyder X Elite) was used to ensure the background and images on the two monitors were uniform and true to colour. The presentation of the real object and image on the right or left side was counterbalanced across trials throughout the experiment. The monitors were positioned such that participants' eyes were approximately 44 cm from both the front of the real object and the monitor displaying the image.

Odors were emitted through an olfactometer (Osmic Enterprises Inc. fMRI Olfactometer), which pushed pressurized air through a series of tubes that moved through five scent chambers—four were filled with the scented oils and one was empty for the odorless air. The tubes were attached to a manifold which had an outgoing line connected to a nasal cannula, placed in participants' nasal cavity. A "background air" line that did not go through a scent chamber was always open at 0.5 L/min. On an experimental trial, one of the five stimulus air lines would open at 2.5 L/min, as dictated by the experimental script. Between experimental trials, the odorless air line would open at 2.5 L/min. There was a constant airflow of 3.0 L/min.

Between trials a foam-core occluder was manually placed in front of the viewing windows to prevent participants from seeing the placement of the experimental stimuli and to re-center their focus before the next trial. A black dot in the center of the foam-core occluder, was used as a fixation point for participants to look at between trials.

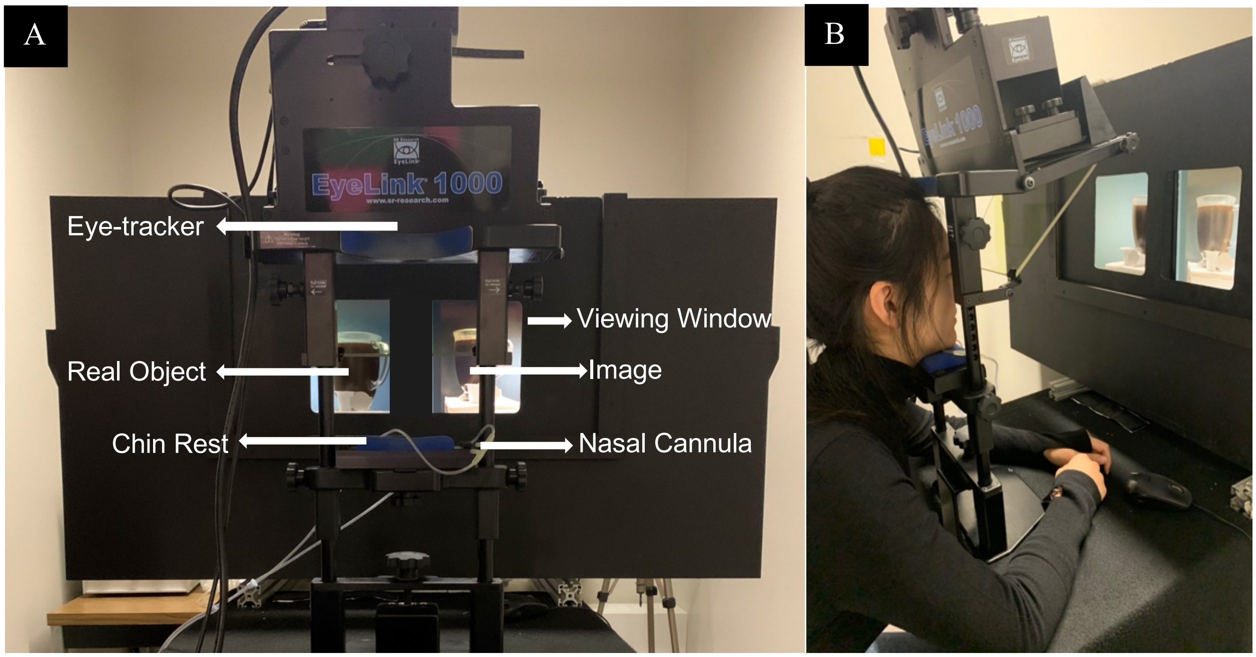

Figure 1. (A) Overview of the apparatus in the experimental set-up from a participant's point of view. Participants rested their chin on the chin rest and viewed a real object alongside an identical image through two viewing windows. The nasal cannula was attached to an olfactometer and was used to deliver the odors to participants' nasal cavity. The eye-tracker tracked participants' eye movements as they viewed the stimuli. (B) Example of a participant viewing the experimental stimuli.

Procedure

Participants received a letter of information and a consent form to sign, stating that the purpose of the study was to investigate how humans use multisensory information to perceive and explore objects using eye movements (see Appendix E). Participants then completed the screening form previously described (see Appendix C), the Burghart “Sniffin” Sticks test (Mueller & Renner, 2006), and the Randot Stereotest (Wang et al., 2010). All participants met the inclusion criteria of the three screening tests.

Participants placed the nasal cannula in their nasal cavity and placed their chins on the chin rest. They were then instructed to freely observe the visual stimuli while they were presented with an odor. The olfactometer attached to the nasal cannula pushed odorized air for 3 seconds, and the visual stimuli were presented for 5 seconds. The presentation of the odor and visual stimuli overlapped for 1 second as the smell lingers before being flushed out for the next experimental trial. Each trial lasted a total of 7 seconds with a 12-second visual inter-trial-interval (ITI) and a 14-second olfactory ITI (see figure 2). During the visual ITI, the foam-core occluder covered the visual stimuli while the experimenter placed the appropriate real object in front of the monitor and set the image-side monitor to the correct position. The image was automatically displayed on the monitor through scripted commands. Three tones were used on each trial. The first tone occurred 2 seconds before the visual stimuli were uncovered and signaled participants to look at the fixation point on the foam-core occluder. The second tone signaled the experimenter to lift the foam-core occluder, and the third tone signaled the experimenter to put the foam-core occluder back in place.

There were 96 randomized trials, which included 12 meaningful conditions (four visual stimuli and three odor conditions) with eight trials per condition. One-third of the trials (32 trials) included a congruent odor, one-third of the trials included an incongruent odor, and one-third included a neutral odor.

The eye-tracker was calibrated and aligned throughout the testing session. Calibrations required participants to look sequentially at 9 dots across the two monitors and occurred once before the first trial, once halfway through the experiment, and as needed any time a participant required a break or removed their head from the chinrest. Alignments required participants to look sequentially at 6 dots per monitor at the edges of the viewing windows and occurred once after each calibration and again every 28 trials. Alignment trials gave the experimenter information about whether the eye tracker was properly recording participants' eye movements.

After the experimental trials, participants were asked to rate the odors for their pleasantness, familiarity, and intensity and were asked to identify the odors (see Appendix D). The participants had an opportunity to re-smell the odors as they filled out the forms. Participants were then debriefed (see Appendix F) and given the opportunity to ask any questions. The entire session lasted roughly 60 minutes.

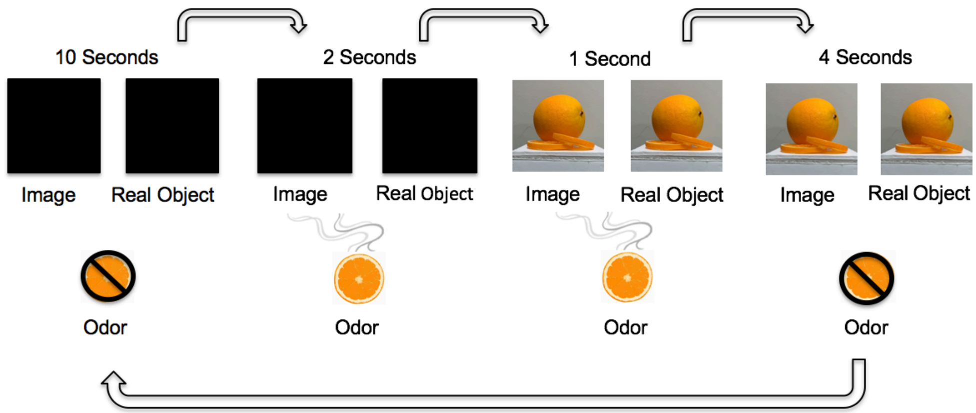

Figure 2. Example of one experimental trial including a congruent odor. For the first 10 seconds of the trial, a foam-core occluder blocked the visual stimuli, and no odor was pushed through the olfactometer. During the next 2 seconds, the olfactometer began pushing odorized air. The following second, the foam-core occluder was lifted while the odor was still pushed through the olfactometer. In the last 4 seconds of the trial, the odor was no longer pushed out of the olfactometer. There was a visual inter-trial-interval of 12 seconds and an olfactory inter-trial-interval of 14 seconds.

Data Analysis

MATLAB and JASP were used to analyze the data. MATLAB was first used to determine the amount of time each participant looked at the real object. Total looking time was calculated as the percent of total fixations within a trial that were within the two viewing windows defined by two boxes traced during alignment trials. Trials required a minimum of 60% of fixations to be within the two viewing windows to be included in the analysis.

The percent looking time towards the real object was then calculated as the amount of time participants looked at the real objects' viewing window divided by total looking time.

Results

Given that the present study is a pilot study that includes only four participants, statistical tests were conducted solely to investigate trends in the data to aid in the development of better methods for future data collection and to demonstrate an understanding of statistical approaches for the purpose of this thesis.

There were two major predictions for the data. First, there would be a trend toward a *real-object preference* collapsed across all four stimuli—directly replicating Schumacher's (2017) results. This would be supported by a one sample t-test that shows the percent looking time towards the real object is greater than 50% in the neutral odor condition. Second, the *real-object preference* was expected to be greater in the congruent odor condition than in the incongruent and neutral odor conditions collapsed across the four stimuli. As such, a one-way repeated measures ANOVA should demonstrate a trend toward significance which would suggest that at least two of the odor conditions may differ in terms of percent looking time at the real object. If so, post-hoc tests would be expected to suggest that people look longer at the real object in the congruent odor condition than in the neutral odor condition.

Real-Object Preference

The data of the present study supports our first hypothesis that there is a real object preference in the neutral odor condition (with the caveat of a small sample size). This is important as it replicates Schumacher's (2016) results and shows that the experimental setup is similar enough to hers that it can extend her research. In the neutral odor condition, participants looked at the real object ($M =$ 77.7%, $SD = 13.4$) significantly more than 50% of the total looking time, $t(3) = 4.14$, $p = .013$, $d = 2.07$. The effect size was large, suggesting that these results would likely also be found with a full dataset ($n = 24$). Visually, this was a robust finding despite the small sample size, as depicted by the lower end of the 95% confidence interval (56.4%) in figure 3.

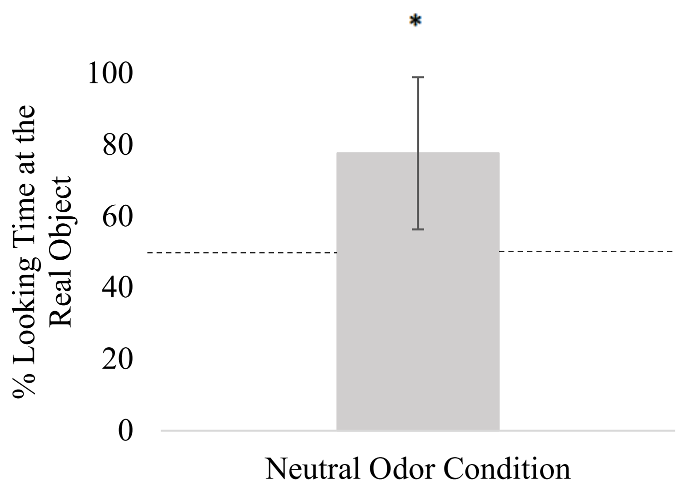

Figure 3. Percent looking time at the real object in the neutral odor condition. Error bar represents a 95% confidence interval. *$p < .05$.

Effect of Odor on the Real-Object Preference

The data of the present study do not fall in line with the second expectation. In contrast, as shown in Figure 4, percent looking time at the real object was high in both the congruent (M = 78.7%, SD = 9.9) and neutral odor conditions (M = 77.7%, SD = 13.4) but reduced in the incongruent odor condition (M = 61.4%, SD = 22.1).

Mauchly's Test of Sphericity was found to be nonsignificant, $W = 0.12$, $p = .119$ and there was little reason to assume the assumption of circularity was violated. Thus, no alterations in degrees of freedom were required and results were further examined with sphericity assumed. Independent random sampling and normality were assumed.

The repeated measures ANOVA revealed a weak trend, $F(2,6) = 0.08$, $p = .126$, η^2 = .499—as expected given the small sample size. The trend demonstrates that the incongruent odor condition decreased percent looking time at the real object compared to both the congruent and neutral odor conditions, and that the congruent odor condition did not affect percent looking time at the real object compared to the neutral odor condition. The large effect size indicates that 49.9% of the variability in percent looking time at the real object can be attributed to the odor condition and suggests that there is practical significance for these results despite the lack of statistical significance.

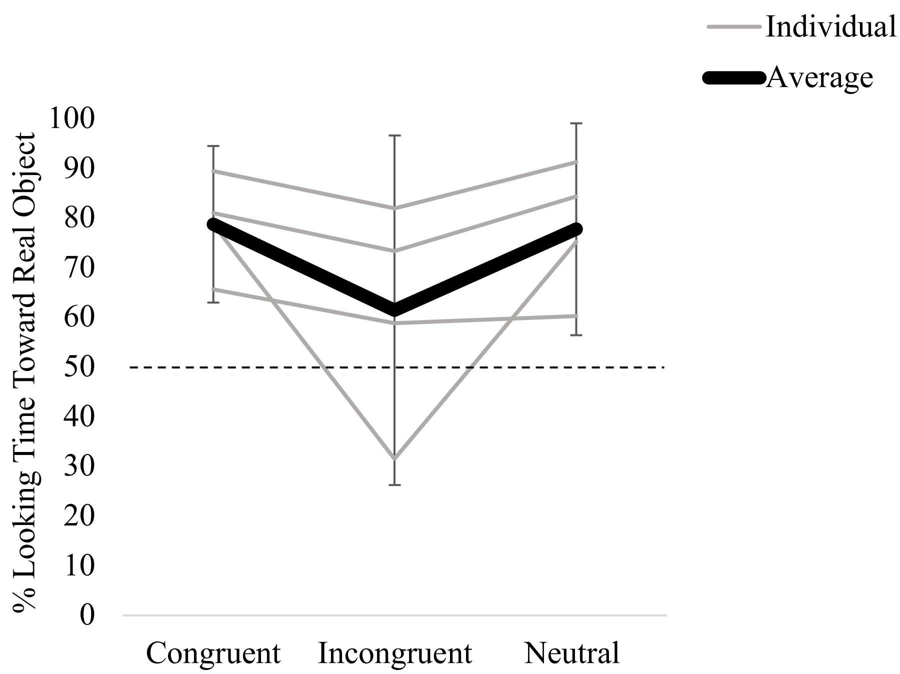

Figure 4. Average percent looking time at the real object in the congruent, incongruent, and neutral odor conditions, including each individual participant's average percent looking time. Error bars represent a 95% confidence interval.

Discussion

The objective of the present study was to determine whether visual-olfactory associations can strengthen the *real-object preference.* Two hypotheses were proposed. First, it was hypothesized that when no odor is present, there would be a *real-object preference*. Second, it was hypothesized that congruent odors would result in a greater *real-object preference* than neutral or incongruent odors. Consistent with the first hypothesis, a *real-object preference* was found in the neutral odor condition. In contrast to the second hypothesis, there was a trend in the data in which congruent odors did not affect the *real-object preference* while incongruent odors decreased the *real-object preference* compared to neutral odors.

The finding of a *real-object preference* in the neutral odor condition directly replicates Schumacher's (2017) findings and adds to the mounting body of evidence that there is a *real-object advantage* (e.g., Bushong et al., 2010; Carver et al., 2006; Gerhard et al., 2016; Gomez et al., 2018; Marini et al., 2019; Snow et al., 2001; Snow et al., 2014). Importantly, the existence of a *real-object advantage* challenges the ecological validity of research using images as proxies for real objects. Since real objects show distinct processing and behavioural advantages, studies that have used images in place of real objects likely found weaker results than they would have if they used real objects. These studies should consider replicating their findings with real objects and comparing the results.

Given that real objects have multisensory properties while images do not, and that olfaction has been shown to influence visual attention (Seo et al., 2010), it was expected that people would look even more at the real object when presented with a congruent odor compared to a neutral odor. Nonetheless, the findings of the present study suggest that congruent odors may not strengthen the *real-object preference*. This may be explained by the fact that people tend to not notice odors that match their expectations (Köster et al., 2014). Research suggests that conscious recognition of olfactory information is uncommon (Sela & Sobel, 2010). Interestingly, when odors and visual inputs are congruent, visual information is dominant over olfactory information (Hörberg et al., 2019). Specifically, when presented with an odor and congruent visual image simultaneously, people are more accurate at identifying the visual stimuli than the olfactory stimuli (Hörberg et al., 2019). This may suggest that when presented with olfactory cues that match our expectations, our visual system receives privileged access to higher-order processing. Therefore, it is possible that in the present study, odors on congruent trials were overlooked, making congruent trials essentially equivalent to neutral trials. This would explain why there was no difference in looking time at the real object in the congruent odor condition compared to the neutral odor condition.

Greater attention toward olfactory cues on congruent trials may require an explicit cue that directs attention towards the odor. For example, one study found that people are faster at discriminating between whether an odor is of low or high intensity when first explicitly cued to attend to the odor than when not cued to attend to the odor (Spence et al.,2001). Since participants in the present study were not told to specifically attend to the odors, it is possible that the olfactory information was neglected on congruent trials when the odors matched their expectations.

It is also possible that higher concentrations of the odors would facilitate greater attention toward congruent odors. For example, although people can detect ethyl mercaptan (clear liquid with a distinct odor of natural gas) at extremely low concentrations (0.009 parts per billion), spontaneous attention toward ethyl mercaptan only occurs at a much higher concentration (0.5 parts per billion; Sela & Sobel, 2010). Perhaps using a more intense concentration of the odors would have facilitated consistent olfactory attention in both congruent and incongruent trials. In the present study, the ratings of the odors were inconsistent across both participants and odor. While some reported that the odors were very strong, others reported that they were moderate to weakly strong. This suggests that people's sense of smell differs and that using a higher concentration of the odors may have been better in attracting all participants' attention without explicit cueing.

Interestingly, participants in the present study showed a reduced *real-object preference* when the odor and visual stimuli were incongruent compared to neutral or congruent. This result may be explained by research which shows that when visual and odor inputs are incongruent, an odor is more likely to be noticed (Köster et al., 2014). The "misfit theory of spontaneous conscious odor perception" suggests that odor perception occurs only when the situation demands it (Köster et al., 2014). Odors that defy our expectations are surprising and confusing and therefore, are given special attention (Köster et al., 2014; Keller 2011). In such cases, the olfactory system is more dominant than the visual system. For example, when presented with an odor and an incongruent visual image simultaneously, people are faster at identifying the odor than the visual image (Hörberg et al., 2019). When presented with incongruent odors, participants in the present study may have become confused and attempted to search their visual field for a matching object. Thus, they may have taken longer to identify the visual stimuli, resulting in a reduced *real-object preference*.

Ultimately, the results of the present study may suggest that the visual and olfactory systems have asymmetric dominance depending on whether the two are congruent or incongruent. In a congruent situation, the visual system may dominate over the olfactory system, whereas in an incongruent situation, the olfactory system may dominate over the visual system.

If the same results are found in future data collection with a full sample size (*n* = 24), they may have implications for our understanding of sensory processing disorder. Sensory processing disorder involves the inability to process information received through the senses. In other words, it is the disruption of multisensory integration (Kranowitz, 2005). The results of the present study may suggest that when visual and olfactory inputs are congruent, vision is primarily disrupted in those with sensory processing disorder. On the other hand, when visual and olfactory inputs are incongruent, olfaction may be primarily disrupted in those with sensory processing disorder. With a better understanding of this disorder, better treatments and interventions can be created.

Limitations and Suggestions for Future Data Collection

Given that the present study was a pilot study, the major goal was to identify whether the current experimental design needs refining. Several problems with the current methodology have been identified and need to be fixed before more participants can be tested.

A major problem encountered was both incomplete data and data loss. One hour was too short a time span to perform the planned number of trials per participant, and as a result not all participants completed all 96 trials. If the same number of trials are to be kept in future data collection, researchers should adjust timing to be an hour and a half as opposed to an hour to have enough time to collect all the data. Further, out of the 363 total trials completed, 88 trials (24%) had to be excluded because they were missing 40% or more eye-tracking data. There were three major reasons for lost eye-tracking data. First, in some trials participants did not fixate at the central point on the foam-core occluder before the trial began which made the eye-tracking data inaccurate. Second, in some trials participants were looking outside of the two viewing windows. Third, in some trials, excessive blinking or participants' eyes drooping caused the eye-tracker to lose their pupil and/or corneal reflection.

For future data collection, the central fixation point on the foam-core occluder may need to be more salient. To ensure participants look at the fixation point, participants could also be asked to complete a task involving the fixation point prior to completing a trial (e.g. if the fixation point was a square with 10 colors, the researcher could ask them to identify one of the colors).

The fact that many trials were lost due to participant's looking outside the viewing windows suggests that the passive viewing task used in this study may not have been sufficient to attract participants' attention for the entire testing session. One possible solution for future data collection is to include a secondary visual identification task (i.e., what did you see) at the end of each trial to ensure participants pay attention to the visual stimuli on each trial.

To better understand why participants look outside the regions of interest it may be useful to quantify the data differently. Instead of only looking at the data when the participants are looking in the two viewing windows, it may be beneficial to look at the amount of time they spend looking at the center fixation point and outside the two regions. Perhaps participants only look outside the two regions on incongruent trials as they search for a congruent object. By quantifying the data this way, the results can be better understood.

Participants' eyes drooping may suggest that they were bored or restless. Although the present study included a break halfway through, more breaks may need to be included to keep participants engaged. Including a visual identification task may help make the task more interesting. Shortening the task may also be useful for reducing boredom. To see if shortening the task is an appropriate next step, we could quantify the percent looking time at the real object in quartiles. If the effect size is large in the first quarter of trials but smaller in last quarter of trials, then it may suggest that the length of time for the task is too long.

In terms of the olfactory component of the study, one participant was unable to identify the names of odors. Nonetheless, they showed the same trend in the data as the other participants. The identification of odors occurred after the experimental trials and thus, this participant may have been able to recognize the odors in the experimental trials when provided with visual information but not after the experiment when the visual stimuli were absent. To better evaluate data in the future, perhaps an odor identification task (i.e., what did you smell) should be included on each trial to determine whether participants know what they are smelling across trials. It may also be beneficial to change the stimuli to more identifiable odors as many of the researchers themselves found it hard to identify the peach and hot cocoa scents. Prior to future data collection, olfactory piloting should be redone using the same olfactory stimuli in the present study and other fruit and drink smells to determine the best odors to use.

The results of the present study demonstrated no difference in the *real-object preference* when congruent odors and neutral odors were used. As such, the participants may not have attended to the odor stimuli in the congruent odor condition. This is likely since, as previously mentioned, participants were not given any instruction to attend to the odors, rather they were told that as they viewed visual stimuli, odors may be present. It may be worth including an auditory cue prior to the presentation of the odor which signals to participants that they are about to smell an odor and that they should take a deep breath in. Further, increasing the concentrations of the odors (Spence et al., 2001) and including an odor identification task on a trial to trial basis as previously mentioned may also help ensure participants attend to the odors.

As previously mentioned, the present study employed a passive viewing task. This task does not give us any information regarding what the participants were thinking throughout the trials. Include an exit interview at the end of the experiment would be useful to ask participants what their strategy was. Perhaps some did not have any strategy, while others may have been trying to match the odors to the objects. Understanding what is going on in participants' minds will give us better insight into the data.

Conclusion

Ultimately, despite the limitations of the present study and the small number of participants, the results highlight the strength of the *real-object preference.* These results challenge the ecological validity of using images as proxies for real objects. Moreover, the present study's data trended in a way that congruent odors maintained a strong *real-object preference* while incongruent odors decreased the *real-object preference* compared to neutral. This trend may suggest the olfactory and visual system are asymmetrically dominant depending on the nature of the interaction (whether congruent or incongruent). The results of the present study are promising, however, the current methodology could be refined prior to future data collection.

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Appendix A

Ethics Approval Letter

Western Research

Date: 10 February 2020

To: Prof. Jody Culham

Project ID: 108595

Study Title: Behavioral studies of sensory interactions in the processing and exploration of objects

Application Type: Continuing Ethics Review (CER) Form

Review Type: Delegated

Meeting Date: 06/Mar/2020

Date Approval Issued: 10/Feb/2020

REB Approval Expiry Date: 15/Feb/2021

Dear Prof. Jody Culham,

The Western University Non-Medical Research Ethics Board has reviewed this application. This study, including all currently approved documents, has been re-approved until the expiry date noted above.

REB members involved in the research project do not participate in the review, discussion or decision.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario. Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB. The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Daniel Wyzynski, Research Ethics Coordinator, on behalf of Prof. Randal Graham, NMREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Appendix B

Visual Stimuli

Appendix C

Olfactory Screening Form

Please read carefully each of the following questions regarding your health

1. Do you have (or have you had) any of the following health complications? Please tick YES or NO.

	YES	NO
Gestational age below 32 weeks or prenatal injury		
Diabetes		
Endometriosis		
Addison's disease		
Cystic fibrosis		
Epilepsy		
Any sleep conditions (e.g. Insomnia, Narcolepsy, etc.)		
Dry mouth syndrome		
Any kidney problems		
Any thyroid problems		
Any vitamin/mineral deficiencies (e.g. Zinc deficiency, Calcium deficiency, etc.)		

1. Have you ever experienced any visual problems (including "lazy eye" or problems with depth perception)?

   Yes
   No
   1.1 If Yes, describe the problem.

2. Have you ever had any nose or smelling problems (including – but not limited to – nose problems such as a broken nose, any nasal or oral surgeries, a deviated septum, a cleft palate, smelling problems such as rhinitis, chronic allergies, etc.)?

   Yes
   No
   2.1 If YES, please describe the problem.

3. Have you ever had any mouth or taste problems (including but not limited to – mouth problems such as oral surgeries, AND burning mouth syndrome, bad taste in the mouth, etc.)?

Yes
No
3.1 If YES, please describe the problem.

4. Have you ever suffered a head trauma?

   Yes
   No
   4.1 If YES, did you lose consciousness? Please describe the event.

5. Have you ever been hospitalized due to exposure to a toxin? (e.g. asbestos, lead, etc.)

   Yes
   No
   5.1 If Yes, please describe the event

6. Are you taking any medication? Please include prescription and over-the-counter medications, including minerals, vitamins, and dietary supplements.

   Yes
   No
   6.1 If YES, please name the medication and the reason for use.

7. Have you ever been diagnosed with cancer?

   Yes
   No
   7.1 If YES, what type of cancer? Are you currently undergoing treatment? Are you in remission?

8. Do you have (or have had) a known heart problem?

   Yes
   No
   5.1 If Yes, can you please describe it?

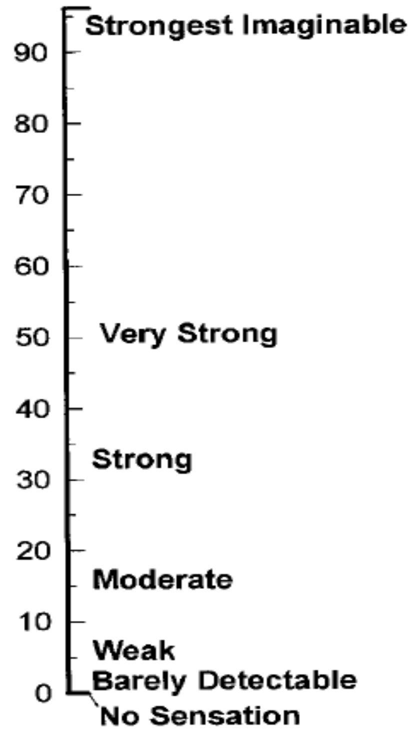
Appendix D

Olfactory Rating Form

Study: ____________
Date: _____________
ID: ________________

Odor _____

INTENSITY



PLEASANTNESS

-5 neutral 5
Extremely unpleasant Extremely pleasant

FAMILIARITY

0 10
Extremely unfamiliar Extremely familiar

IDENTIFICATION

Can you name one or more objects to which this odor belongs?

____

____

____

____

____

____

____

Appendix E

Letter of Information and Consent Form

Western
The Brain and
Mind Institute

Project Title: Behavioral studies of sensory interactions in the processing and exploration of objects

Principal Investigator: Professor Jody Culham, PhD, Department of Psychology, Western University

Letter of Information

1. Invitation to Participate

You have been invited to participate in this research study of sensory interactions for object processing and exploration because you fit the demographic group adults age 18-35 with normal senses of vision and smell.

2. Purpose of the Letter

The purpose of this letter is to provide you with information required for you to make an informed decision regarding participation in this research.

3. Purpose of this Study

The purpose of this study is to investigate how humans use multisensory information to perceive and explore objects using eye movements.

4. Inclusion Criteria

Individuals who are between the ages of 18 and 35, with vision that is normal or corrected-to-normal (with glasses or contact lenses) and with a good sense of smell are eligible to participate in this study.

5. Exclusion Criteria

The following individuals will be excluded from participating in the study:
1. Individuals with visual or neurological disorders that may affect their vision
2. Individuals with a history of “lazy eye” (strabismus) and/or have abnormal depth perception
3. Individuals who are unable to smell odors (anosmia) or have a poorer-than-typical sense of smell (hyposmia)
4. Individuals with any pathologies that may affect the sense of smell (e.g., severe head trauma with loss of consciousness, thyroidism, kidney disease, respiratory diseases)

5. Individuals taking medications that may alter or impair the sense of smell (e.g., antidepressants, antihistamines, hormones)
6. Individuals who smoke more than 5 cigarettes/day
7. Individuals who are allergic to any of the food substances that might be used in the study (e.g., oranges)
8. Individuals with a history of Obsessive-Compulsive Disorder (OCD) or related disorders

If any of these exclusionary criteria are met, you will still be compensated as outlined in section 9 of this form.

6. Study Procedures

If you agree to participate, you will be asked to look at objects and/or pictures of objects. In some cases, you may be asked to smell an odor while you look at the objects. This study will take 30 minutes to screen for eligibility, and an additional 1.5 hours totaling 2 hours to complete the entire study, depending on the experiment version you are completing.

At the start of the session, you will be asked to complete a few tests to confirm your study eligibility. This may include a brief screening questionnaire for OCD or related disorders and a questionnaire to determine your dominant hand. We will also briefly test your depth perception by asking you to tell us which of several visual stimuli appears closest to you. In addition, we will measure the movement of your eyes while you are seated comfortably at a table with your chin and forehead resting on cushioned surfaces that are part of a table-mounted eye-tracking device. In some cases, it is not possible to track a person's eye movements. If we are unable to track your eyes, you will not be eligible to complete the study. However, you will still receive compensation for your time as outlined in section 9 below.

If you are participating in a version of the experiment investigating interactions between the senses of smell and vision, you will be asked a series of questions to determine whether your sense of smell may be at all compromised and your sense of smell will be tested with a series of odorous pens filled with common household odors to be identified. If the testing determines your sense of smell is diminished, you will not be eligible to participate in this experiment.

Once your eligibility is confirmed, you will remain seated at the table with your chin and forehead resting on the cushioned surfaces of the table-mounted eye-tracking device to measure where you are looking. You will be asked to look at 2-dimensional images on a screen or 3-dimensional real objects. These experiments will take 60-90 minutes to complete.

In some experiments, you may also be asked to inhale odorous and odorless air from a tube attached to an olfactometer, a computer-controlled device used to deliver odors, while viewing images and objects. The entire task will take one session lasting up to 2 hours.

The study will be conducted in the Brain and Mind Institute located in the Western Interdisciplinary Research Building (WIRB) of the Western University campus. There will be up to 100 participants taking part in this study.

7. Possible Risks and Harms

There are no known or anticipated risks or discomforts associated with participating in this study. The nasal cannula is made of soft-touch material which will help minimize the irritation and soreness. It has been designed for long-term use (i.e., days) and therefore will not be cause problems in the context of a brief experiment including approximately 40 minutes of smelling time. Such devices have been used in experimental context for longer durations. However, nasal sensitivity is highly variable and we cannot exclude that this cannula may be aversive to some. In case of even a minor irritation, we advise the participant to inform us and leave the study.

8. Possible Benefits

You may not directly benefit from participating in this study but information gathered may provide benefits to society as a whole which include contributing to the knowledge base about how sensory information is used to perceive and explore the world.

9. Compensation

If you are participating through the Psychology Research Participation Pool as a Psychology 1000 student, you will receive one-half credit for each half hour of research participation. If you do not complete the entire study or if you meet any of the exclusionary criteria, you will still receive the credits based on the length of time you participated. Students participating via the SONA system for a course other than Psychology 1000 will receive participation credits equivalent to what is outlined in their course syllabus.

If you responded to a recruitment poster, you will receive $5 for each half hour of research participation. If you do not complete the entire study or if you are found to meet the exclusionary criteria you will still be compensated at the $5/half hour rate.

10. Voluntary Participation

Participation in this study is voluntary. You may refuse to participate, refuse to answer any questions, or withdraw from the study at any time with no penalty. If you withdraw your consent at any point after agreeing to participate, your data will be discarded and your confidentiality will remain protected. You do not waive any legal rights by consenting to this study.

11. Confidentiality

All data collected will remain confidential and accessible only to the investigators of this study. If the results are published, your name will not be used. Any information pertinent to your identity will be kept in a locked cabinet in a secured room requiring key access for five years following completion or publication of the study (whichever is later). After five years the information will be shredded and discarded.

12. Contacts for Further Information

If you require any further information regarding this research project or your participation in the study you may contact ***Professor Jody Culham***, 519-661-3979, jculham@uwo.ca

If you have any questions about your rights as a research participant or the conduct of this study, you may contact ***The Office of Human Research Ethics*** (519) 661-3036, email: ethics@uwo.ca

Representatives of The University of Western Ontario Non-Medical Research Ethics Board may contact you or require access to your study-related records to monitor the conduct of the research.

13. Publication

If the results of the study are published, your name will not be used. If you would like to receive a copy of any potential study results, please contact Professor Culham, 519-661-3979, jculham@uwo.ca. Completion of the consent form attached with today's date and your signature will be used as an indication of your consent to participate.

This letter is yours to keep for future reference.

Consent Form

Project Title: Behavioral studies of sensory interactions in the processing and exploration of objects

Principal Investigator: Professor Jody Culham, PhD, Department of Psychology, Western University

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

Participant's Name (please print): ______________________

Participant's Signature: ______________________

Date: ______________________

Person Obtaining Informed Consent (please print): ______________________

Signature: ______________________

Date: ______________________

Appendix F

Debriefing Form

Western

Debriefing Form

Behavioural study of real objects' influence on visual and olfactory association

Thank you for participating in this study. The purpose of this study is to gain a better understanding of the association between visual and olfactory processing. More specifically, we are interested in examining where individuals look when viewing real objects versus images (Preliminary Experiment), and how looking preferences are affected by a smell that matches one of the items (Main Experiment). Today you were asked to look at a series of real objects and images. If you were a participant in the Main Experiment, in some of these trials, while viewing these stimuli, you would have breathed in different smells, some of which matched the expected smell of one of the objects you were viewing. We are interested in seeing which objects participants spend the majority of their time looking at and whether it is affected by smell. Past research has found that people look more towards an item when its smell is present. We are also looking to see if this effect is more pronounced when viewing real objects or images.

In order to maintain the validity of the study, this goals of the study could not be disclosed to you prior to task completion, as knowing the purpose of the study could bias which objects you spend time focusing on. Withholding this information allows us to study behaviour that is as natural as possible, and helps to ensure that participants' looking behaivour is only influenced by the factors under study.

You participation in this study is voluntary, and you can withdraw your consent at any time, which will involve having the data that has been collected destroyed. Your personal information is not directly associated with the data collected, and all data is kept confidential and only disclosed to those involved in the study.

Please feel free to ask any questions about this study, including the procedures that were used today.

Thank you again for participating.

If you have any questions about the study, please feel free to ask the experimenter or contact the Principal Investigator, Professor Jody Culham jculham@uwo.ca, 519-661-3979.